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The Silk, Versatile Material for Biological, Optical, and Electronic Fields: Review

By Luigi Bibbo, Karim Khan & Ayesha Khan Tareen
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Luigi Bibbo α, Karim Khan σ & Ayesha Khan Tareen ρ

Abstract- Silk, seen as a material, is a fiber made from silkworm cocoons and spiders. They have standard structural components and hierarchical structures. Different manufacturing techniques allow obtaining silk in films, fibers, hydrogels, microspheres, and sponges. We can tune the properties through the structure of secondary proteins. The paper explores the application in biomedical, optics, and electronic fields by analyzing the technological trend.

Keywords: silk fibroin, biomaterial, tissue engineering, bone implants, electronic devices, sensors, optics.

I. Introduction

Silk is one of the oldest fibers used above all in the textile field. The continuous research developed on its properties, the chemical modifications of silk fibers, and the functionalization, lead it to be a versatile material used in many contexts from the biomedical field (tissue engineering and regenerative medicine), pharmaceutical, cosmetic, up to optical and electronic.

Previous silk reviews have focused on a single specific sector such as biomedical or optical, or electronic. At the same time, after researching the literature to analyze more recently updated testimonials, the one we propose embraces a wide range of more applications in the same single review. Attractive in different fields. It reports both recent progress in manufacturing processes and innovative applications. The objective of the manuscript is to investigate both of these aspects, from the biological to the industrial one, considering the different process methodologies applied to create a variety of structural forms. The approach is to analyze the nature of the fiber and its potential applications. It starts with the structure and properties and continues with the innovative preparation technologies and functionalization to modify its mechanical properties or give the silk the desired functionality. Then the latest emerging applications are reported. In some sections, representing the experiences carried out, we can see how the silk, among other things, can effectively contribute to the achievement of the objectives of sustainable engineering.

Particular attention is paid to silkworms for their availability in large quantities from sericulture. The arachnid species is difficult to raise due to their cannibal tendencies, but their silk has the best characteristics. The biotechnological production of proteins (spindrois) makes it possible to overcome this obstacle. The availability of recombinantly produced spider silk protein is essential for experimentation and their use in applications. Their application was mainly in the biomedical field. Silk extracted is combined with other biomaterials to form biopolymer compounds. The review analyzes applications that use worm and spider silk, although for the latter to a limited extent due to the fewer testimonies in literature. If not clearly expressed, we refer to both types.

II. Structural Aspects

Historically the silk used in the textile field is obtained by Bombyx mori silkworm (Fig.1a).

In nature, there are different types of silks produced by other animals, such as the Trichoptera, mites, and spiders [1]. It is precisely the silk of spiders that becomes the subject of study by exceptional properties (Fig.1b). There are 48,000 species, divided into 120 families. There are several different types of silk. One of the most interesting is the dragline which has features superior to other silks. The silk fibers are suitable for implants. Both spiders and silkworms use protein spun in the salivary glands. While the former weaves silk to create cobwebs to capture prey, the silkworm uses silk to produce cocoons for the metamorphosis cycle. Silk fibers show up resistant to traction, and some are distinguished by having a high degree of elasticity. Silks, with these properties, exhibit significantly greater hardness than those of synthetic fibers. Silkworms produce silk with a consistent thickness, while spiders produce silk with varying thicknesses, high resistance under stress, exceptional elasticity, resistance to high temperatures, have piezoelectric properties but at the molecular level haven't sericin. Mechanically the silk of the silkworm is much weaker and less extensible than that of the spider. We can modify the characteristics of the silk produced by the worm according to the spinning conditions.

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Tab. 1 shows the features of two different kinds of silk.

Bombyx mori | Spider

Fig. 1: Bombyx mori, Spider

Tab. 1: Features of silkworm silk and spider silk

Feature	Spider silk	Silkworm silk
Glands	Multiple glands near	Secreted via mouth
External coating	Glycoprotein	Sericin
Protein	Spidroin	Fibroin
Glycine	37%	46%
Alanine	21%	29%
Serine	4.5%	12%
Beta Sheet	30%	40-50%

The silk spun are different but have a typical structure: they have a protein chain and a hierarchical structure [2]. Fibroin is the core protein of fiber, and it is composed of amino acids arranged in β-sheets. The protein chain is an alternation of hydrophobic and hydrophilic domains. Fig. 2 shows the primary structure.

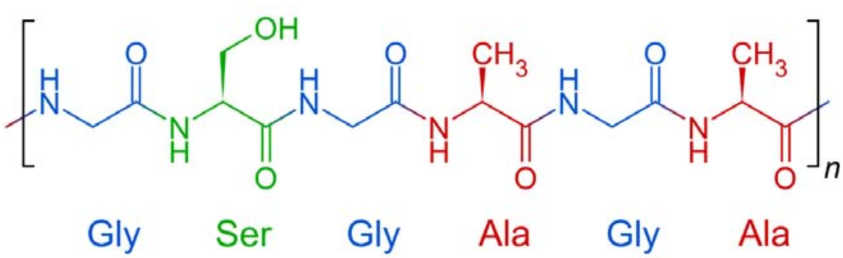

Fig. 2: Primary structure-Gly-Ser-Gly-Ala-Gly-Ala amino acid sequence

Fibroin is a fibrous protein-containing serine, alanine, glycine (Fig. 3), and tyrosine.

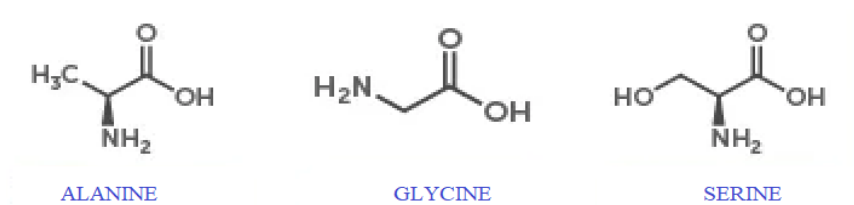

Fig. 3: Alanine, Glycine, Serine

Silkworm cocoon is sericin and fibroin, in proportion to 25% sericin and 75 % of fibroin. The fibroin is linked by glycoprotein sericin [3], with a small amount of waxy and dye material. Sericin is composed of serine and glycine. Fig. 4 shows the cross-section view, while Fig. 5 highlights its structure.

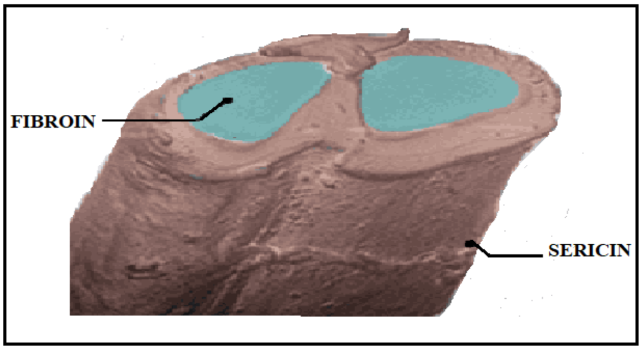

Fig. 4: Cross-section of fiber structure of Bombyx mori

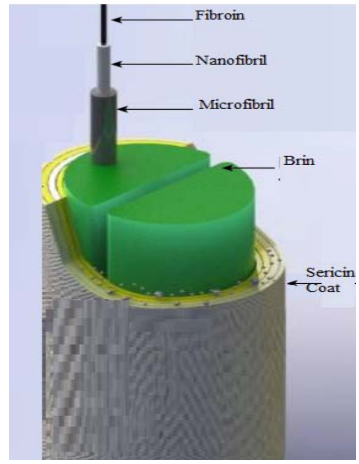

Fig. 5: Hierarchical structure

III. Properties

Silk is the most potent natural fiber, made up of thin films (β-sheets) with a controllable thickness from 100nm to 100μm. Lightweight, strength and toughness, elasticity, good resistance to failure in compression, and significant crystallinity are the characteristics that have greatly enhanced silkworm silk in the textile sector. In addition to these physical properties, silk as a natural biopolymer also shows biocompatibility, programmed biodegradability, and non-immunogenicity. Thanks to the evolution of materials manufacturing techniques, it is now possible to obtain polymeric materials based on silk protein for specific purposes. We modified the silk with organic composites to fabricate an interface between a bulk biopolymer and a conductive substrate of a polymeric optical device [4]. SF materials for their exceptional characteristics and structure also represent active optics, photonics, electronics, and optoelectronics applications. Silk materials with suitable morphologies and architectures are the right components for wearable sensors [5].

The efforts made in the production processes focused on the preparation of biotechnological methods for the recombination of silk fibers.

a) *Biologically properties*

The hierarchical structure of the hydrophobic parts and the blocks in silk show an extraordinary capacity for self-assembly, allowing devices with particular biological characteristics for innovative biotechnological applications. In particular, fibroin-based biomaterials show specific flexibility properties, rigidity, hydrophobicity, and hydrophilicity. We can control time and degradation under certain conditions. These characteristics stem from the conformation taken from the regenerated fibers during the dissolution process. The presence of amino acid sequence allows making chemical changes. For the functionalization of silk fibers, a series of reagents such as amines, alcohol, phenols, carboxylic groups were tested [6].

i. *Biocompatibility and cell interaction in vitro and in vivo*

We can obtain SF in various formats. For biocompatibility, after sericin removal, different studies demonstrated that the protein could shape structures to favor the attack and growth of cells.

Surgeons apply silk sutures in neurosurgery and cardiac surgery. In many cases, we have to remove the silk suture for an inflammatory reaction.

Previous studies believed that sericin might be the cause of the inflammatory state. Recent studies supported by information from in vitro, in vivo, and clinical trials show that silk sericin does not cause allergic reactions and is safe for medical applications. It can be considered an antioxidant, anti-tyrosinase, and tumor inhibitor for several biological properties in vitro and in vivo. However, sericin in the presence of fibroin should be used with caution because generating biological responses can be dangerous to human cells [7].

Overall, we can compare the degummed and sterilized silk products to polylactic acid (PLA) and collagen [8].

Many studies in vitro show that silk fibroin in contact with human cells has no interaction with a component of the inflammatory system, and fibroblast and other cells proliferate in silk fibroin scaffold. The use of water vapor induces the transition to β-sheets structure that makes cell proliferation easier [9]. Many studies involving subcutaneous implants showed no inflammation and their tolerance in the integration with the living tissue.

ii. *Biodegradability*

Biodegradability is a critical aspect of the biomedical field. Degradation refers to both in vitro and in vivo. The US Pharmacopeia defines bioabsorbable materials that degrade 60 days after implantation in vivo. Though natural silk fibers are considered not degradable by this definition, they degrade over a long period (months, years). Regenerated silk materials (films, gels, etc.) degrade over a short time (days, weeks).

Many factors can influence the degradation process, such as implantable site, patient's medical conditions, type, and shape [10].

Some in vivo studies showed that changing the method and variables to processing silk scaffolds can modify the degradation process [11].

Cell culture highlighted that the silk fibroin scaffold degrades slowly with loss of mass after four weeks. Bacterial and enzymatic degradation influence its biodegradability [12]. Methanol degradation may reduce the rate of degradation. Implanted scaffolds degrade as tissues regenerate, and the time depends on the type of tissue affected. We can tune degradation by controlling dissolution, hydrolysis conditions, and lyophilization [13, 14].

We also found that it can control the degradation of a silk fibroin scaffold through the contents of the sheet structure β [15]. The possibility to control silk material properties is an essential advantage over other biopolymers like collagen, chitosan, and alginate, favoring the silk over other biomaterials in tissue reconstruction. The control over the physical form and the insertion, through different post-processing techniques, such as alpha -helices and beta-sheets, favor the process of biodegradability.

For bone tissue engineering, the ability to maintain an intact scaffold for a long time favors the transport of nutrients and waste products. Meanwhile, we have bone growth and vascular network formation.

IV. Processability and Modulation of Silk Properties

Silk is composed of water, fibroin, and sericin. We produce it in a neutral PH, in an aqueous solution, and at ambient temperature.

The first step of the manufacturing process is the elimination of cocoons from the fibroin solution. In the next step, we remove the sericin by boiling the silk cocoons in solution with degumming agents. The obtained silk fibers are then dissolved with appropriate solvents in an aqueous solution of purified fibroin by removing salts by dialysis. We can activate the solution of water and fibroin by inserting different organic dopants (enzymes, proteins) and inorganic (metal nanoparticles, quantum dots). We then deposit it on a particular substrate. The crystallization process occurs through the self-assembly of the proteins stored in the air. Thus, we can create different films or absorbable substrates for electronic or photon devices.

We report the steps of the manufacturing process in the following flowchart (Fig. 6). The degumming represents the first step to the removal of sericin for biomedical applications.

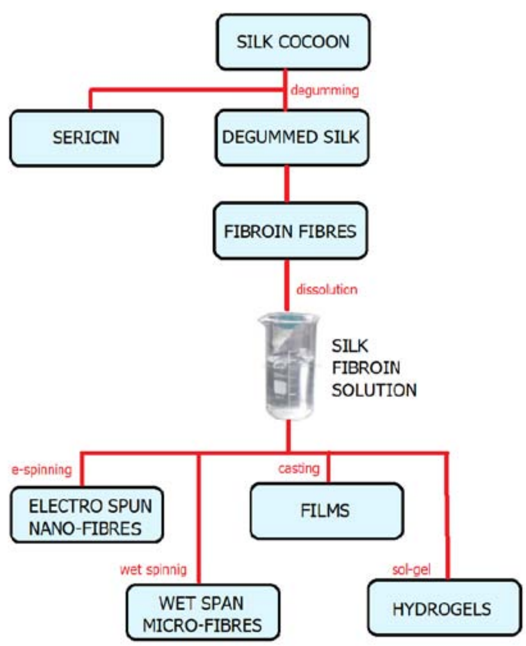

Fig. 6: Stages of the silk manufacturing process

Different degumming techniques obtain fibroins. New methods based on microwaves, ultrasounds, and CO2 supercritical fluid have been introduced [16]. Chemical dissolution of sericin is obtained partly by hydrolysis and partly by dispersion, independent of the method.

Soapy degumming is a commonly used technique that determines a chemical bond between the alkalis, produced by the hydrolysis of soap, with sericin making soda salts. The sericin is separated from the soap and dissolves in the water [2]. Mixtures of soaps and alkalis improve the quality of the silk. The degumming phase is associated with the bleaching phase obtained using hydrogen peroxide in alkaline conditions, acting on the PH through ammonia [17].

Silkworm degummed with citric acid treatment at 30% gave better results than treatment with soap and alkali, obtaining the removal of the sericin at almost 100 %; the total weight loss resulted of 25.4% in the silk fibers. Degumming with citric acid improves tensile strength and surface morphology [18].

The use of chemical components causes environmental pollution; therefore, it is preferable to replace them with natural enzymes extracted from papaya peel or pineapple peel that help improve the degumming process. Enzymes act with a method of proteolytic degradation of sericin without affecting fibroin. In India, the researchers tested unripened papaya as an enzyme. The proteolytic enzymes promote the hydrolysis process of the peptide bonds produced by amino acids. The experimentation required careful tuning of some elements such as degumming time, PH, process temperature, the percentage of the enzyme, and simultaneous selection of mordanting and dyeing [19].

Traditional degumming processes are expensive and harmful to the environment. They require a large quantity of hot water to eliminate contaminants such as oil wax and natural pigments, producing high temperatures and dispersing many chemicals into the environment. The new process has become more ecological and less expensive. One of the most valuable techniques in removing sericin is supercritical fluid CO2, requiring less water and energy. This process involves a pre-treatment with an organic acid which can be citric acid or tartaric acid. It involves soaking the silk in purified water or deionized water for many hours and then transferring the silk from the bath to containers of CO2 with a glycol-type non-ionic surfactant. With containers heated to temperatures around 100 ° C, keeping CO2 levels between 150 and 400 atm. After the removal of the CO2 emissions, we obtain the raw silk without sericin. [20].

Sericin contains water-soluble proteins such as serine and aspartic acid [21]. The degumming process is based precisely on the difference in solubility between silk sericin (SS) and silk fibroin (SF), so using alkaline hot water, SF fibers remaining insoluble are separated.

As an alternative to techniques based on hot solutions, the microwave technique penetrating inside the particles heats them simultaneously.

Irradiation, compared to other methods, takes less time to achieve the same degree of degumming. The process involves verifying the effects produced on the properties of silk through the scanning electron microscope [22]. The survey examined the weight loss, strength, and elongation of the samples found 10 % of weight loss and 8 %. It also occurred that the addition of Marseille soap improves the efficiency of the process. Adding baking soda to Marseille soap, the performance improves further. It turned out that the increase in degumming time, on the one hand, improved both weight loss and elongation of the silk while the strength worsened. The removal of the sericin allowed to obtain these results.

The good results obtained in the wet processing of fabrics have led to extending ultrasonic irradiation in the field of silk degumming. Traditional degumming is expensive and polluting. A group of researchers applied ultrasonic irradiation to a conventional heating bath. They then carried out a comparative analysis using degumming agents: citric acid, sodium carbonate, and papain [23]. Tests carried out on sericin degumming rate, fiber morphology, characteristics of their structure, and their tensile properties have shown that ultrasonic irradiation compared to the conventional heated bath is more effective, especially degumming at a temperature of 60°.

Furthermore, having found that the frequency variation in the wet processing of fabrics influences the efficiency of the process, they also analyzed their effect in the degumming of silk. They obtained the best results with ultrasound at a lower frequency. Regarding degumming agents, they found that with papain, compared to citric acid and sodium bicarbonate, we get a more significant elimination of sericin. They obtained a degumming rate of 22% at a temperature of 60° C and 40 kHz. However, the presence of papain causes excessive loss of the whiteness of the silk. Tests with infrared spectrography and X-ray diffraction showed minor changes in the characteristics of the structure of the silk fibers. The ultrasonic frequency has negligible effects on fiber structure and tensile properties.

The process based on the use of ultrasound represents a green alternative to the conventional method.

After the degumming step follows the dissolution of silk fibroin to make regenerated silk fibers in different forms [24], it is necessary to use solvents that require other dissolution times and temperatures depending on their solubility power [25].

In the process of dissolution, there is always a search for suitable and cheap solvents. An efficient practice washes the one developed by some researchers [26] who used a system with a methanol solvent instead of water and a low concentration of CaCl2, which is a protein denaturant.

They obtained a change in the solvation scabbard of ions in the solvents with the volatilization of methanol.

The process continues up to a stable concentrated SF solution. The remaining solvent

Global Journal of Researches in Engineering (F) Volume XXI Issue III Version I Year 2021

interacts with fibroin chains to complete the solvation sheath. They found a concentration of CaCl2 of 26% at the end of the process, and silk fibroin almost totally dissolved. The residual calcium interacted with SF molecules to form nanofibril molecules. Other techniques allow obtaining different structures, starting from fibroin solution for producing films, fiber, and sponges.

Silk fibroin offers a great opportunity in the biomedical field thanks to its particular anti-inflammatory and biocompatible characteristics when it's implanted in the human body [27].

The possibility to tune the silk properties offers advantages compared to other commonly used polymers. The researchers can tune the properties thanks to the secondary structures: α-helix and β-sheets produced with different processes. These processes may act on the degree of hydrophobicity, degradation, mechanical stress, porosity, oxygen permeability, and thermal stability [28].

Different treatments use solvents and water vapor. The technique with methanol produces mainly secondary structures as β-sheets, although there are other structures. The transition to the β-sheet forms depends on the exposure time and the level of concentration of the solvent (Fig.7). It ensures better conditions for tissue engineering, such as mechanical properties and resistance to degradation.

The method water vapor acts as a lubricant for the movement of the chains of protein [29]. With the increase of secondary structures, there is an improvement in degradation and hydrogel bond.

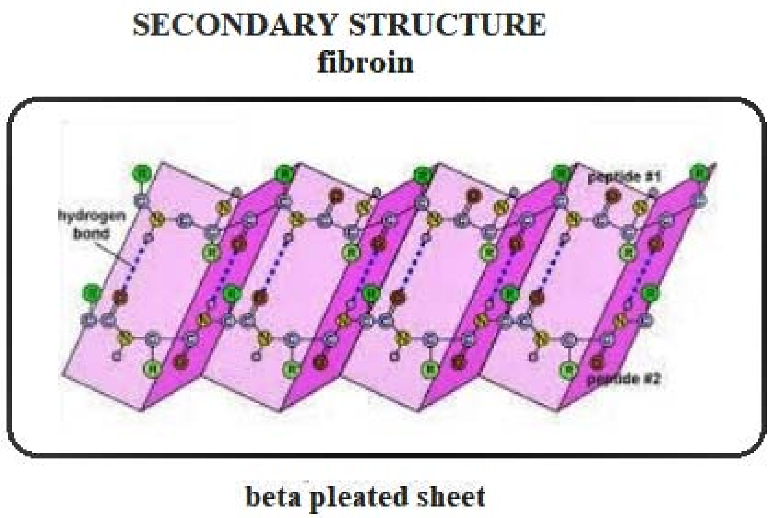

Fig. 7: Secondary structure of fibroin

V. Silk Biomaterials

SF finds application in the biomedical field for its particular characteristics of biocompatibility and biodegradability and its high tensile strength; it can be obtained through different processes or starting from silk fibers or silk fibroin solutions as regenerated fibers. Its combination with other materials favors the creation of various mechanical properties and physical characteristics. The milling process makes it possible to obtain silk in the form of a submicron particle [30].

Dissolution is the phase of the reprocessing of silk fibroin (SF) that allows the production of films, hydrogel, porous scaffolds, and electrospun fibers. Dissolving SF produces molecular chains and different properties, depending on the single solvent system, for each specific application [31].

Treatment with methanol is reported in several experiences, highlighting the formation of β-sheet, although they are also present in α-helix and random coils regions. The concentration of the solvent and its exposure time strongly influenced this transition [32].

a) *Native silk fiber*

Native silk fibers, derived from the Bombyx mori silkworm, represent the raw material used to produce regenerated silk solutions. Native silk fibers are composed of fibroin, which provides high tensile strength. They are applied initially in the medical field as sutures. Moreover, silk fibers also have the property of permeating water vapor and oxygen and promoting skin fibroblasts and collagen formation. Subsequently, they have found wide applications in the biomedical field [33].

The filaments are suitable for constructing a porous nonwoven silk material for cell seeding, the fabrication of the mesh structure, and scaffolds for ligament repair [34].

Methylcellulose (MC) is also valid in tissue reconstruction for its resistance and anti-toxicity properties. Recently, however, composites in silk fiber and methylcellulose (SF/MC) have been made to engineer bone. The results obtained showed improved osseointegration between bone and composite and provided a reasonable degradation rate, bioactivity, biocompatibility, and mechanical properties. The solvent casting technique allows obtaining a porous composite [35].

b) Regenerated Silk

Silk solution allows you to produce several different regenerated structures (Fig. 8). After the phase of degumming, we can dissolve the silk fiber with a salt solution followed by dialysis to obtain an aqueous silk solution; the silk solution is formed [36, 37].

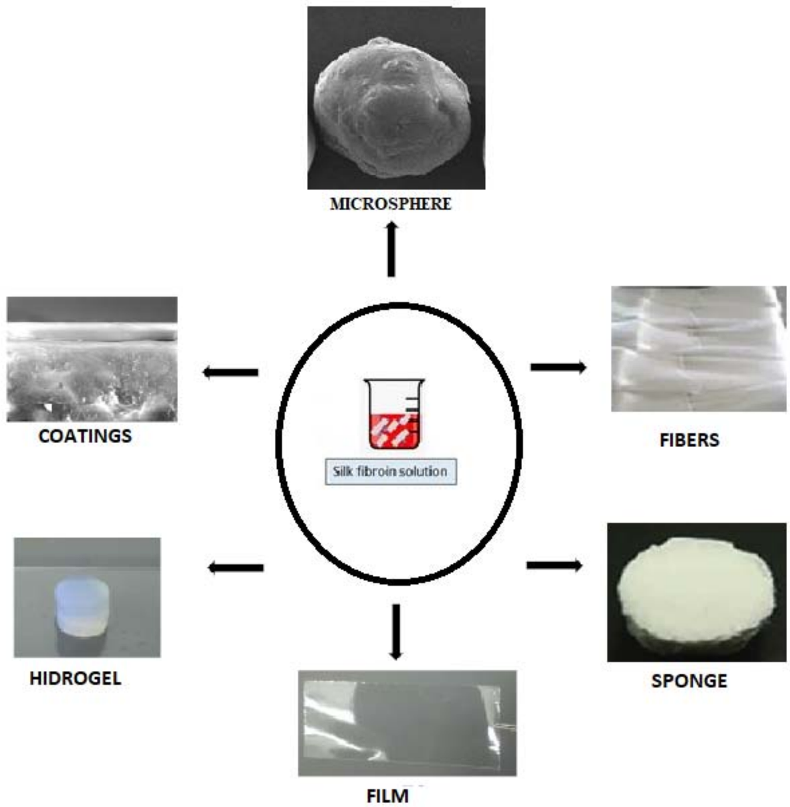

Fig. 8: Derivatives of regenerated silk

i. *Silk film*

For corneal engineering, centrifugal casting produces fit silk fibroin films [38]. They show lower roughness than those made by dry casting and are also better for elasticity and transparency, revealing a good proliferation of human corneal keratocytes. Another suitable technique is the spin coating and layer-by-layer deposition [39]. At the end of the synthesis process, silk fibroin solution has approximately 7.5% concentration wt./vol. The spin-coating solution with glass substrates produced ten samples with a different number of layers: drying at room temperature for some and heating at 60°C for others. Then the optical transmittances observed over the visible-to-near-infrared region showed the values of 95% in the samples at room temperature and 98% in those at 60°C. The number of layers and the heating time don't affect the results.

Each specific biomedical application has modulated biodegradability and its mechanical-optical properties. Studies have shown that the film can support various cell-like epithelium, endothelium, and fibroblasts for tissue engineering [40].

Recently some researchers have designed a technique for the production of patterned silk films to improve cell proliferation [41].

The technique of water annealing after casting allows producing water-insoluble films by forming secondary structures α-helix and β-sheets [42].

Recent work pointed out the validity of the silk fibroin matrix for storing the antibiotic tetracycline and rubella vaccine for six months at 60°C [43].

The silk films constitute the substrate to fabricate electronic components that can be readily integrated and applied by medical care and wearable device. Recently by patterned "casting" strategy, conductive Ag nanowires have been introduced into the silk film for manufacturing conductive devices. The silk fibroin film with patterned Ag nanowires can operate as an interdigital capacitive sensor [44].

ii. *Hydrogel*

The transition to hydrogel occurs under specific requirements [45]. Their preparation takes place without the need for any chemical crosslinking agent.

An increase in temperature or protein concentration and a decrease in ph can control the process. In these conditions, with the change from random coil formation to β-sheets formation, the solution will gel. Subsequently, further aggregation can create gels with a three-dimensional network structure [46].

The low PH and high temperature make the solution unstable. The concentration of the solution shapes the mechanical properties and pore size of the hydrogel.

Currently, the hydrogel products are classified into physical or chemical gels depending on the cross linking method used. The formation of hydrogels occurs through physical interactions such as hydrogen bonding, hydrophobic interaction, electrostatic interaction, and ion interaction in the physical cross linking process. The applied methods are self-assembly, ultrasonication, cutting, electric field, choice of appropriate values of temperature and pH, use of organic solvents and surfactants, etc. The chemical crosslinking method favors the creation of a spatial network structure through covalent bonds between the molecular chains of silk. Chemical hydrogels are physically more stable and more resistant to traction than physical ones. The methods used are essentially photopolymerization, irradiation, use of chemical and enzymatic agents [47].

The possibility of controlling the structural and functional characteristics of silk hydrogels and integrating new biological features have made it possible to obtain a new generation of hydrogels suitable for tissue engineering and drug delivery [48].

Researchers applied also ultrasound energy for the manufacture of silk fibroin hydrogel. Ultrasound causes structural changes and can control the gelation rate through sonication parameters, such as power output, ultrasound time, and silk fibroin concentration [49]. This method is faster and more effective. Adhesive hydrogels can repair hard tissues such as teeth and bones and soft tissues such as the liver and kidney [50].

The Hydrogels are also helpful in maxillofacial and dermal filling applications [51].

iii. *3D Porous Scaffold*

Different experiences have reported the use of silk scaffolds for bone repair and regeneration [52].

The porous 3-D sponges have a high surface area that creates a suitable environment where cells grow at different times [53]. They also model the growth of hydroxyapatite facilitating the osseointegration process [54]. Silk 3-D porous scaffolds require other manufacturing techniques [55]. The silk fibroin concentration represents a decisive element for final porosity formation and mechanical properties. Some work shows that the porosity could be dialed from 80% to 90% by ranging the fibroin concentration between 8% and 16%, respectively [56]. The implanted scaffolds degrade as tissues regenerate, and the degradation rate depends on the type of tissue involved. The researchers can determine the degradation rate through controlling dissolution, hydrolyzing conditions, and freeze-drying [57]. Different techniques allow 3-D scaffolds for bone and cartilage repair with particular reference to porosity and pore size [58].

Researchers had a new experience by inserting the structure of the sponge into a collagen gel. The collagen gel/sponge composite scaffold exhibited better mechanical compression characteristics than the simple collagen gel. It also presented favorable conditions for the proliferation of human mesenchymal stem cells (hMSCs) [59].

iv. *Electrospun fiber*

The scaffolds are a temporary structure to promote tissue regeneration.

Some works show the use of electrospinning to manufacture scaffolds for various tissue engineering applications [60]. The electrospun fibers have a large surface area and porous morphology that favor cell adhesion, proliferation, and differentiation. The authors have further functionalized on the surface by incorporating biomolecules, such as DNA, growth factors [61]. Thus, they can control the proliferation, differentiation, and integration of cells seeded on the scaffold. With this technique, in which the action of an elevated electric field can stretch a polymer jet, it is possible to produce filaments of 2-5nm. The high fineness of the electrospun fibers allows the production of materials with a very high surface/volume ratio and a high porosity. An electrospinning plant mainly consists of an extruder that pushes the molten or solution polymer inside a capillary and a collector placed in front to it (Fig.9). Electrostatic repulsion between the charges at the surface of the solution droplet produces the fiber. The high voltage power supply is applied to the tip of the capillary tube. As the electric field strength increases, the hemispherical surface of the fluid at the end of the capillary tube elongates to form a cone called "Taylor cone," with further expansion, the charged fluid jet is expelled, and stretches becoming very long and thin. Following the evaporation of the solvent, the filled fibers solidify and their collection is done on the collector [62].

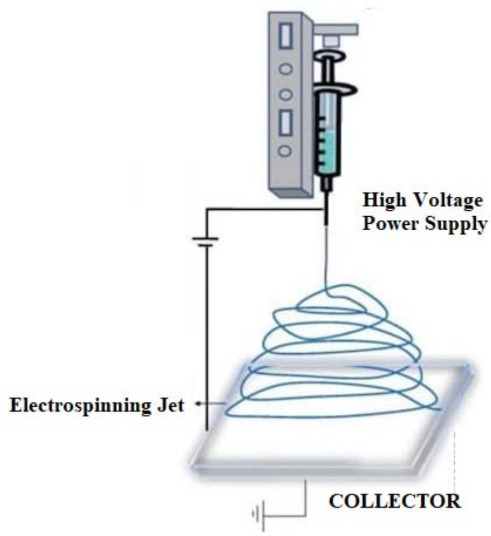

Fig. 9: Scheme of the electrospinning process

We can use two processes: solution electrospinning (employs a system polymer-solvent binary), melt electrospinning (uses melted polymer). Then we characterize the scaffold's properties by acting on various process parameters, such as flow rate, voltage, air gape distance, and solution concentration.

Human platelet lysate (hPL), a set of growth factors and cytokines, can significantly help regenerative medicine. Still, the rapid degradation at room temperature and the difficulty of handling hPL gels have limited its application. Recent studies have shown the possibility of enclosing hPL in an electrospun matrix of silk fibroin to allow its wide use [63]. Fibroin is suitable for preserving hPL activity at temperatures up to 60 ° C. The porosity, conferred by electrospun fibers, favors cell proliferation and makes simple the absorption of exudate.

Electrospun nanofibers have also attracted tremendous attention in manufacturing bone tissue [64], concerning the following conditions: stem cells that differentiate into bone cells, scaffolds that can simulate the extracellular matrix (ECM), and growth factors for a cell. A characteristic that the scaffolds must possess is the high porosity to favor the adhesion of osteogenic cells. Experimental data confirm that patterns obtain the best results with a large surface area, high porosity, and pores of adequate size. Additionally, most tissue regeneration applications require fully biodegradable or absorbable scaffolds. The rate of degradation must be in tune with the growth of the tissues to have a good interaction between fibers and ECM. The electrospun silk fiber osteogenic agents are incorporated into the electrospun silk fibers, thus making the SF a suitable material for reconstructing bone tissue. With the addition of polyethylene oxide (PEO), an increase in viscosity is obtained [65].

These materials have proved useful to produce tubular scaffolds as a small-diameter vascular graft [66]. The methanol promotes the transition from random coil structure to β-sheets.

v. *Microspheres*

Microspheres are materials with spherical shapes and diameters of micro-nanometer dimensions widely used in the biomedical field. The evolution of nanotechnologies made their manufacture possible. Its manufacturing process is complex and requires rigorous control; there are different fabrication methods [67] Recently, researchers developed a method to meet the requirements of crystalline β-sheet structure and size in silk nanospheres [68]. The crystalline content of the β sheet structures is strictly connected with the drug delivery capacity and with the biodegradability rate. The process requires adding polyethylene glycol so that preparation does not require other toxic chemicals and solvents. The salt added to the solution makes the microspheres more homogeneous.

We can produce microspheres by adding lipid vesicles for the controlled application for drug delivery to a targeted area of the body [69]. The removal of lipids occurs subsequently using methanol or sodium chloride, getting microspheres with β-sheets structure. The transition rate from random coil structures to β-sheets depends on methanol concentration. The microspheres treated with NaCl have a smoother surface compared to the methanol treatment. Both types have a mixture of multilamellar and unilamellar structures. For the process is used a lipid (e.g., 1, 2-dioleoyl-sn-glycerol-3-phosphocholine) film to emulsify the solution [70]. Later, with freezing/thawing cycles and lyophilization, water is removed. With centrifugation, the lipid is removed, getting SF microspheres.

The application of polyvinyl alcohol (PVA) is another method for preparing silk microspheres [71]. This methodology foresees a fibroin solution with PVA. The foreseen steps are drying of the solution in the form of films and subsequent dissolution of the films, then removal of the residual PVA by centrifugation. By acting on the concentration of the silk or PVA solution, we can change the size of the spheres. Before mixing the silk solution with the PVA, we must proceed with encapsulating the drugs. The mass ratio between silk and drug is in the measure of 100:1.

VI. Applications

Silk is a textile fiber, also a biopolymer. Its extraordinary biological and functional properties have found wide application from the biomedical field to microelectronics (Fig.10).

Application in the biomedical field

One of the first silk applications was in the medical field due to its essential properties of:

- Biocompatibility, is not rejected by the immune system, does not favor the onset of thrombi;
- Biodegradability, the possibility of regulating its degradation rate in the absence of inflammatory reactions, and its
- Easy sterilization makes it preferred to other materials of a synthetic nature;
- Realization of scaffolds represents a structure suitable for in vivo tissue repair by promoting cell adhesion and growth.

Application in the pharmacological and therapeutic field

Another silk application is the controlled release of drugs to pre-established organs and the monitoring of definite pathologies. We create different forms to encapsulate pharmacological molecules, bioactive macromolecules such as enzymes, or other types of cells.

Application in the field of microelectronics

A further silk application is the realization of biosensors for monitoring physiological parameters such as heart rate or body temperature and implantable silk bio-electrodes in the human body to replace invasive needles.

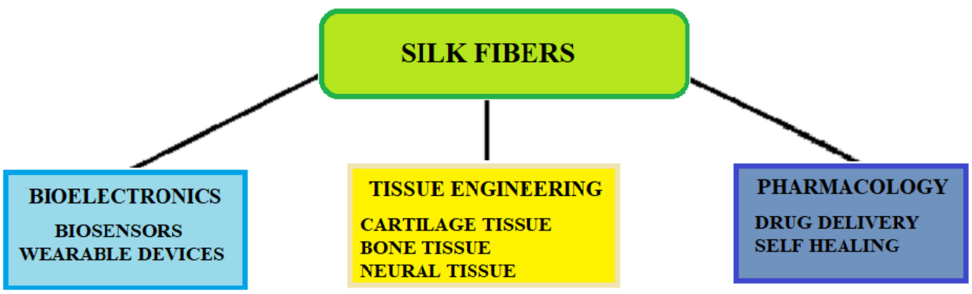

Fig. 10: Silk applications

VII. Biomedical Applications

The recognized natural silk has extraordinary properties that make it suitable to regenerate or improve the functions of damaged tissues and organs. They are biocompatibility, biodegradability, anti-inflammatory, the capacity of promoting the attachment, proliferation, and differentiation of many different cells type. For these properties, it is also an essential structure for the adhesion of growth factors and to incorporate drugs [72]. In addition to rebuilding damaged areas, silk matrices also provide bioactive molecules, genes, and cells.

The path for the preparation of tissue for reconstructive medicine consists of several steps (fig. 11).

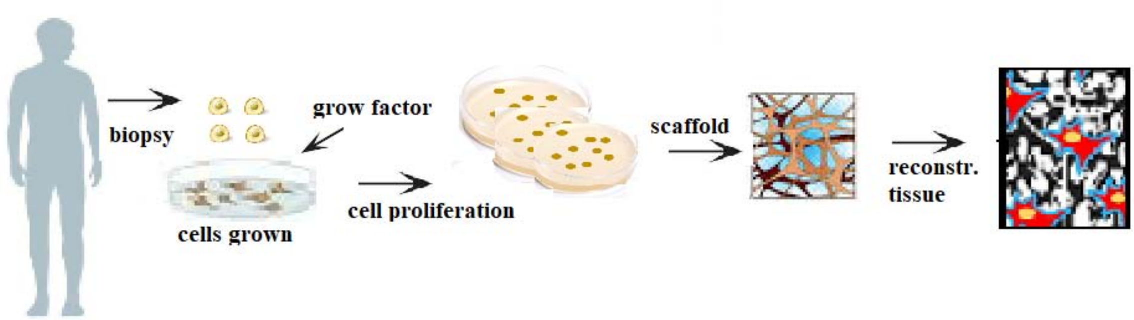

Fig. 11: Engineered tissue preparation steps

Cells are biopsied from patients and grown in 2D culture to which we add growth factors. Subsequently, these cells, once expanded, are seeded on scaffolds for the engineering of specific tissues. We can transplant the reconstructed tissue into the patient.

a) Wound healing

The skin protects the human body from dehydration, infectious agents, and, more generally, from environmental conditions. Any damage produced by burns or wounds on the skin reduces its protective effect, so tissue engineering interventions restore skin loss. Studies conducted in vitro and in vivo highlighted that the silkworm or spider SF-based biomaterials favor cellular adhesion and fibroblast proliferation on skin wounds and improve plasmatic imbibition capabilities to promote wound healing [73]. Thanks to its properties, this biomaterial is applied alone or scaffolds for nanofibrous mats, hydrogels, sponges, or films tailored to tissue engineering. SF films showed to have more cure potential than conventional hydrocolloids. Wounds treated with silk films have better collagen regeneration, easier re-epithelialization, and heal earlier. The nonwoven SF is biocompatible and allows the growth of any type of human cell [74]. The histological finding revealed that dermal fibroblast proliferates on fibroin coating and scaffold without an inflammatory response. Oral keratinocytes can proliferate on woven fibroin meshes. Researchers developed chitosan-based (CS) hydrogels loaded with silk proteins (SF) and l-proline (LP), an amino acid necessary for collagen synthesis, via physical crosslinking to speed up the healing process. Studies showed that hydrogels incorporated into LP, compared to other composites, reduce the healing time [75]. The nanofibrous membranes have a high surface-to-volume ratio.

Furthermore, interconnected pores promote cell penetration and nutrient exchange and favor hemostasis and absorption of exudate from the wound. To increase wound healing were produced, electrospinning, nanofibrous asymmetric membranes. These had a top layer which is composed of SF and poly (caprolactone) (PCL) and a bottom layer compound of SF with hyaluronic acid (HA). The combination of SF with PCL lets it get epidermis-like properties such as hydrophobic character, waterproof ability, and mechanical resistance. The combination of SF/HA allows dermis-like properties such as absorption of the exudate from the wound, cell adhesion, and proliferation [76].

b) Drug Delivery

We can use fibroin nanoparticles for the controlled delivery of drugs for specific clinical needs (Fig.12) adjusting the encapsulation capacity and release rate through the crystallinity and concentration of the silk fibroin. They are also used to deliver proteins and peptides [77]. Recently, they are applied to target cancer cells. The technique used allows to target the diseased cells and save the healthy ones, thus reducing the toxic effects and improving the effectiveness of the therapy [78]. Some researchers applied a therapy based on lyophilization of SF with emodin-loaded liposomes and methanol to treat breast cancer [79]. Also, curcumin in silk nanoparticles has proven to be an effective method for treating breast cancer [80]. Another innovative experience is that carried out for the release of anticonvulsive adenosine with silk encapsulation of adenosine dust reservoirs. The thickness, crystallinity, and morphology of silk were analyzed to study the relationships between the silk coating of the adenosine reservoirs and the release time. The thickness of the tank coating and the number of layers applied to affect adenosine release; with their increase, the average rate of release decreases by increasing its duration [81].

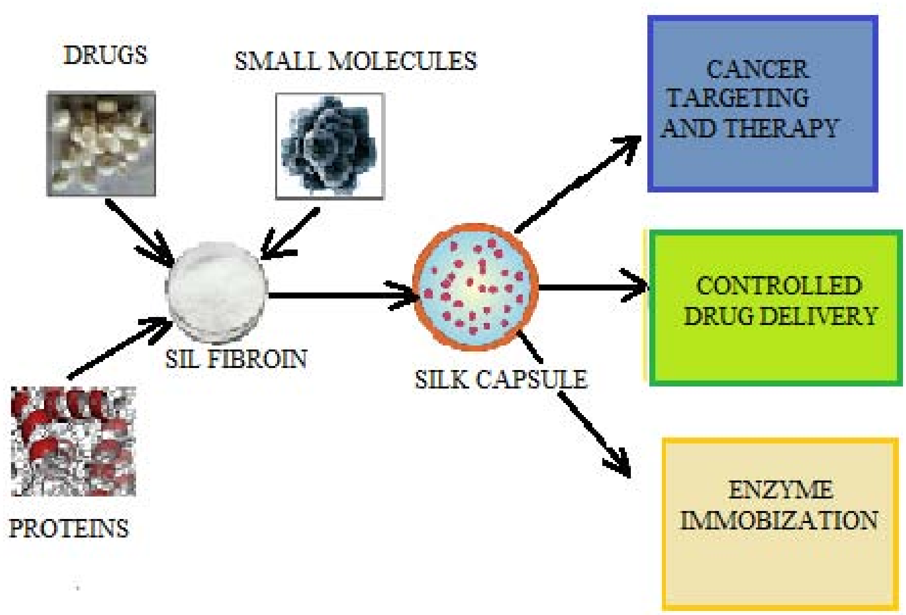

Fig. 12: Drug delivery

c) Bone Tissue Engineering

The application of silk proteins in bone regeneration allows modelling the growth of hydroxyapatite by improving the osseointegration process [82].

The healing time in fractures or bone defects is closely related to the extent and extension of the damage.

There are two different repair techniques; one is called autograft and the other allograft. The first refers to the transplant of tissue within the same body. The second refers to how the tissue comes from a foreign body. The first research for human tissue reconstruction by silk took place at Tufts University of Boston (USA) [83], where they applied different forms, such as film, electrospun scaffold, and 3-D porous scaffold. They preferred the use of silk, as a basic structure, over other different materials available, for its property to improve the osseointegration process [84]. Then with the addition of rBMP2 (recombinant human bone morphogenetic protein-2), a rapid diversification of osteoblasts is also obtained [85]. Researchers have made compounds by incorporating silk into various biopolymers. Compounds of silk and hydroxyapatite (HA) have also been effective in bone repair as HA is biocompatible and has good osteoconductivity and osseointegration [86, 87]. It has been noted that combining SF with HA, a good compound biopolymer suitable for bone engineering, is obtained [88].

Researchers experimented with solutions of poly (ethylene oxide) PEO mixed in fibroin and analyzed how fibroin on PEO matrices influences the healing process of the breast implant [89]. The level of silk concentration affects the conformation of the PEO scaffolds structure and the process of cell adhesion and proliferation of HaCaT (human keratinocytes cells). The first cells surrounded the wound but subsequently the following factors influenced their increase: growth factors, degree of cell adhesion, and their differentiation. Therefore, it is possible to have composites without defects by acting on the silk concentration during the electrospinning process. Silk hydrogels with Arg-Gly-Asp (RGD) peptide gelling adhesive and bone marrow-derived mesenchymal stem cell encapsulation are suitable for bone engineering beyond improving cell adhesion and favoring osteogenic differentiation. [90].

Xenografting refers to the transplantation of human tissues or cells into animal models and is widely used in research to evaluate the effectiveness of the graft and its physiological interactions [91]. The graft must satisfy specific characteristics to ensure the formation of new and healthy tissues. In the first place, a porosity of such dimensions allows the vascularization and construction of new bone. Secondly, a surface will enable vascular growth, attachment of bone cells, migration, and proliferation. The third is adequate mechanical resistance to compression and elasticity. The last requirement is sufficient dimensional stability. Xenograft models find use in cancer research and therapy. In addition to applications in regenerative medicine, xenograft models of human bone are also used as experimental models of skeletal diseases, allowing for studying disease states in vivo, which would otherwise be impossible on human subjects.

Stem cell-based (BTE) bone tissue engineering represents a clinically meaningful solution for bone repair. We present a pure 3D silk fibroin (SF) scaffold used and fabricated by the freeze-drying method in the study. Human adipose-derived mesenchymal stem cells (hASCs) were seeded into the scaffold to facilitate bone regeneration [92]. The researchers evaluated the efficacy of xenograft SF-hASCs scaffold on the ability of bone regeneration in critical vital defects in the rat.

Previously, the culture of HASCs in organic and inorganic sources highlighted their potential for osteogenic differentiation. This coupling produced rapid vascularization of the implanted area and improved bone formation. The researchers after generating two 5 mm (diameter) cranial bone defects in the skull of the model of 30 mice model, with the aid of a dental bur, inserted the xenografts The defects were partly filled with the SF-hASCs scaffold and partly with the SF scaffold only. The implant was successful without any bleeding or infection complications, confirming the perfect biocompatibility of silk fibroin. After a period of six and twelve weeks, the researchers performed the micro-CT analysis to verify the growth of new mineralized bone. The results confirmed the newly formed bone is densely localized at the edges of the defect, especially in the xenograft SF-hASCs compared to the SF. They also observed that the degradation rate of the scaffolds was compatible with the regeneration of bone tissues. The results obtained revealed that the SF scaffold incorporated with hASCs had superior biocompatibility and osteogenic capacity to promote bone regeneration.

The presence of hASC in the SF scaffold favored the transformation of osteoblasts into osteocytes producing an effective bone remodeling process and an improved bone extracellular matrix in the defect area. These results confirmed that the union of stem cells and SF may be an excellent functional bio-scaffold for forming new and healthy tissues.

Alloplastic bone repair materials are a valid alternative to autograft. Alloplastic is synthetic bone substitutes easily accessible and that do not require a patient donor. The alloplastic materials must possess specific requirements such as biocompatibility with host tissues, non-inflammatory and non-antigenicity. Furthermore, they must reproduce the porosity of the cancellous bone. The pores of the bone substitute must be of sufficient size so that there can be migration of cells and passage of blood vessels through them. The pores must be connected, not isolated.

Additionally, they must stimulate bone induction, resorbable and replaceable by bone, stable in varying temperature and humidity.

The researchers analyzed many materials to make these synthetic grafts, including metals, ceramic materials, polymers, and their composites. Choosing the most suitable material is essential as it must have the mechanical properties suitable to support the expected loads depending on the type of application.

Metals such as titanium, nickel-titanium, and magnesium alloys are biocompatible, resistant, workable but have a higher elastic modulus than bone which can cause stress-shielding. (This phenomenon consists in a loss of density due to the reduced load on the natural bone compared to the metal fixation device, no stimulus for continuous remodeling necessary to maintain bone mass).

Because of their fragility, ceramic materials are challenging to use as a scaffold for synthetic bone tissue.

Polymers are excellent candidates for bone grafts due to their physical properties and chemical, have excellent biocompatibility. Still, their poor properties of mechanical strength make them inappropriate to manufacture bone scaffolds that they must instead support excessive loads [93].

In recent years, researchers have developed manufacturing studies on alloplastic grafts based on organic and inorganic materials that can mimic the structure and function of natural biomaterials. They obtained satisfying results with the combination of SF membranes with hydroxyapatite (HA). Hydroxyapatite (HA) is a hydroxylated calcium phosphate salt with a high degree of hardness and a significant component of the inorganic substance found in bones and teeth. For its characteristics of bioactivity and resorption and facilitating the binding of the graft to living tissues, it allows obtaining the slow and gradual degradation of the implanted material simultaneously with the growth of new tissues.

SF / HA scaffolds are preferred over other HA-based bio-materials as they reduce the risks during bone implantation due to their excellent bioactivity, proliferation activity, and osseointegration. Their porous structures ensure better transport of blood and body fluids for metabolism and bone growth. These properties make them very similar to natural bones. The researchers apply several techniques to prepare SF / HA scaffolds, such as freeze-drying, electrospinning, gelation, and cold drying.

Researchers at Tufts University in Boston, led by Kaplan, were the first to study the efficacy of SF / HA old scaffolds in bone regeneration. They found that hydroxyapatite is a substance with exceptional biocompatibility and bioactivity and is substituted, after grafting, with the bone growing through the osteoinduction process. Regeneration occurs via two methods, osteoconduction of the surrounding bone in the defect area and nucleation. They noted that reconstruction in the presence of the hybrid composite was faster than regeneration by the surrounding bone and that ossification was constant in all areas, including the center of the bone defect [94].

Researchers investigated bone regeneration using silk hydroxyapatite hybrid composite in a rat alveolar defect model [95]. For testing, they were used thirty-six male Sprague-Dawley rats of 9 to 10 weeks of age and weighing 240–250g, divided into three groups of 12. The first group was sutured without a scaffold bone graft, the second group was sutured with a silk scaffold graft, while the third group was grafted with a hybrid scaffold of silk and hydroxyapatite. In rats, a 7 x 4 x 1.5 mm alveolar defect was created by incision using a power drill in the mucous membrane between the hard palate of the right upper jaw and the alveolar bone. They produced scaffold by mixing an aqueous silk fibroin solution, previously refined, with granular hydroxyapatite at a 10: 1 ratio and sterilized by irradiating with gamma rays after freeze-drying three days. The pretreated scaffold was cut to the same size as the bone defect and grafted into the created cavity. The mucosa was then sutured using black silk. Inspections were carried out every four weeks from the fourth to the twelfth to verify the state of growth of the new tissues. They used different types of analysis, visual analysis, tissue analysis, and CT of the bone defect; in the twelfth, they used the Western Blot technique to verify the degree of bone generation. The authors found that mature osteoids appear at the eighth week and only at the twelfth week, observed through the bone defect tissue analysis, forming bone cells. Moreover, they observed that in the samples in which the hybrid scaffolds were present, the generation was faster, and there was constant ossification in all parts of the defect, including the center. The new bone is generated via two processes, osteoinduction, and osteoconduction, from the boundary and the center of the bone defect.

d) Ligament/tendon

Ligament/tendon injuries are common in sports. The repair frames must have high mechanical strength, ligament formation capacity, and biodegradability. Silk can be aggregated with other compounds, making it suitable for the repair of ligaments and tendons. Experiences have shown that silk scaffolds are valid for repairing the anterior cruciate ligaments (ACL), Achilles' tendon, and other ligaments [96]. Researchers found that silk scaffolds and, in particular, knitted silk scaffolds and silk sponges facilitate the growth of mesenchymal stem cells. The silk fibers deprived of sericin can be wrapped in yarns for the production of ligament matrices. These matrices have the same structure as collagen fibers present in human ligaments. It also features the same mechanical stimulation as the native ligament. The native Bombyx mori SF lacks the peptide sequence RGD (arginine-glycine-aspartic acid) responsible for cell adhesion to the ECM [97]. It is necessary to resort to either the surface coating or the chemical coupling with the RGD or specific growth factors to favor the adhesion.

Another study experimented with a composite formed by an electrospun scaffold of SF and collagen with the addition of BMP-13 (bone morphogenetic protein-13). Subsequently were crosslinked with methanol and ethanol, the treatment with methanol ensured a higher mechanical resistance. There was a good adhesion and proliferation of stem-derived adipose cells (ASC) on these structures, demonstrating that BMP-13 is a factor that improves cell infiltration. The scaffold obtained is a regenerating matrix with improved tensile strength [98].

TEND (Tissue Engineered Device), obtained by mixing type 1 collagen and PDLLA (poly DL-lactide) solubilized in DMSO (dimethyl sulfoxide), represents an effective solution. The morphological dimensioning of this structure allows improving cell adhesion, ensuring tissue integration and mechanical resistance [99].

e) Cartilage

Hyaline cartilage is the cartilage most present in the body and covers the surfaces of the joints, favoring the transmission of mechanical loads with a low coefficient of friction. The hyaline cartilage matrix is rich in collagen fibers type II and proteoglycans; it is an avascular and aneural tissue. It can be damaged if subjected to significant mechanical strain. The damage is produced either by trauma or by deterioration due to age. Surgery on cartilage essentially takes place in the orthopedic sector to restore joint function or repair the loss in an auricle, trachea, nose, or eyelid. Silk scaffolds are also valid in the regeneration of cartilage tissues, but they must be appropriately structured to allow the growth and differentiation of chondrocytes. The scaffolds can be used for in vitro cultures or transplanted directly into the organism as a colonization medium for stem cells [100].

Pioneers in the combined use of silk scaffolds and human chondrocytes were researchers from Tufts University in Boston (USA) [101]. They experimented with the combination of SF with PLLA (polylactide) scaffolds. The results obtained from in vitro experiments found that the adhesion, growth, and proliferation of chondrocytes are significantly better than unmodified PLLA scaffolds [102]. They also compared porous silk fibroin scaffold with collagen scaffold regarding adhesion and proliferation of human articular chondrocytes and mesenchymal stem cells. In vitro cultures porous silk scaffolds showed the best results; the GAG (glycosaminoglycan) content was also higher. Based on previous experiences on the ability of silk fibroin scaffolds to behave in the same way as ECM (extracellular matrix) towards chondrocytes [103], some researchers have fabricated curcumin and silk scaffolds with saline leaching method [104]. The scaffolds obtained were porous and rough, thus favoring cell adhesion [105]. Curcumin is a yellow polyphenolic pigment found in turmeric spice. It is known to have antioxidant, anti-carcinogenic, antiangiogenic, and anti-inflammatory effects [106]. These last two properties lengthen the cellular lifespan. The tests carried out showed that increasing the concentration of curcumin improves the device's mechanical strength and increases cell proliferation and ECM formation.

The reconstruction of the auricular cartilage uses composites with PVA [107]. Polyvinyl alcohol (PVA) hydrogels form hydrophilic 3D polymer networks. They ensure an excellent elasticity that makes them preferable in reconstructing tissues and, in particular of cartilage. In particular, they possess some specific properties of ear cartilage, such as cell immobilization, solidity, flexibility, and resistance to pressure and traction [108]. Its mechanical strength is very similar to that of human cartilage [109]. We tried to create composites with different percentages of silk and PVA, also using various techniques such as salt leaching and freezing-thawing. But from the results obtained for the growth of chondrocytes and mechanical characteristics, the best were those with 50% PVA and 50% S.F. They also did not exhibit any rejection or inflammation reactions.

f) Vascular Tissue

SF produces highly biocompatible tubular vascular graft architectures by preventing fibrous tissue responses, thus providing an adequate solution for vascular dysfunctions. In coronary or peripheral vascular bypass surgery, it is necessary to integrate the current procedures to replace vascular tubular tracts taken from one's own body or with artificial lots. Sometimes auto-grafts are not possible for several critical factors related to the presence of already carried out self-grafts or advanced auto sclerosis of the arteries. Even small-caliber wholesalers made from polyethylene compounds involve several complications that discourage their use. For its characteristic properties of biodegradability or biocompatibility, silk fibroin is a suitable solution for small-caliber blood vessels. Silk electrospun tubular scaffolds are used for vascular tissue engineering as they are porous and resistant mechanically [110]. The porosity is ideal for the endothelization of vascular grafts.

Different techniques for the production of tubular scaffolding range from filament winding to spinning gel weaving and electrospinning. The research aims to construct multilayer tubular scaffolds to get as close as possible to the functional characteristics of the artery [111-112]. Crosslinking agents are also used to make them more porous and elastic and to set degradation. A tubular scaffold SF ES-TEX-ES (Silk Graft) provided good results to treat small-caliber blood vessels [113]. The structure has a three-layer hybrid architecture, formed by E.S. (electrospun) layers, one inside and outside, and in the middle TEX (textile) layer. The hybrid architecture was engineered for the pre-surgical manipulation of the device and to improve the aggregation between the tissues and the mechanical resistance. It is the TEX layer that gives the device a high mechanical resistance. It is obtained, first electrospinning, during the manufacturing process, coating the TEX surface with the ionic liquid to achieve complete adhesion between the three layers, ensuring the high mechanical resistance. After a series of in vitro tests, the researchers implanted artifacts in large animals for in vivo tests. Experiments allowed to study the type of interaction with fibroblasts and endothelial cells; cytokines and chemokines were analyzed to verify the proliferative and anti-inflammatory capacities. The researchers also performed a blood component test. The results obtained were all encouraging for subsequent in vivo experimental studies.

Micro-nanoscale topographies influence the process of cell adhesion, proliferation, and migration.

Experiences made, designing fibroin silk with different structures [114] confirmed their suitability for the manufacture of micro blood vessels. Small-diameter graft structures of S.F. electrospinning and coated with silk sponges showed good mechanical resistance and water permeation [115]. The results obtained found that the coating with silk sponges increases endurance and elastic modulus of the device while the permeability decreases, enhancing the fibroin silk sponges.

When the fibroin is coated with gelatin, the properties to promote endothelial cell attachment and the development of a micro vessel-like structure improve [116]. Studies showed adequate morphological properties combined with good stability in an aqueous environment and good mechanical properties.

Experiments proved that the culture of endothelial and osteoblasts in silk fibroin is essential in forming micro vessel-like structures. These materials have good anticoagulant activity and platelet response. The ability to promote vascularization while withstanding vascular pulsating pressure makes silk fibroin a suitable graft for blood vessel repair.

VIII. Optical and Photonic Applications

Thanks to its physical and structural properties, technological evolution in production, and functionalization techniques, it was possible to apply silk in technical fields, including optics and photonics. By modulating their self-assembly through the regeneration process of the silk fibers, it is possible to obtain materials in different formats also in the optical sector. Among other things, the possibility of getting structures on a micro-nanometric scale associated with its biocompatibility and biodegradable properties has made it possible to create implantable and sustainable optical devices, contributing to the reduction of environmental pollution [117].

Furthermore, taking into account the variability of its structure in correlation to surrounding factors, it was possible to manufacture tunable optical devices in the field of environmental sensors [118]. The regenerated silk fibers show many attractive characteristics, such as making them suitable for realizing devices in the optical and photonic fields with the other property of creating optically transparent and multifunctional supports.

One of the sectors in which silk has found application, using its high refractive index, is that of the manufacture of optical fibers and waveguides with low optical losses [119]. The guides were made either by integrating regenerated silk with other optical platforms or combining different silk formats with distinct refractive indices or using natural silks spun directly from silkworms or spiders with higher optical losses.

It is possible to manufacture plasmonic devices by integrating metallic plasmonic nanostructures with silk matrices [120]. These hybrid structures generally consist of periodic or aperiodic arrays of nanocylinders, nanospheres, and nanoantennae. Some designs applied matrices of silk and metals such as gold and silver.

They can function as biosensors using the refractive index shift in correspondence with strong plasmonic resonances [121].

Other integrated compounds are the metamaterials with silk proteins. Metamaterials are artificially structured compounds whose properties arise from their structural composition rather than from materials. Silk represents the substrate of the device in which plasmonic and metamaterials patterns are incorporated. It constitutes the platform of optoelectronics devices that sensors or implantable devices can use. [122]. The variation of the dielectric constant of silk in the presence of humidity monitored the level [123].

Researchers resort to silk to obtain structural color materials that have different optical characteristics than pigment colors. The interaction of light with periodic nanostructures makes structural colors. We can achieve structural color functions through nanofabrication techniques associated with the intrinsic properties of silk. Many structurally colored materials are iridescent, such as opal; the color changes with the viewing angle and orientation. The experience made on the possibility of obtaining controllable structural color through nanostructured periodic lattices in silk protein films is helpful [124]. The periodic lattices of nanopores give particular scattering features to the films by realizing a coloration when they are hit by white light. The lattices exhibit a different coloration as a function of the variation of occupied space. Furthermore, by varying the refractive index, a shift in the spectral response occurs. This phenomenon makes it possible for photonic gratings as substrates for optical sensors.

Researchers developed numerous experiences in recent years; some considered innovative solutions are listed below.

a) Sensors

Due to their excellent features, silk fibers also find application as optical fibers. Dragline spider silk acts as a sensor to detect humidity, and more generally, as a chemical substance detector (ethanol, ammonia, etc.), representing a better alternative to glass fibers that usually require coatings [125]. The physical principle underlying this experience consists of the optical fiber's reaction in contact with the targeted chemical species. Under the action of these substances, the fiber will change throughout its volume. Consequently, the parameters of the light (intensity, phase, spectrum) that propagate along it will also vary. From the analysis of the light spectrum, it is possible to trace the presence of the substance. The light is kept wholly confined to the fiber, and the effect accumulates over its entire length. We produce Dragline silk extracted from spider glands and spinning with a constant diameter and smooth surface as a chemical sensor for its sensitivity to different chemical substances. Their presence affects the birefringence of the silk fibers [126]. Due to humidity, the phenomenon of infiltration of water molecules occurs, which attacking the coil structures of silk fibers breaks the hydrogen bonds that hold the protein threads together. This phenomenon will cause the silk to relax, causing it to contract. The sample designed to measure the relative humidity of the environment is placed on a support and blocked at the two end parts.

As the fiber is held back from resting, it tends to swell, producing a change in its geometry. The researchers tested the sample using a set-up consisting of a laser to produce polarized light injected into the silk fiber positioned inside an air chamber and an analyzer polarization located downstream of the air chamber to analyze the state of polarization (SOP). The hermetic closure of the air chamber ensures that the pressure and temperature are kept constant so as not to affect the test results. The points of change of the SOP of the outgoing light are reported as positions on the Poincarè sphere. By increasing the humidity level inside the chamber from 40% up to a maximum of 65%, a corresponding variation is noted on the sphere's rotation angle between the initial and final positions. The remained almost constant when the experiment was performed, keeping the humidity rate stable. This result confirms the high sensitivity of the sensor.

Another experience is the realization of a capacitive type sensor for respiratory monitoring based on the detection of the dielectric constant of silk fibroin film [127]. The variation of the capacity produced by the introduction of steam provides information on the respiratory state. The knowledge of the respiratory state is a determining factor for knowing the state of health of the subject concerning the activity performed such as sleep or physical exercise or for the detection of abnormal cardiovascular situations such as the presence of flu, pneumonia, and asthma [128]. The changes in the respiratory state are related to the changes in humidity produced during the inhalation and breathing phases. The changes in resistance or capacity of the humidity sensors provide the measure of respiratory changes. The researchers used sensors consisting of interdigital electrodes of silver nanowires (IDE Ag NW) associated with an S.F. sensing film. The sensor can distinguish the type of breathing, whether regular, deep, and fast, by detecting the frequency value for a range up to 4 Hz. The sensor is placed under the nose because there are local changes in humidity in the mouth and nose area. The results obtained showed that, with the penetration of vapor, through the variation of the film's dielectric constant, it is possible to detect human respiration.

b) Filter

Researchers developed an eco-friendly physical dispersion process with partial diffusion to exfoliate silk fiber into mesostructures like nanorods, nanofibrils, nanoparticles. The resultant mesh silk dispersion can be treated to produce mesostructures of different sizes. Compared to those produced by silk fiber solutions, these materials have maintained the same microarchitectures but are also enriched with structures and properties deriving from mesh sizes effects such as ultra-high specific surface area and a system like extracellular matrix. These characteristics make it possible to use them in electronic and environmental applications, making them better than other commonly used materials. They were applied as a filter for water treatment, recycling organic solvent, like sensors, and nano fertilizers [129].

Another application is a thin silk paper created as a filter by adding two wt% silk microfibr il suspensions for the water treatment. At the end of the air drying, silk paper in A4 format was obtained, which was softer and foldable in different shapes compared to the traditional cellulose-based paper. SEM showed a uniform mesoporous structure. This mesostructure was used directly as a microfilter of water for bacteria and other micro-sized contaminants. To remove organic solvents, it was necessary to reduce the pore diameter of the silk paper using nanofibrils. SEM images confirmed the filtering effectiveness of these silk papers. The membranes used for water treatment were produced from Bombyx mori silk nanofibrils [130]. Organic solvents dissolve them; Antheraea pernyi silk nanofibrils were chosen because most solvents tolerate them. Therefore A. pernyi silk nanofibrils were preferred as filters for organic solvent.

Scientists used silk paper as a conductive device by printing an electronic pattern such as a circuit board and sensors loops. It can be chosen as electronic prototyping. They are suitable for modulating electrical signals but being flexible can measure the deformation of objects subjected to stress. Devices subjected to several bending cycles show no deformation when returning to the initial realignment position.

The excessive use of pesticides and fertilizers in agriculture has created significant environmental problems such as soil foul-up from antibiotics and acidification and pollution of the aquatic environment due to excess nitrates and phosphates. As a result, nano fertilizers have developed in recent years and controlled release pesticides. The goal is to create products absorbed by the cultures without interaction with the external environment [131]. For this purpose, researchers tested whether the use of A. pernyi silk nanoparticles of 11 ± 4 nm can provide fertilizers. Bulbs of Narcissus pseudonarcissus (N. pseudonarcissus) incubated in a culture medium were grown, using homogeneous dispersion of silk and rhodamine B (RhB) nanoparticles to deliver small molecules for drugs and fertilizers. The bulbs continued to grow during the eight days of incubation, showing that both RhB and silk nanoparticles were not harmful. They studied cultures with a fluorescence microscope, and synchrotron Fourier transform infrared microspectroscopy (S-FTIR); the provided images validated that the silk nanoparticles facilitated the release of nutrients. Furthermore, they found that adjusting the rate of release of the nano-fertilizers can reduce the quantities.

c) Waveguide

Silk is suitable for manufacturing implantable optical fibers and waveguides thanks to its high refractive index. We can also integrate it with other optical platforms for the realization of light guiding. Non-regenerated Bombyx mori silk fibers are designed as waveguides, especially when embedded in living tissue, thanks to their biocompatibility and bio absorbability. The images obtained from the samples produced [132] showed configuration defects such as helical torsion and symmetry breaking in the fiber center. These factors are both determined at the pre-processing stage [133]. Their effects are limited through multiple rinsing operations but not entirely removed by pre-processing. To evaluate their applicability as waveguides, we can characterize them optically using two methods: the cutback method commonly used to determine losses in waveguides as is usually done in telecommunications for optical fibers.

The technique uses the Beer-Lambert law of attenuation, which considers that the propagation losses along the fiber length are prolonged. The other method used is Image-based Analysis, according to which the performance of the fibers is evaluated directly from the microscope images. This method is based on the scattered light at a certain point of the fiber that is proportional to the radiation of the wave that propagates within it. Therefore, the measure of wave attenuation inside can be deduced from scattered light as a function of position along with it. The researchers experimented that when a large amount of light is highlighted in a certain point of the fiber, it means that point is the localized scattering center of the light wave that travels in it. From that point on, the optical power gradually decreases along with it. The optical wave continues to propagate with a lower intensity. The loss coefficient obtained depends on many factors, such as the effects produced by the localized scatterers, the structural characteristics of fiber and waveguide. From the images acquired by a non-linear microscope, the second and third harmonic presence was noted in the signal, with the third harmonic present along with the entire fiber. In contrast, the second was more relevant in the center where the center-symmetry breaks due to twisting of the fiber around this point.

A further experience gained in the field of optoelectronics was the design of waveguides with the use of direct femtosecond laser writing (fs-DLW). This innovative approach represents a suitable platform for biophotonic applications [134]. A femtosecond laser is widely applied to fabricate optical devices presenting physical effects and interactions with various materials different from traditional processes [135]. The laser beam develops intense energy capable of producing structural changes at the micrometric level. It also has the advantage of reducing thermal effects. The SEM images found that the magnitude of the impulse determines the groove width without damaging the surrounding areas. The analysis of AFM images showed that the tracing of the profiles is obtained by transferring material from the central location towards the edges. This effect is due to the way the laser beam operates according to the Gaussian profile. RAMAN spectroscopy made it possible to highlight structural changes in densification zones. The spectra analysis showed that there are no significant structural changes in the irradiated fibers. The images obtained confirmed that the light propagates along with the areas where there is the densification of the material.

The same behavior occurs for both linear and curved guides. From research emerged that propagation losses were (5.8 ± 1.0) dB / cm and (6.8 ± 1.0) dB / cm at 632.8 nm for linear and curved waveguides. The propagation losses in these guides are more significant than those obtained by direct ink writing. This greater loss is probably attributable to

Global Journal of Researches in Engineering (F) Volume XXI Issue III Version I Year 2021

surface roughness in the thickening areas of the material. Although the losses are high, they are comparable with those found in unprocessed silk fibers (10.5±4) dB/cm, in the range of 800–850 nm [136]. The results obtained through simulation and experimentally showed an almost symmetrical mode in which the light confines to the waveguide edges. The radiation produces deformation on the edges of the irradiated area by varying the refractive index, which is lower in the central region than the edges with a value equal to $\Delta n \sim 1 \times 10$-3. A He-Ne laser with 632.8 nm light produced the characterization of the waveguides. We obtain the optimal conditions for the manufacture of the waveguides by varying the pulse energy in the range of 16-34 nJ and the scan speed in the field of 50-400 μs, obtaining the best results for 26 nJ and 100 μs.

d) Lenses

The silk fibroin protein can be a biocompatible alternative to conventional emitting diode polymers [137]. The blue light-emitting diodes allow enormous energy savings by implementing a total replacement of traditional light sources [138]. Recently, light-emitting diodes are also present in automotive, home, office, and display applications. The increase in the use of LEDs will consequently also lead to a more excellent production of electronic waste upon their disposal, which, although in part is recycled, the remainder still damages the environment [139]. In a typical LED chip, among the various components, there is also a lens manufactured with non-biodegradable silicone-based polymers and epoxy resins. Therefore, finding solutions on eco-compatible materials to realize LEDs represents a significant step toward improving environmental protection. Since there are currently applications of silk hydrogels in electronic devices, their feasibility for manufacturing light-emitting diode lenses has been tested. The tests carried out found that the concentration rate of the silk and the type of crosslink used characterized the optical properties. By decreasing the concentration of proteins, the transmittance increases, while the average transmittance of the hydrogel decreases slightly in the visible spectrum compared to the phase of the silk solution. The refractive index was also evaluated, its value is slightly higher than that of the silk solution, resulting in 1.35 at 448 nm.

The distribution of the intensity of the spatial radiation was tested using silk hydrogel lenses in the shape of a dome and crater. The comparison of the emission profiles showed that the dome hydrogel lens focused in the center similar to that of the LED without lens, while the crater lens had two maximum values at 20 ° and -20 ° of the viewing angle. Then the researchers tested the stability of the silk hydrogel lenses. To increase their durability, they synthesized polyester-urethane biocompatible reference material with which coated the lens; stability is increased approximately three times and significantly by using edible paraffin.

This type of lens can be considered an environmentally friendly electronic device.

IX. Electronic Applications

Silk-based devices have characteristics that make them suitable for applications in the electronics field. Silk as planar structure replaced inorganic oxide layers such as PMMA or SiO2. It is present in organic transistors as gate electrodes, source and drain electrodes, or also as a substrate on ITO gate layers and as a p-type and n-type organic semiconductor (Fig.13).

Silk is a material whose properties are suitable for flexible electronics. We must generate silk fibroins in films (RFS) that exhibit the desired optical, mechanical, and chemical properties. The creation of fibroin structures around carbon nanotubes (CNTs) has made it possible to create flexible and transparent films that are more sustainable and degradable, although similar to synthetic polymers.

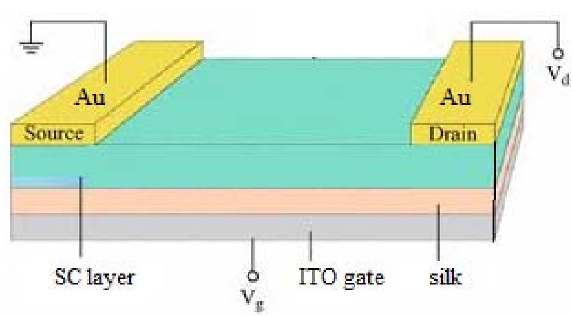

Fig. 13: Organic silk transistor

a) Semiconductor

Researchers used regenerated Bombyx mori silk matrices integrated with zinc oxide and copper oxide nanoparticles to produce n-type and p-type semiconductors, respectively [140]. To optimize the electrical conductivity of the silk nanocomposite films and metal oxide produced by the solvent casting method, samples with different metal oxide concentration values and film thicknesses were tested [141]. The tests carried out showed that the nanocomposites films with lower thickness and the higher concentration of metal oxide exhibited the best conductivity. The presence of metal oxide nanoparticles in the matrix influences the mobility of the vector (electron-hole) in the matrix by modifying the conductivity of the films. The SF/ZnO nanocomposite film had the highest conductivity between the two semiconductors. The results showed that the conductivity of the semiconductor depends on the type of carrier concentration, the entity of the metal oxide nanoparticles, and the content of the β sheet.

To study the semiconductor behavior of nanocomposite films, the researchers used the Hall effect, which is a physical phenomenon. A potential difference is produced in a transverse direction in a conductor or semiconductor when it is crossed by an electric current in a longitudinal direction and is subjected to a perpendicular magnetic field. Through the Hall effect, we can consider the semiconductor type p if its value is positive or type n if its value is negative. The incorporation of zinc oxide nanoparticles makes the device an n-type semiconductor, while copper oxide makes it p-type. From the analysis of the optical properties of the nanocomposite films, the researchers identified an increase in transmittance and attributed it to the presence of metal oxide nanoparticles that produce structural changes in the device, and a decrease in the refractive index. Furthermore, by the structural analysis, a homogeneous surface is observed due to the difference in the crystal structures of the β sheet of the regenerated silk.

b) Electro-tendon

The researchers made robotic humanoid hands replace human limbs with a transmission system based on a fiber that simulates the human tendon to strengthen the joints (Fig.14). Currently, the materials available for their manufacture are characterized by low toughness and conditioned by significant friction [142]. Furthermore, these tendons must be conducive to the transmission of signals to the tendons. Available materials such as nylon, silicon rubber, etc., do not simultaneously possess all those properties that need to manufacture robotic tendons: elasticity, conductivity, and toughness. Some researchers engineered an electro tendon using spider silk characterized by the toughness of 420 MJ/m3 and conductivity of 1,077 S/cm [143]. Electro tendon has been equipped with carbon nanotubes to provide further toughness and PEDOT: PSS electrically enhance it. Electro-tendon subjected to tests for more than 40,000 flexion-elongation cycles, it turned out tough and durable. It did not show variations in conductivity; mounted on a robot enabled the finger to handle different objects. This tendon represents the most suitable solution for solving the need for a robotic finger to have the same fiber for both the transmission of activation and detection signals.

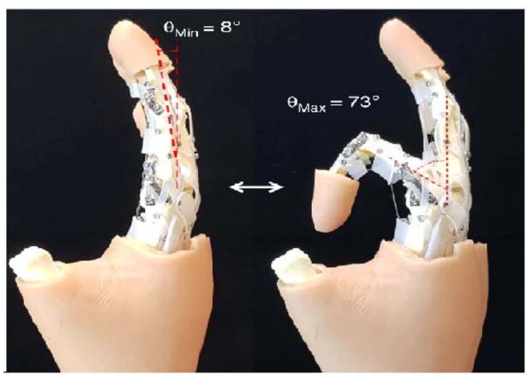

Fig. 14: Electro-tendon from Liang Pan et al. Nature Communication 2020

c) Conductive composites

Conductive silk-based biomaterials are suitable for the fabrication of systems for healthcare and tracking human motion. The transformation of the silk fiber into conductive biomaterial requires the filling of conductive fillers such as carbon nanotubes (CNTs.) or graphene. In the experiment reported, the researchers used bio-based carbons as a conductive filler to make SF biomaterial conductive [144]. They obtained this material called hydro char [145] from the aqueous thermochemical process (HTP) that transforms the biomass into a carbonaceous solid (biocarbon-HC). Then they converted it, by physical activation, into conductive biobased carbon. By acting on the HTP parameters, it is possible to adjust their nanostructure and their chemical functionality. The bio-based carbon can be rapidly doped with polar functionalities, adding oxygen and nitrogen, promoting dispersion in silk fiber suspensions. They studied the effects produced by the variation of the dopant elements. Bio-based carbons thus obtained dissolve in formic acid with CaCl2 silk fibers to produce thin films. The films are flexible and stretchable at room temperature and humidity of 50%. The tests carried out showed that the mechanical properties improve due to the presence of carbon nano materials. The resistivity of these films is lower than those produced without resorting to the thermo chemical process. These materials show good cytocompatibility due to the absence of toxic solvents. From the molecular dynamic simulations, a good conductivity has emerged without causing significant changes in its secondary structure or the bonds with hydrogen. The results obtained highlight the possibility of getting bio-based carbons with different morphologies and properties starting from biomass with other biochemical parameters such as temperature, water biomass ratio, and reaction time.

The fields of application are different from biomedicine to electronics.

d) Flexible electronics

One of the most recent applications in which silk has found wide use is flexible electronics with the construction of wearable and implantable devices [146]. Soft and extensible electronic devices are crucial in wearable and implantable applications to easily conform to the skin's surface. Many flexible materials such as polydimethylsiloxane (PDMS), polyimide, or silicone rubber that show remarkable mechanical characteristics of foldability and elasticity are suitable for the manufacture of flexible electronic devices. Still, none possess the characteristics of biocompatibility and biodegradability essential for implantable devices. Therefore, research has focused on developing flexible natural materials such as cellulose, melanin, pectin, chitosan, and silk fibroin. The latter is preferred not only for its specific properties but also for its simplicity and favorable cost. In recent years, manufacturing oriented on devices in which SF, in the form of silk films, silk hydrogels, and silk fibers, is the fundamental component of wearable electronics. Researchers prefer silkworm because, despite having characteristics of less resistance and extensibility than that of spider, can be produced more efficiently on a large scale. The wide variety of shapes associated with its mechanical, optical, and biological properties have made silk a fundamental or functional component in the manufacture of wearable devices. There are different experiences in flexible electronics in which silk allowed the construction of specific devices with predetermined functions such as substrates for optical devices [147], transistor dielectrics [148], and active layers of memristors [149]. Carbon nanotube coated silk due to its Young's modulus found application in strain sensor.

Flexible electrodes have favorable characteristics for the manufacture of wearable and implantable devices. Compared to traditional electronic systems, possessing the same mechanical characteristics as human organs, they can ensure accurate signals even during movement [150]. The silk film is preferred as it is more suitable for the preparation of functional substrates. However, its use is limited in cases where good elasticity is required, such as producing electronic devices conformable to the epidermis.

In the experience proposed, the authors overcame this problem by manufacturing a plasticized silk film [151]. Silk proteins represent the base layer on which to manufacture soft and elastic electrodes on the skin. The plasticization was achieved by adding CaCl2 and with subsequent environmental hydration. This process made it possible to obtain silk with a softness-like skin. The electrodes are manufactured by metalizing a thin silk film and creating a rough surface after hydration. The electrodes obtained, by modifying both Young's modulus and the elasticity by tuning them respectively to 0.1-0.2 MPa and> 100%, were highly conductive and extensible, making them suitable for recording high-quality electrophysiological signals. The softness of the electrodes allows perfect adhesion to the skin with a low interfacial impedance, ensuring the high-quality recording of EMG signals on the skin. The water with Ca2 ions determines a lower Young's modulus and better elasticity from the instrumental results and those of the dynamic molecular simulations.

The electrodes must also be transparent as well as flexible, biocompatible, and biodegradable. In recent years, efforts have focused on fabricating different types of transparent materials for SnIn2O3 doped electrodes. But ITO film on flexible substrates with polyethylene (PET) and polyimide is unsuitable for wearable devices, making it not biocompatible with the human body. Compared to ITO film, the researchers found that the use of silver nanowires embedded in a silk fiber substrate fully satisfies the requirements of flexible electronics.

In recent research, the authors created a highly extensible, transparent, flexible SF-based film with a low modulus of elasticity, perfectly adherent to the skin. The film integrated with silver nanofibers (AgNFs) / SF synthesized through a water-free procedure showed low resistance (10-5Ω/Sq), high transmittance, good extensibility. After numerous bending cycles, it is offered excellent stability. We can identify it as an electrode for the manufacture of intelligent touch sensors [152]. The sensor was sensitive to pressure and deformation, showing permeability to water and air and not producing inflammation; it was implanted directly on human skin. The experiment was done by gluing it on the arm at the elbow and on the larynx. Positioning on the larynx enabled the trachea and esophagus vibrations to be detected in real-time, thereby monitoring swallowing, drinking, and pronunciation. Abnormal pressure values are related to the onset of diseases of the laryngeal organs. Positioning on the arm allows monitoring finger/arm movement and muscle contraction. The functional element of the pressure-strain sensor is given by the sandwich structure in which the authors placed an Eco-flex layer acting as a dielectric between the two AgNF / SF electrodes (Fig.15).

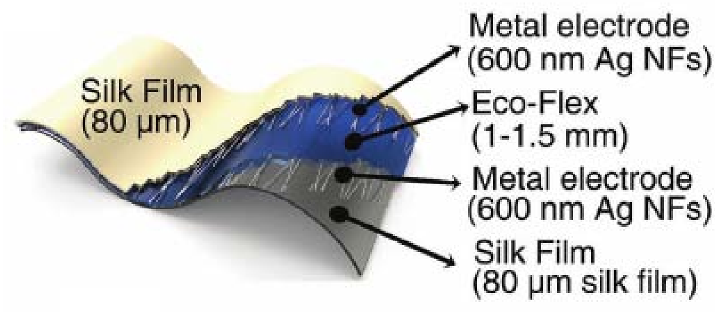

Fig. 15: Structure of the pressure-strain sensor from C. Hou et al. Small 2019

The results obtained in the absence of inflammation confirm the feasibility of this technology in the manufacture of wearable electrodes.

The electronic skin can simulate the human skin and implement tactile sensation made by thin, soft, and elastic devices, suitably functionalized to realize these functions. Research is developing new solutions to improve flexibility and elasticity and make the various electronic skin adaptable to human skin. Silk films are an ideal material to make electronic skins.

Below is an experience based on SF (SFCM) composite membrane with polyurethane that acts as a substrate of electronic skin for human thermoregulation [153]. The SFCM showed characteristics of high transmittance (>90%), excellent stretch-ability (>200%), heat-resistant ability (up to 160 °C). The use of inkjet print allowed to manufacture flexible circuit on substrate: two networks on each of the faces, one based on Ag nanofibers (NFs) and one on Pt NFs introduce functions of heaters and temperature sensors. This integrated protein-based electronic skin (PBES) with Ag NFs/SFCM/Pt NFs sandwich structure can realize temperature control mounted to the human body. Electric circuits were printed to transfer temperature and heating signals. The Ag NFs network as the heater highlight high thermal resistance, heating cyclicity, tensile stability, while the Pt NFs net-work highlights temperature sensitivity (0.205% °C-1), reliability, and rapid response (<2 s).

Some researchers [154] used engineered silk protein hydrogel for artificial electronic skin. They showed that devices based on silk protein hydrogels glued to the skin are suitable for collecting piezoelectric (PZ, based on mechanical stress) and triboelectric (TB, based on electrostatic induction) energy. They obtained poor results compared to conventional inorganic-based PZ devices, such as ZnO, CuO, SnO2, et al. incorporated in polymers as polyvinylidene fluoride (PVDF), polyvinylchloride (PVC), and polydimethy lsiloxane (PDMS). For the manufacture of artificial skin PZ with silk hydrogel, among the materials with good PZ performance, ZnO was chosen, which in addition to being biocompatible and economical, is also physically / chemically stable. [155]. As an artificial PZ energy-generating skin (EG-skin), the structure, adhesive to human skin, incorporates ZnO nanotubes (ZnONR), capable of collecting biomechanical energy and detecting movements. The presence of ZnONR improves the piezoelectricity eight times compared to native silk hydrogels. The PZ response can be further enhanced when the EG-skin is encapsulated within two thin silk membranes. Tests carried out on biodegradability, and adhesive properties on the skin showed that these EG-skin devices constitute a perfect interface between the artificially generated skin and natural tissues. To verify the energy generation capacity of the EG-skin, the device was placed on the forearm to measure the muscular effort when we apply a force to the hand: the action induces a power of 6.2 μW / cm2. The device was also positioned on the elbow to collect the energy produced by the flexion-release of the elbow: the power had 0.2 μW / cm2. In light of the results obtained, the hybrid skin made of engineered silk protein hydrogel can be a versatile platform for wearable and implantable devices.

Due to its biodegradability and programmable water solubility properties, researchers used SF as a component of implantable devices both with different shapes (silk film, silk sponges, and silk hydrogels) and for various applications (wireless thermal therapy, drug release, bone repair). Programmable water solubility is achieved through a post-treatment process to change the crystal structure. The possibility of controlling some of its specific properties made SF a suitable biomaterial for biological transfer, allowing for a perfect integration between biological tissue and electronic devices. The use of SF to manufacture implantable and degradable biosensors allowed us to overcome the problems connected with mechanically flexible and implantable sensors. For their removal, it is necessary to proceed with an extraction surgery.

The experience made by some researchers, in realizing an organic biosensor, shows a structure in which only conductive silk ink is used plus a flexible silk substrate without any metallic component[156]. The structure consists of an integrated three-electrode configuration. The organic electrode as a working electrode, Ag / AgCl as the standard reference electrode, and Pt as the counter electrode are manufactured by an organic conducting ink. The conductive silk sericin ink is micro-patterned on a layer of fibroin with a photolithographic process. The designers realized the electrical connections using a conductive polymeric wire coated with silk fibroin. This entirely organic device can allow the biomonitoring of analytes in the human body or the environment for a controlled period followed by a degradation phase [157]. The researchers tested the device to verify performance as a biosensor; they chose ascorbic acid (AA) as a target. It is essential for the human organism as it is decisive in collagen formation to develop bones, muscles, and blood vessels. The rapid response time of the sensor was on the order of few seconds, showing a high sensitivity. They also extended the test to the proteolytic degradation phase. The researchers found operating stability during the first four days, followed by an improvement in sensitivity, presumably due to the biodegradation of the silk matrix, which exposed PEDOT: PSS led to an improvement in the transfer of electrons from the electrolyte to conductive polymers. From 4th to 7th, sensitivity remained unchanged; to 10th connections deteriorated, and it was no longer possible to detect its behavior. These results suggest replacing transitional devices to monitor phenomena where a short observation period is required. They verified the performance of the biosensor against biofouling. In vivo monitoring of metabolites can lead to contamination of biosensors with a consequent reduction in performance [158]. Nonspecific adsorption of proteins or cells can lead to biosensor occlusion. The presence of a membrane layer of organic material can reduce the biofouling phenomenon. The biosensor having an organic structure has shown a natural resistance to biofouling. Therefore, the fully organic silk biosensor with core-sketch PEDOT: PSS silk fibroin conductive wires can permit real-time, continuous monitoring of health parameters without compatibility problems, with perfect adherence to the epidermis. In addition to AA, we can investigate a wide variety of target metabolites. It is possible to immobilize enzymes and antibodies in the conducting ink.

For the performance shown, the device can be a transient biosensor for monitoring metabolites in cases where a long period of operation is not required.

Energy harvesting technology is a cutting-edge topic for application in wearable technology and the energy stored connected with motion tracking. The availability of intelligent clothing has been beneficial for monitoring human health conditions by preventing harmful events and favoring health improvement conditions. These clothes are possible thanks to the advent of wearable, elastic devices and the possibility of transforming the mechanical energy associated with human activities into electrical energy [159]. We can compare the triboelectric nanogenerators (TENGs) with conventional power supply systems such as electromagnetic generators, thermoelectric generators, and solar cells. They have the advantages of possessing excellent sustainability characteristics, diversified material selection, and efficient low-frequency energy harvesting. The operation mode of TENGs exploits the phenomenon that when two materials come into contact with each other, there is a transfer of charges between them due to their difference in polarity; consequently, a current is generated. The integration of polymeric fibers/tissues with nanomaterial allows manufacturing fabrics to collect energy with TENG technology [160]. The mechanical robustness and structural stability of these devices are not able to provide high functional performance. SF is selected in the manufacture of TENGs because it has the necessary prerequisites.

Moreover, SF has a solid ability to lose electrons; therefore, pairing it with those materials that quickly gain electrons can ensure high performance. In the application we propose [161], the authors with 3D printing made a TENG device with a coaxial composite fiber of carbon nanotubes and SF, where CNT acted as a conductive core and SF acted a dielectric sheath. The dielectric material, another component of the triboelectric pair, was polyethylene terephthalate (PET). The tests showed that this configuration resulted in a maximum power density of 18 mW/m2. This structure has the advantage of having a high integration of functional and electrode materials and simple fabrication for the 3D printing technology used.

The following table highlights the field of applications of silk.

Tab. 2: Summary of silk applications

Application	Component	Properties
Wound healing	Scaffold, hydrogels, sponges, layers	Biocompatibility, biodegradability, reduced healing time
Drug Delivery	Nanoparticles, encapsulation	Biocompatibility, biodegradability
Bone Tissue Engineering	Film, scaffold, electrospun scaffold, 3D porous scaffold	Biocompatibility, osteoconductivity, osteointegration.
Ligament/ tendon	Scaffold, sponges	Biocompatibility,biodegradability, good adhesion and cell proliferation
Cartilage	Porous scaffolds	Biocompatibility, good adhesion, growth and chondrocytes
Vascular Tissue	Electrospun tubular scaffold, graft structure of SF electrospun coated with sponges.	Biocompatibility, good aggregation between tissue and mechanical resistance, water permeation.
Sensors	Functional layer	Biocompatibility, flexibility, good sensitivity to chemical substances
Filters	Substrate, functional layer	Flexibility, conductive pattern for circuit board
Waveguide	Substrate	Biocompatibility, biodegrability, complete transparency, high refractive index
Lenses	Functional layer, hydrogel	Transparency, crosslink, stability
Semiconductor	Substrate	Conductivity, structure β sheet
Electro tendon	Fiber composite SWCNT	Elasticity, conductivity, toughness
Conductive composite	Silk fibroin composite CNT or graphene	Biocompatibility, conductivity, flexibility, stretchability
Wearable electronics	Substrate	Biocompatibility, biodegrability, elasticity, softness
Implantable electronics	Substrate, encapsulation	Biocompatibility, biodegradability, flexibility, low surface resistance, high transmittance
Energy harvesters	Functional layer	Biocompatibility, flexibility, stretchability, piezoelectricity

X. Conclusion

For future developments, silk, with its specific properties, is the solution to meet the need to have multifunctional, non-polluting, and economical devices.

It can be subject to different processes modifying its original structure with different shapes and chemical and mechanical properties for tissue engineering application. Recent work shows the possibility of using silk for peripheral nerve regeneration and intervertebral discs. The particular characteristics of the material, from the structure to the process, the flexibility of modification of the properties, and the availability of functionalization techniques, have made silk ideal as a technological platform. It is suitable for creating sustainable, implantable, and bioabsorbable optical and electronic systems to replace traditional materials.

The Sustainable Development Goals (SDGs) require a drastic reduction of electronic waste. Current technology in electronic and photonic devices applies processes that use chemicals that generate equally hazardous waste once their lifespan has expired.

Therefore, we must orient technological efforts towards applying materials of biological origin to cope with the depletion of oil and the reduction of toxic by-products.

The silk can provide a substantial contribution to solving the problem.

Due to its exceptional biodegradability and biocompatibility properties, it can represent a promising material for biomedical applications. For the future, we can think of entirely organic electronic devices, implantable for a controlled period, in which silk fibroin and sericin can allow the creation of structural and functional elements with the same characteristics as conventional systems which have the disadvantages of creating possible damage to living cells and are not biodegradable.

It usefully satisfies the objectives proposed by the Green Economy.

Furthermore, future developments will be oriented towards the realization of new generation multifunctional devices. The biomedical need for intelligent materials has led to a structural change in the design of biomaterials. Having devices with multiform and multifunctional integration represents a promising application opportunity towards "intelligent" optics. The silk can be the ideal solution for the realization of dynamic biopolymer systems. Controlling the ability of structural proteins to modify their conformation and response behavior to stimuli leads to the creation of innovative solutions for micro-nanopatterning of dynamic and multifunctional biocompatible interfaces.

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By Thomas L. Hemminger

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Index Terms: PVDF, piezoelectric film, vibration sensing, Sallen-Key.

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I. Introduction

As the integration level of electronic systems increases and becomes more sophisticated, producing these devices grows more complicated and expensive. Not only does fabrication become increasingly difficult, but inspection and testing are also more demanding. One of the problems facing automated production and inspection equipment is resonant and ambient vibration. The design described here was motivated by the specific needs of an industrial sponsor. However, it can be useful for many applications requiring low-cost sensors for monitoring vibrations and accelerations. Polyvinylidene Fluoride (PVDF) is an extremely effective material for converting mechanical movements into electrical signals and has some of the strongest piezoelectric effects of all known polymers [1]. This property makes the material an effective candidate for use in the construction of vibration and acceleration sensors [2]-[7]. There are, however, some disadvantages when working with PVDF. Not only does it exhibit a high piezoelectric constant, but also a considerable pyroelectric constant, indicating that the material produces high voltage variations when exposed to changes in temperature. There can be as much as an 8-volt change in output voltage per degree Celsius [8]. This can be managed with a combination of shielding and a DC offset control. PVDF material is also highly capacitive and is sensitive to IR and RF interference, but careful design can reduce these effects. All of these potential problems were considered and addressed in the finished system.

Initially, several currently available designs were evaluated to investigate the properties of PVDF sensors and the signal processing characteristics of the associated amplifiers [9]. Improved amplification and conditioning circuitry was designed, constructed, and tested for use with several types of these sensors. Frequency response, dynamic range, and measurement axes are important, but cost is another important factor. The analog system described here is robust, low-cost, and portable. It can employ batteries, a single +5volt supply, or a plug-in wall adapter. Excessive vibrations are indicated through a simple LED arrangement, or the system can be connected to a data acquisition recorder for time and/or frequency analysis. The specifications for the overall system are illustrated in Table 1.

Table 1: Required signal conditioner specifications

Parameter	Specification
Frequency Range	0 Hz to 10 kHz, at selectable ranges
Filter roll-off	60 dB/decade
THD	<0.02%
Linearity	<0.2% deviation
Resolution	$0.1\mu g/\sqrt{Hz}$ in conjunction with sensor
Gain	Selectable up to 150
Thermal Stability	Minimal effect
Dynamic Range	$\pm 50\,g$
Transverse Sensitivity	< 1%
Output	+/- 10V

II. System Design

This design is composed of seven blocks, which are described in the following subsections. The high-pass and low-pass filters are of similar configuration. Therefore, only the high-pass filters will be described in detail. Component values are included for all of the filtering elements. A block diagram of the conditioner is shown in Fig. 1.

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a) Power supply

One specification required of this design is that it operates from a single 5-volt DC power supply. Therefore, a Newport NMA0512S one-watt to DC-to-DC converter was employed to power all components. This model has an internal oscillation frequency of 100 kHz, which is well beyond the frequency ranges being monitored. The low-power design presented here lends itself to battery operation, which is advantageous over plug-in wall adapters because of AC line interference.

b) Input impedance control

High input impedance is necessary to successfully measure PVDF sensor signals at low frequencies. This is due to the capacitance characteristics of the film [10-11]. The capacitance of PVDF is a function of its geometry, indicating that the cutoff frequency is usually determined by the amplifier input impedance alone ($f_e = 1/2\pi RC$). For example, if an amplifier has an input impedance of $10k\Omega$ for a given PVDF capacitance of $3nF$ it yields a cutoff frequency of $5.3kHz$ which is unacceptable for this application. One goal is to amplify signals of very low frequency near the DC level. To achieve lower cutoff frequencies the input resistance of the amplifier must be increased. Consequently, a non-inverting JFET voltage follower with an input impedance of about $10^{12}\Omega$ was chosen to enable measurements at very low frequencies. This produces a cutoff frequency of about $5.3x10^{-5}Hz$. The drawback to a non-inverting buffer is that input bias currents of the op-amp cause the amplifier to saturate. This condition can be alleviated by providing another high impedance path to ground (see Fig. 2). The value of R must be high enough to provide a cutoff frequency below the lowest frequency of interest. For example, to achieve a cutoff frequency of 10 Hz with a sensor that has a capacitance of $3nF$ would require a $5.3M\Omega$ resistor. For this example, $R = 50\ M\Omega$ which results in a cutoff frequency of about 1 Hz which fits the required specifications. The impedance control resistor determines the input impedance of the buffer so this resistance should be chosen with knowledge of the physical characteristics of the sensors to be used with the system.

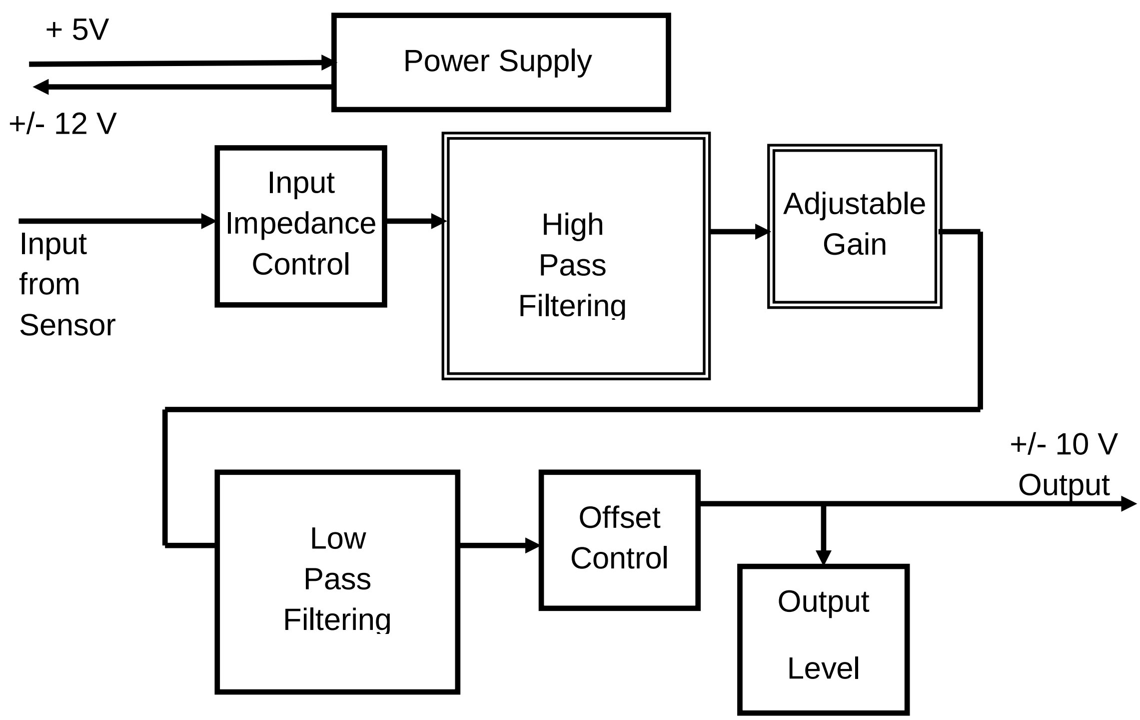

Fig. 1: High-level design of the signal conditioner

Because of the possibility of high voltage spikes from PVDF sensors, the design includes two zener diodes to regulate the input signal. Diodes should be chosen with breakdown voltages higher than the op-amp supply voltage. For the prototype amplifier, zener diodes with a 20V breakdown voltage were selected.

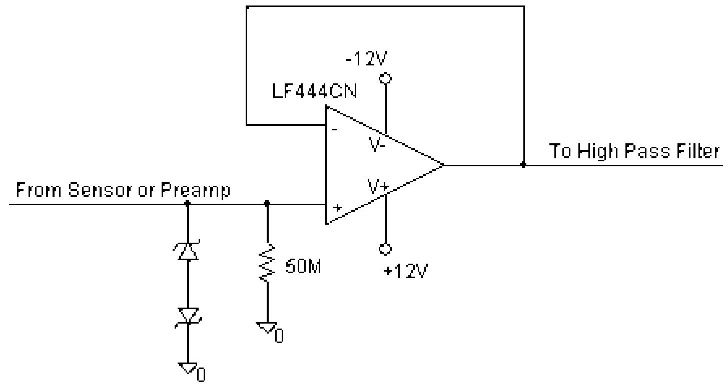

Fig. 2: Input buffer and impedance control circuit with over-voltage protection

c) Filter Banks

G-force amplitudes and corrupting frequencies have been a concern. Therefore it was decided to have a selectable frequency range via switches on the circuit board. A range of high-pass and low-pass filters in a cascade arrangement was decided upon, each having the ability to be independently activated. The low-pass cutoff frequencies were 100 Hz, 500 Hz, 1 kHz, and 10 kHz. The high-pass cutoffs were 3Hz, 100 Hz, 500 Hz, and 1 kHz. With this design the user may select 15 combinations of high-pass and low-pass filters. An "all-pass" switch has been included in both filter banks as a bypass. The LF347 op-amp was chosen because it has several useful features, e.g., extremely high input impedance (10^{12} Ω), low input bias current (50 pA), and wide bandwidth (4 MHz).

Several active filter models were investigated, but after reviewing the tradeoffs, the Sallen-Key configuration was most suitable [12-14]. The high-frequency specification for this system is 10 kHz, which is well below the 1 MHz level at which this filter begins to degrade. Also, since the amplification is done in a separate circuit, all filter stages are unity gain, alleviating gain-bandwidth product issues. Filter selectivity is certainly an important factor but linear phase response is also significant, so only two filter families were explored i.e., Butterworth and Bessel. The Butterworth has a much stronger roll-off than the Bessel, but the phase response is not as flat. However, Bessel filters have such a gradual roll-off that the required order becomes prohibitive. Also, as shown in Fig. 3, the phase response of the Butterworth is nearly linear in the pass-band, translating into an acceptable group delay. Further examination of the delay shows us that it has little effect on the output of the filters. The delay is uniform through the majority of the pass-band—up approximately 4 kHz for 4th order. This was verified by comparing the total harmonic distortion of these two filters at frequencies near the cutoff. For 5 kHz, 9 kHz, and 10 kHz input signals the THD of both filter types is less than 0.006%. For these reasons the Butterworth was chosen.

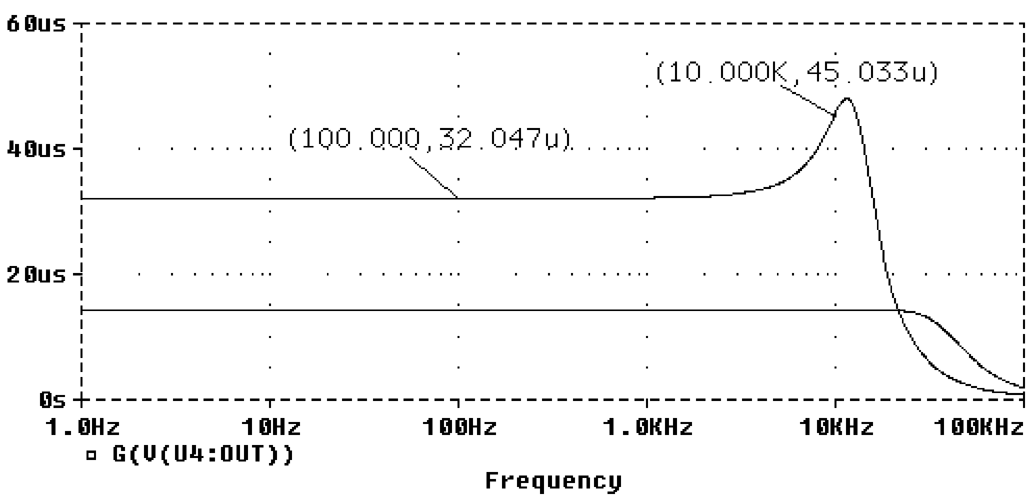

Fig. 3: Butterworth filter versus Bessel filter group delay comparison

Eight filters were designed for this research project. One tool employed was the Filter Pro low-pass filter design program from Texas Instruments. A MATLAB program was also written to verify the results of Filter Pro, and to aid in the selection of component values. The transfer functions for the 2nd order low-pass and high-pass Sallen-Key are shown here:

$$H(s)=\frac{K\dfrac{1}{C_1C_2R_1R_2}}{s^2+s\left[\dfrac{1}{C_2R_2}+\dfrac{1}{C_2R_1}+\dfrac{1-K}{C_1R_1}\right]+\dfrac{1}{C_1C_2R_1R_2}} \tag{1}$$

$$H(s)=\frac{K}{1+\dfrac{R_2(C_1+C_2)+R_1C_2(1-K)}{\varpi_c R_1R_2C_1C_2}\cdot\dfrac{1}{s}+\dfrac{1}{\varpi_c^2 C_1C_2R_1R_2}\cdot\dfrac{1}{s^2}} \tag{2}$$

Each filter used in this project comprises two cascaded 2-pole filters, yielding a 4-pole configuration with all filters designed to have less than 0.5 dB attenuation in the pass-band. Fig. 4 illustrates the layouts of the high-pass and low-pass 4-pole Sallen-Key filters. Values for all resistive and capacitive components are shown in table 2.

Table 2: Low-pass and high-pass filter component values

	Freq.	R1	R2	R3	R4	C1	C2	C3	C4
Low-Pass	100 Hz	2.32 kΩ	21.2 kΩ	18.2 kΩ	18.9 kΩ	1.0 nF	3.3 nF	470 pF	10 nF
	500 Hz	1.66 kΩ	16.3 kΩ	2.33 kΩ	19.0 kΩ	6.8 nF	22 nF	3.3 nF	22 nF
	1 kHz	2.18 kΩ	18.4 kΩ	1.59 kΩ	17.2 kΩ	22 nF	68 nF	10 nF	220 nF
	10 kHz	8.93 kΩ	37.5 kΩ	3.55 kΩ	18.9 kΩ	20 nF	220 nF	100 nF	220 nF
High-Pass	3 Hz	17.6 kΩ	15.0 kΩ	42.4 kΩ	6.21 kΩ	3.3 μF	3.3 μF	3.3 μF	3.3 μF
	100 Hz	15.5 kΩ	11.3 kΩ	26.6 kΩ	3.89 kΩ	220 nF	100 nF	220 nF	220 nF
	500 Hz	4.85 kΩ	4.14 kΩ	14.5 kΩ	2.04 kΩ	100 nF	100 nF	100 nF	68 nF
	1 kHz	2.43 kΩ	2.07 kΩ	16.2 kΩ	1.40 kΩ	100 nF	100 nF	100 nF	22 nF

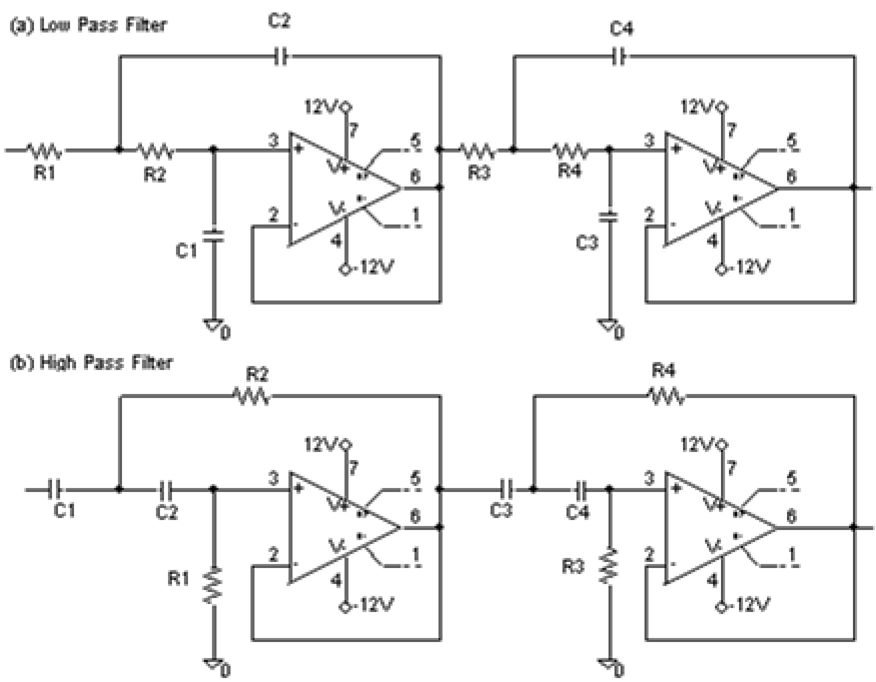

Fig. 4: Four pole Sallen-Key low-pass and high-pass filters

Figures 5 and 6 illustrate the filter selection circuitry. Because the input to the high-pass filters is linked directly to the impedance control circuit, this is the optimum place to remove any DC offset, which may be present in the input. For this reason a low voltage DC offset adjustment was added to the non-inverting terminal of the summing amplifier (Fig. 6). This circuit allows any small op-amp bias voltages to be removed from the output of the summing amplifier before proceeding to the gain control, and possibly corrupting the output. The low-pass filter selection circuitry is nearly identical to that of the high-pass block. The only difference is that the DC offset control is not present because any significant offsets will have been removed in the high-pass stage. The switches used to operate the selection circuitry are of the double pole single throw slide type. The center tap of the switch is connected to the input of a classic summing amplifier, which is shown in Fig. 6. The other two terminals are connected to the outputs of their respective filters and to ground. The ground, or off position, assures that none of the inputs to the summing amplifier are left floating.

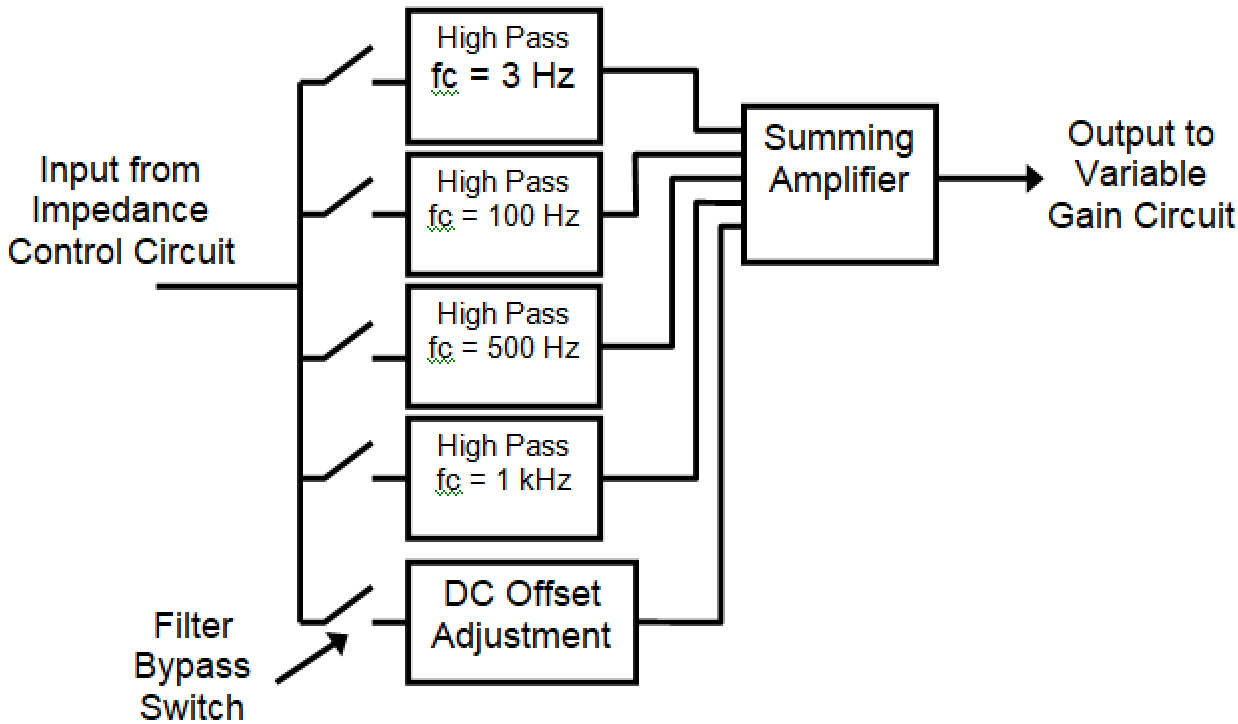

Fig. 5: High-level filter layout. High-pass and low-pass have similar configurations

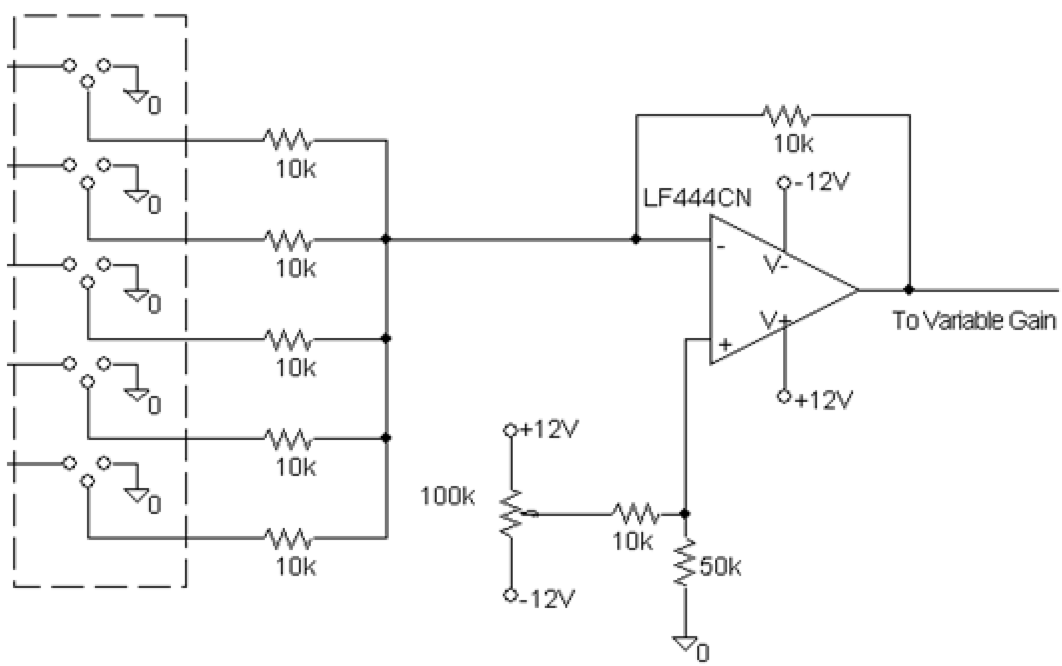

Fig. 6: Summing amplifier with filter selection

d) Amplifiers

The amplification circuit is composed of a simple inverting op-amp. Several other circuits were considered, but the inverting op-amp was selected for its ease of implementation, small number of components, and input/output impedance characteristics. For added versatility, the gain of the inverting op-amp is controlled by shorting a series of resistors in the feedback loop of the amplifier. By connecting the resistors in series, a wide range of gains can be selected. As illustrated in Fig. 7 this circuit employs 10 kΩ, 50 kΩ, 100 kΩ, 500 kΩ, and 1 MΩ resistances allowing for gains ranging from 1X to 166X. The gain is controlled via switches that short various resistors. For example, shorting the 500 kΩ and 1 MΩ resistors yields a gain of 1X+5X+10X for a total of 16X.

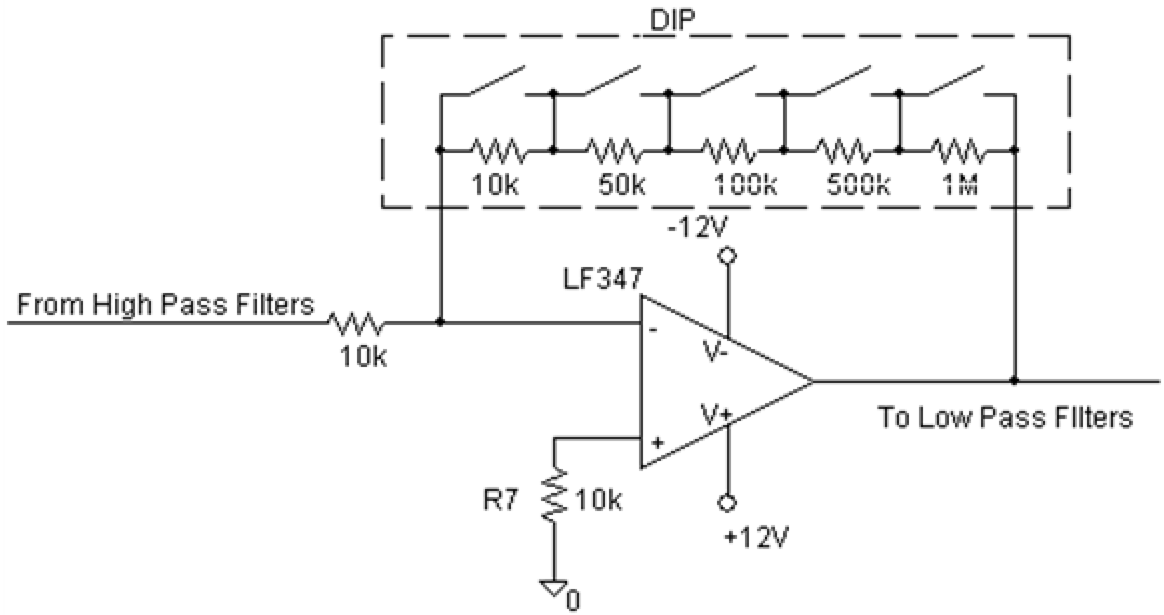

Fig. 7: Amplifier variable gain circuit. Note: The LF347 op-amp was used for testing purposes

e) Output

A visual display was added to the amplifier to alert the user of the presence of excessive g-forces. This simple readout eliminates the need to use an oscilloscope to view the output when portability is an issue. The method chosen to accomplish this task was the illumination of three LEDs. Yellow, green and red LEDs illuminate when the output of the amplifier reaches a peak value of one, seven, and ten volts respectively. Two sets of LEDs were used to indicate positive and negative g-forces. The circuit is illustrated in Fig. 8. The input is isolated by using an op-amp buffer to assure that the rectifier circuit does not interfere or load the output. It should be noted that the output of the rectifier circuit is not exactly equal to the peak AC value of the input due to the approximate 0.6V drop over the diode. This drop must be accounted for when designing the comparator circuit that lights the LEDs. The visual display circuits compare the DC voltage from the rectifier circuits with a predetermined threshold voltage. Operational amplifiers were employed here as well for design simplicity and to reduce component count.

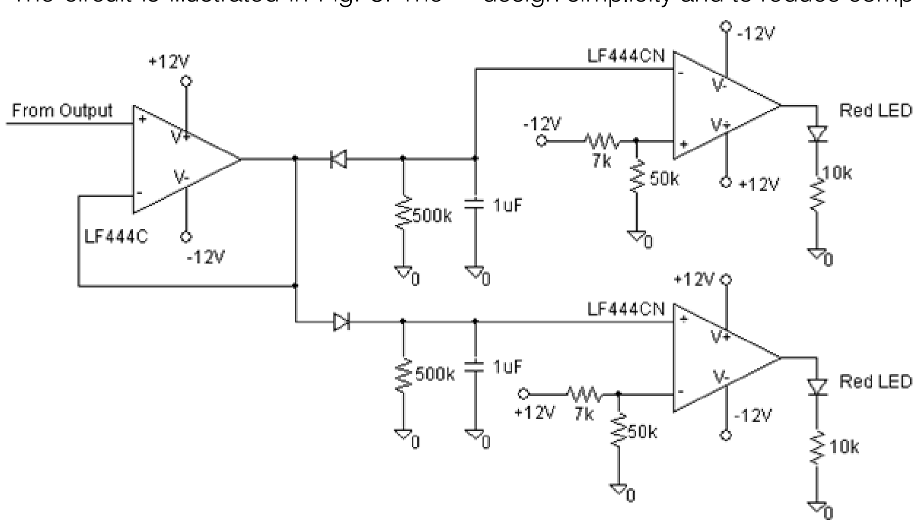

Fig. 8: Comparator and display circuit for one LED pair

The resistor values shown in this instance will cause the red LED to light at approximately 10V. One can calculate the resistor values using a voltage divider equation, remembering to add 0.6 V to the desired threshold voltage.

III. Results

Multiple mechanical frequencies must be utilized to test the accuracy of the filters and the sensitivity of the amplifier. To achieve clean consistent vibration signals, an aluminum cantilever beam was used to create vibrations and accelerations of varying amplitude and frequency (see Fig. 9). Testing of low frequencies was accomplished using the cantilever beam, while high-frequency testing was completed using an electrodynamic shaker.

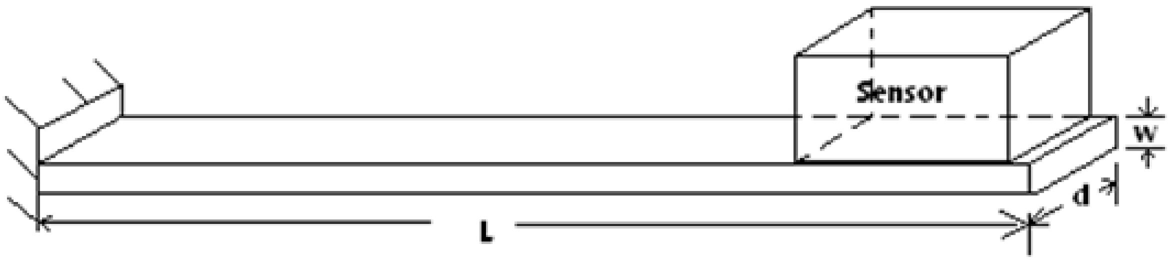

Fig. 9: The cantilever beam setup for low frequency testing

To analyze the functionality of the amplifier in a time-efficient manner, the output of the sensors was read through a data acquisition system for comparative purposes. This test arrangement was composed of the amplifier, a Keithley data acquisition board, and a computer running National Instruments' Lab VIEW software.

As with most signal amplifiers, linearity is a significant factor in this design, therefore two tests were employed to verify the efficacy of each stage. Initially, the amplifier was set to 1X gain with all filters bypassed. The input voltage was incrementally increased from 0V to 10V while recording the outputs and calculating the respective correlation coefficients. The test was repeated with one high-pass and one low-pass filter activated to validate the filter circuits. The process was then repeated for numerous combinations being careful not to saturate each stage. The worst-case deviation from linearity is illustrated in Fig. 10. With a 1X gain selected, the upper 3dB point of the amplifier is 220 kHz. With the gain set at 166X, the 3dB point is shifted to 18 kHz, reducing the operating bandwidth as expected, but still remaining within the design limits. The 3dB point for each filter was within 5% of the calculated value, and the roll-off rates exceeded 65 dB/decade.

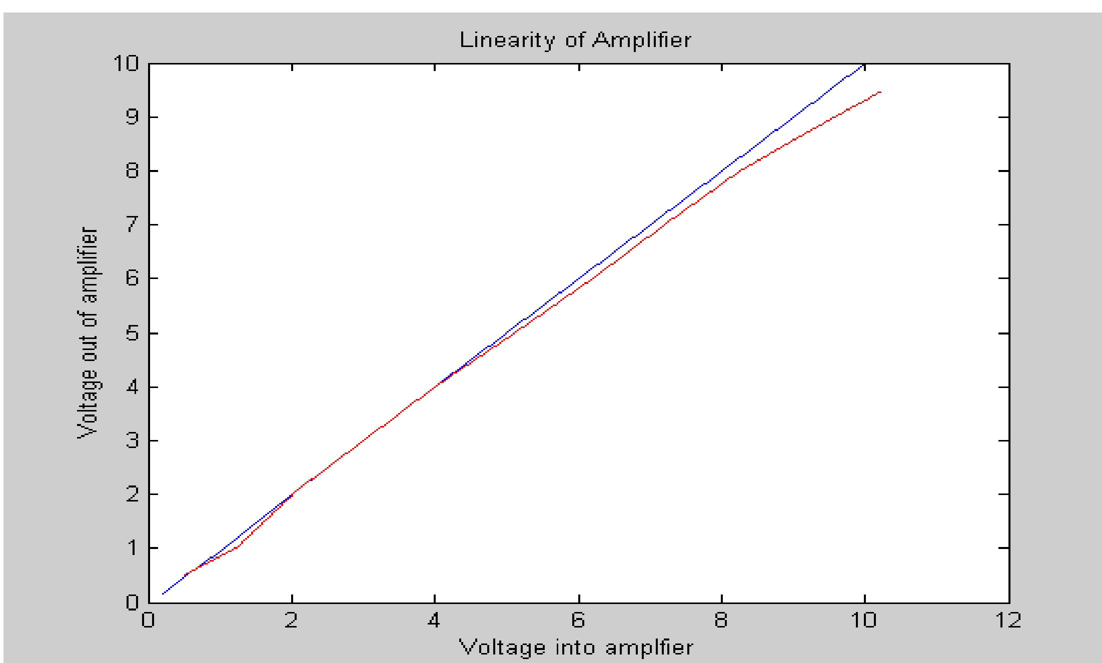

Fig. 10: Linearity test for amplifier with correlation coefficients shown

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In order to scale the output correctly the gain values must be accurately known, otherwise significant errors will result when calculating the acceleration or vibration magnitudes. All five gain switches were toggled to determine the influence of each. The results are summarized in table 3. Small deviations from the predicted values can be attributed to component variations but are still within design limits. All goals of table 1 were accomplished or exceeded.

Table 3: Actual verses predicted gains

Vin	Vout	Gain	Actual Gain	%error
1.525	1.55	1	1.016	3.25%
0.31	1.575	5	5.081	1.59%
0.135	1.375	10	10.18	1.82%
0.105	5.2	50	49.52	-0.96%
0.0525	5.1	100	97.14	-2.94%
0.052	8.625	166	165.8	-0.08%

Table 4: Measured signal conditioner performance

Parameter	Measured Results
Frequency Range	0 Hz to 10 kHz, at selectable ranges
Filter roll-off	>65 dB/decade
THD	<0.012%
Linearity	0.11% deviation
Resolution	$0.04\,\mu g/\sqrt{Hz}$ in conjunction with sensor
Gain	Selectable up to 166
Thermal Stability	Minimal effect
Dynamic Range	$>50\,g$
Transverse Sensitivity	< 1%
Output	+/- 10V

IV. Conclusion

An alternative technique for analyzing signals from PVDF sensors has been introduced and this signal conditioning system has proven to be useful, inexpensive, and relatively easy to fabricate. It also provides reliable and repeatable results for several PVDF sensor models. With the output connected to an analog-to-digital converter card the signal processor described here exceeded the capabilities of similar products tested. This conditioner adds several useful features to comparable products such as a selectable gain, high-pass and low-pass filters, and a simple output indicator. This amplifier is an excellent alternative to comparable designs but at a significantly reduced cost. Its versatility makes it suitable for use with most PVDF sensors. This work was initiated from an industrial need for a simple and reliable acceleration and vibration signal conditioning system for automated integrated circuit placement, still there can be many other uses, e.g., impact sensors, flow meters, contact microphones, etc. Several sensors can be connected to similar conditioners, and by simultaneously monitoring the outputs of two or more devices, one can gain a better understanding of where vibrations are originating.

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Design and Simulation of Rectangular Microstrip Patch Antenna for X-Band Application

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Keywords: microstrip patch antenna, inset-fed, HFSS, gain, VSWR, return loss, efficiency, radiation pattern, Xband.

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I. Introduction

Wireless communication services have been growing at a very rapid rate in recent years (Parchin et al., 2019), and the need for compact and multifunctional wireless communication systems has spurred the development of antennas with small size (Ullah, et al, 2018). With the increasing number of wireless users and limited available bandwidth, wireless service providers are always trying hard to optimize their network for larger capacity and improved quality coverage, as to satisfy the mobility need of users (Yildiran, 2017). This surge has led the field of antenna engineering to constantly evolve, and accommodate the users need for wideband, low-cost, miniaturized and easily integrated antennas (Ab Wahab et al, 2019). Amongst the various types of antennas that include wire antennas and reflector antennas, microstrip patch antennas are the most popular, versatile, and easy to fabricate antennas (Hala, 2010).

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Microstrip antenna is very popular due to its distinguishing characteristics such as low profile, low cost, light weight, ease of fabrication, and conformity to planar and non-planar surfaces (Tarparaet al., 2018). These advantages have made microstrip patch antennas to be widely employed for various civilian and military applications in television, broadcast radio, mobile systems, global positioning system (GPS), radio-frequency identification (RFID), multiple-input multiple-output (MIMO) systems, vehicle collision avoidance system, satellite communications, surveillance systems, direction founding, radar systems, remote sensing, biological imaging, missile guidance, etc (Garg et al, 2001; Liuet al, 2012; Obotet al, 2019).

Nevertheless, despite the advantages offered bymicrostrip antennas, they are associated with some disadvantages, such as low gain, narrow bandwidth, and low power handling capacity (Tarpara et. al., 2018; Ullah et al, 2018). Over the years, a lot of researches have been undertaken to overcome these disadvantages associated with microstrip antennas. Some of the popular techniques proposed by researchers to improve the bandwidth and gain of conventional patch antennas is by using different antenna feeding techniques and dimensions, thick substrate, resonant slots called defected ground structures (DGSs), multi-resonator stacked patch structure (metamaterials), and through the use of array antenna configuration (Islam et al, 2009; Kim, 2010; Liu et al, 2012; Kaur and Rajni, 2013; Khraisat, 2018; Obot et.al., 2019).

The aim of this research work, is to design and simulate an insetfed Rectangular Microstrip PatchAntenna (RMPA) for X-band application. The research pursued a lightweight antenna that operates with an operating frequency of 10GHz in the X-band range of 8-12GHz, and with a high gain, wider beamwidth, and a high radiation efficiency. This research work is most significant in meeting the demand for long distance wireless communication, and for various X-band applications in Synthetic Aperture radar (SAR) onboard aerial platforms. The significant of microstrip antenna design application, as a panacea for achieving effective signal reception in wireless communication system, will avail the communication industry with a market full of lightweight antenna system and devices that offers high gain, improved efficiency, wider bandwidth, agile beam steering, decreased signal interference and increase Signal-to-Noise Ratio (SNR) for various applications in wireless communication systems.

II. Literature Review

Several research papers have reported on design and simulation of microstrip patch antenna. These research works used different design techniques, topologies and electromagnetic simulators to achieve better antenna performance.

Huque, et al., (2011) in their work, designed and analysed a microstrip antenna for X-band applications using SONET simulator. They observed that radiation efficiency declines rapidly with dielectric constant for 10GHz frequency. The designed antennas yielded return losses of -4.21dB to -25.456dB at frequencies around 10GHz for a dielectric substrate with permittivity (εr) of 2.2 and height, h of 1.588 mm. Othman et al., (2014) designed a novalspanar printed antenna for X-band frequency spectrum for 10GHz radar system application using CST microwave Simulation software. The spanar antenna was designed with a small patch size of 24.8 mm x 8.0 mm on a FR4 substrate of 31.7 mm by 18.5 mm, having a thickness (h) of 1.6 mm and a dielectric constant (εr) of 4.7. The designed antenna achieved a gain of 4.123 dBi with a directivity of 5.587 dB and proved to be suitable for wireless system operating at X-band.

In Midasala and Siddaiah (2016), the authors designed and simulated a Rectangular Microstrip Patch Antenna (RMPA) for X-band application using HFSS software. The simulation of designed antenna showed good performance in terms of return loss, VSWR and Gain. In Vijaykumar (2017), a steerable Microstrip patch antenna for UAV applications at 5.6GHz was proposed using HFSS software. To increase the proposed antenna design gain, the author used an inset fed microstrip line. The gain of a single element in set fed patch antenna was found to be 7.2d Biresonating at5.6GHzwith10dBbandwidthrangeof190MHz.In Datto et al. (2017), an optimized Microstrip Patch Antenna was designed and simulated to enhance gain for S-Band application. In this work, the single element MPA is firstly designed on Rogers RT/duroid 5880 substrate using HFSS software quarter wavelength transformer. In Obot et al. (2019), the work addresses the problem of low gain of single microstrip antenna element by designing an inset fed rectangular microstrip antennas using HFSS software. The simulation of the designed antenna achieved a gain of 5.26 dBi at the resonating frequency of 2.4 GHz. In the work of Ab Wahab, et al. (2019), the author designed and simulated an inset-fed rectangular microstrip patch antenna for WLAN application using CST software and a RO4350 dialectic substrate,

The combined work of Nataraj and Prabha. (2019) proposed a design for a Wideband Rectangular Patch Antenna for X- Band Applications. The antenna was printed on an FR4-epoxy substrate with 1.58mm thickness and patch dimensions of 9.13 mm by 6.27 mm. The design was simulated using Advanced Design System (ADS) software and achieved a return loss of -33.53 dB at 10.58 GHz operating resonant frequency, with an overall efficiency of 60-70% in the frequency range of 8-12 GHz.

It can be seen that there has been numerous literature contribution and techniques to designing a microstrip antenna for wireless communication system. Majority of the existing research work in microstrip antenna design has addressed the problems that are closely related with low gain, narrow bandwidth and low power handling capacity. Hence, the significant contribution of microstrip antenna design in reviewed literatures is to enhance the performance of a microstrip antenna to achieve higher gain, wider bandwidth as well as to improve the power handling capacity of microstrip antenna in wireless communication devices.

III. Design Methodology

The present aim of the research work is to design and simulate a rectangular microstrip patch antenna for X-band application. To achieve this, the choice of simulating software, design specifications and parameter (dimension) calculations to achieve a light-weighted microstrip patch antenna should be considered.

a) *Choice of Simulation Software*

To design a microstrip patch antenna, several software can be employed such as: COMSOL, MATLAB, IE3D, MWO, SONNET, FEKO, ADS, HP MDS, CST MS and HFSS etc (Odeyemi et al, 2011; Patir, 2015). However, for this research work, the ANSYS HFSS (v.15) software is chosen for design and simulation, as it is based on the Finite Element Method (FEM) techniques (Felippa, 2004). The HFSS software is the most accurate, versatile and appropriate for modelling volumetric structures like the Microstrip patch antenna.

b) *Design Procedure*

The procedure to achieve the design and simulation of an inset-fed rectangular microstrip patch antenna involves the following steps:

1. Specifying the frequency of operation called resonant frequency (f_o)
2. Choose a suitable dielectric substrate material
3. Decide on the substrate height (h)
4. Calculate the appropriate patch dimensions (width and length)
5. Select a feeding method
6. Find the feed location.

c) *Design Specification*

Before designing a microstrip patch antenna, the first step is to consider the design specification of the antenna based on its intended application. There are three essential design specifications that must be considered when designing a Rectangular Microstrip Patch Antenna for various wireless application. These are:

1. Frequency of Operation (f_o): The proposed antenna is intended for X-band application range of 8 – 12 GHz, for UAV and radar wireless communication system. Thus, an operating frequency (f_o) of 10 GHz in the X-band range of 8 – 12 GHz is selected for the antenna design.
2. Dielectric Substrate Material (ε_r: While designing MPA, substrate selection is as decisive as the design itself. Radiating properties of MPAs depend on the substrate used for the antenna design (Hanumante and Roy, 2012). The substrate material chosen for the design of the RMPA is Rogers RO4350 with a dielectric constant (ε_r) of 3.66 and aloss tangent (δ) of 0.0032. A substrate with a relatively low dielectric constant is selected since it will reduce the patch size of the antenna, desirable for radar application of the proposed X-band antenna. The reason for choosing a ROGERS substrate is however, due to its consider able properties, such as, low surface wave excitation, low moisture absorption, lowest electrical loss, uniform electrical properties over frequency, and relatively low cost (Rogers, 2020).
3. Height of dielectric substrate (h): For the microstrip patch antenna to be used for X-band application of 10GHz, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate (thickness) selected is 31 ml (≅ 0.79 mm). This height of the RMPA is chosen based on the equation given by Kumar and Ray, (2003) as:

$$h \le \frac{0.3c}{2\pi f_o \sqrt{\varepsilon_r}}$$

where, c is velocity of light in mm and f_o is the operating frequency in GHz.

The other factor considered in the design specification, is the feeding method for the proposed antenna. For this research work, the inset feed microstrip line feed technique is to be employed. Table 1 shows the design specifications, which is used for the design of proposed antennas.

Table 1: Microstrip Antenna Design Specifications

Parameters	Operating Freq (f_o)	Substrate	Dielectriccon stant (ε_r)	Substrate Height (h)	Feeding Method
Specification	10 GHz	Roger RO 4350	3.66	31 ml	Inset-fed

d) Design of Rectangular Microstrip Patch Antenna

To design the proposed inset-fed RMPA, design parameter dimensions of the antenna need to be developed, using essential equations required to perform this process. The transmission line model is used to calculate the design parameters of the antenna, because it gives a good practical and easy insight into the design of the RMPA.

i. *Calculations of Design Parameters*

The detailed procedure and parameter equations for designing the single element, single band rectangular microstrip patch antenna are as follows:

Step 1: Calculation of the patch width (W):

For an efficient radiator, the width (W) of the microstrip patch is calculated based on the transmission line model equation given by (Balanis, 2016) as:

$$W = \frac{c}{2f_o}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Substituting $c = 3 \times 10^{11}\ mm/s$, $\varepsilon_r = 3.66$ and $f_o = 10\ GHz, W = 10\ mm$

Step 2: Calculation of effective dielectric cconstant (ε_{eff}):

The effective dielectric constant is obtained Matin and Sayeed (2010) as:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

Substituting $\varepsilon_r = 3.66, W = 10\ mm$ and $h = 31ml$ (0.79 mm), $\varepsilon_{eff} = 3.28$

Step 3: Computation of effective length (L_{eff}) of patch:

The effective length of the patch is calculated from Balanis (2016) as:

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}}$$

Substituting $c = 3 \times 10^{11}\ mm/s, f_r = 10\ GHz$ and $\varepsilon_{reff} = 3.28$, we get: $L_{eff} = 8.28\ mm$

Step 4: Estimating the patch length extension(ΔL):

The patch length extension is obtained from Garg, et al. (2013) as:

$$\Delta L = \frac{0.412h(\varepsilon_{eff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{W}{h} + 0.8)}$$

Substituting $\varepsilon_{eff} = 3.28, W = 10\ mm$ and $h = 31\ ml$ (0.79mm), weget: $\Delta L = 0.37\ mm$

Step 5: Calculation of the actual length of the patch (L):

The actual (physical) length of the patch is calculated from (Kumar et al., 2013) as:

$$L = L_{eff} - 2\Delta L$$

Substituting$L_{eff} = 8.28\ mm,$ and$\Delta L = 0.37\ mm$, we get: $L = 7.5\ mm$

Step 6: Determination of the inset feed depth (y_0):

An inset-fed microstrip line feed is to be used in this design. The feed depth is given by y_0. The feed point must be located at that point on the patch, where the input impedance (Z_0) is 50 ohms for the resonant frequency. The resonant input edge resistance (Z_{in}) of the rectangular patch is estimated using an online microstrip patch antenna calculator (em.talk, 2011) as $Z_{in} = 209.7\Omega$. Therefore, the inset feed depth (y_0) is calculated from Matin and Sayeed (2010) as:

$$y_0 = \frac{L}{\pi} cos^{-1} \sqrt{\frac{Z_0}{Z_{in}}}$$

Substituting $Z_0 = 50\Omega$, $Z_{in} = 209.7\Omega$, and $L = 7.5\ mm$, we get: $y_0 \cong 2.6\ mm$

Step 7: Calculation of the width of microstrip line (W_o):

The width of microstrip line (W_o) is determined according to Pozar (2012) as:

$$\frac{W_o}{h} = \begin{cases} \frac{8e^A}{e^{2A} - 2} & for\ \frac{W_o}{h} < 2 \\ \frac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] & \frac{W_o}{h} > 2 \end{cases}$$

Using the formula for $\frac{W_o}{h} > 2$, and substituting for $B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}}$, the above equation becomes:

$$W_o = \frac{2h}{\pi}\left[\frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} - 1 - \ln\left(\frac{120\pi^2}{Z_0\sqrt{\varepsilon_r}} - 1\right) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln\left(\frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} - 1\right) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right]$$

Substituting $Z_0 = 50\Omega$, $h = 31ml$ (0.79mm) and $\varepsilon_r = 3.66, W_o \cong 1.73mm$

Step 8: Calculation of the inset (feed) gap (g):

The feed gap (notch width) in millimeters is computed based on equation given in Matin and Sayeed (2010) as:

$$g = \frac{4.65 \times 10^{-18} c f_o}{\sqrt{2\varepsilon_{eff}}}$$

Substituting $c = 3 \times 10^{11}\ mm/s, f_o = 10\ GHz$ and $\varepsilon_{eff} = 3.28$,$g = 0.55mm$

Step 9: Determination of the feed length (L_f):

The feed length of the microstrip transmission line can be determined using:

$$L_f = 3h$$

Substituting $h = 31ml$ (0.79mm), we get: $L_f = 2.37\ mm$. However, since this is assumed to be 50Ω microstrip transmission feed line, an online microstrip calculator (em.talk, 2011) was used to determine the transmission line as 2 mm and was added to the inset depth (y_0) of 2.6 mm, to get an optimized length $((L_f)$ of $4.6\ mm$ used as the feed length of the proposed RMPA in this research work.

Step 10: Calculation of ground plane dimensions:

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, Balanis, (2016) stated that it is essential to have a finite ground plane, that is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, the length (L_g) and width of ground plane (W_g) were computed using:

$$L_g = L + 6h$$

$$W_g = W + 6h$$

Substituting $L = 7.5mm, , W = 10mm$ and $h = 31ml$, we get: $L_g = 12.24\ mm$ and W_g =14.74 mm. However, in this work, a square ground plane dimensions of 40mm by 40mm is used for both L_g and W_g respectively of the RMPA design.

ii. *Geometry of Proposed inset-fed RMPA Design*

Based on the calculated design parameters, the proposed antenna geometry of the inset fed Rectangular Microstrip Antenna (RMPA) is as shown in Fig.2.

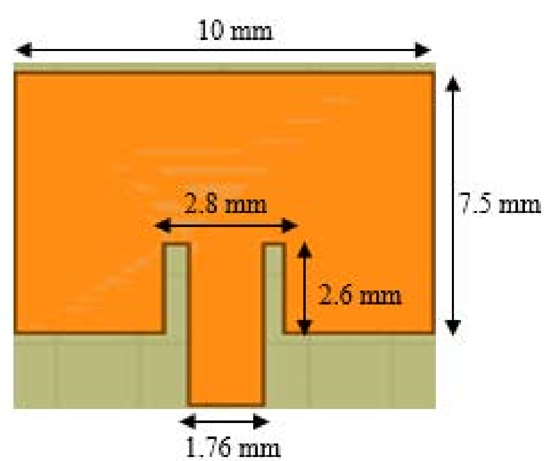


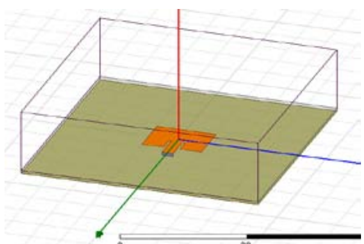
Fig. 2: Top-view dimensions of inset-fed RMPA Design

The summary of the optimized design calculations and specifications for various dimensions of patch, ground plane and matching inset feed line for the proposed inset-fed RMPA is given in Table 2 below.

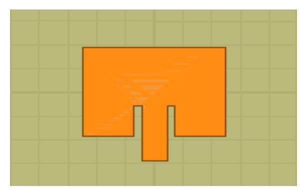
Table 2: Dimensions for the proposed inset fed RMPA

Parameters		Dimensions
(a)	**Patch dimensions**	
	Width of the patch (W)	10 mm
	Length of the patch (L)	7.5 mm
(b)	**Ground plane dimensions**	
	Length of the ground plane (L_g)	40 mm
	Width of the ground plane (W_g)	40 mm
(c)	**Inset feed line dimensions**	
	Inset feed depth (y_0)	2.6 mm
	Inset feed gap (g)	2.8 mm
	Feed length of 50Ω microstrip line (L_f)	4.6 mm
	Width of 50Ω microstrip line (W_0)	1.76 mm
	Characteristic impedance offeedline (Z_0)	50 Ω

The designed inset-fed RMPA in HFSS is shown in Fig. 3 below.



(a): 3D view of RMPA



(b): 2D view of RMPA

Fig. 3: Designed inset-fed RMPA using HFSS software

IV. Results and Discussion

The simulation results of the single element RMPA using HFSS (v.15) software are shown from Fig. 4 to Fig. 9. The HFSS software that has been used to simulate the antenna design has the ability to display several antenna parameters such as return loss (S_{11}), VSWR, gain, directivity, radiation pattern, Half Power Beamwidth (HPBW) and efficiency. To analyze and evaluate the antenna performance of the proposed antenna design using these antenna parameters, the summary of the results of the simulated antenna designs for designed RMPA are presented and discussed below.

a) Return Loss (S_{11})

Return loss is an important parameter that measures the effective power delivery of the designed antenna (Balanis, 2016). Fig. 4 below plots the return loss or reflection response (S_{11}) of the designed RMPA. From Fig. 4, it is evident that the designed RMPA is resonating at the operating frequency of 10 GHz, with a measured return loss of -19.61 dB. This return loss value of -19.61 dB is a good value since it is below (less than) the -9.5 dB minimum specified value for a good practical MPA design, and signifies that minimum power is reflected from the antenna to the source input port.

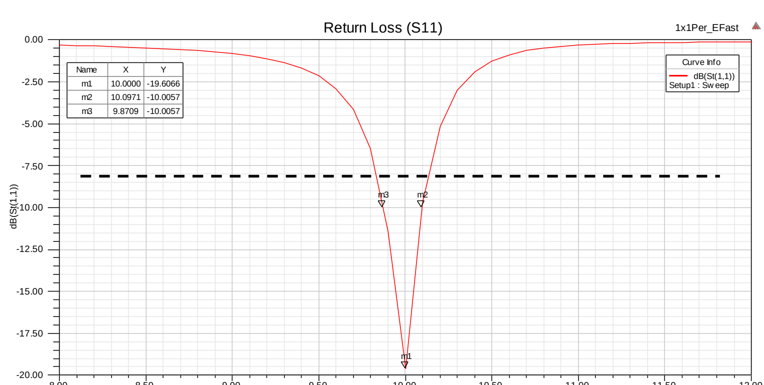


Fig. 4: Return Loss vs frequency plot of designed RMPA

b) Bandwidth

The bandwidth of an antenna is the range of frequencies within which a particular antenna can radiate and receive energy properly (Balanis, 2016). Within this bandwidth limits of the antenna, the characteristics (gain, VSWR, etc) of the designed RMPA provides satisfactory operation (Alsager, 2011). As can be seen from fig. 4, the -10 dB bandwidth of the designed antenna is 226.2MHz, with a resonate frequency of 10GHz.The 226.2MHz impedance bandwidth of the designed antenna is approximately 2.26%, and can further be improved by using antenna array configurations, or by using aperture coupling and several other methods discussed in many literatures.

c) Voltage Standing Wave Ratio (VSWR)

Voltage standing wave ratio (VSWR) is a way to measure transmission line imperfections (Alsager, 2011). The desirable VSWR range of 1<VSWR< 2 is desired for a good antenna operation of any designed antenna (Pozar, 2012). From Fig. 5 below, the designed RMPA, achieved a VSWR of 1.82 at the resonant frequency of 10 GHz. The VSWR value of 1.82 indicates a good impedance matching, as it is slightly below the acceptable maximum value of 2 for a well-matched antenna.

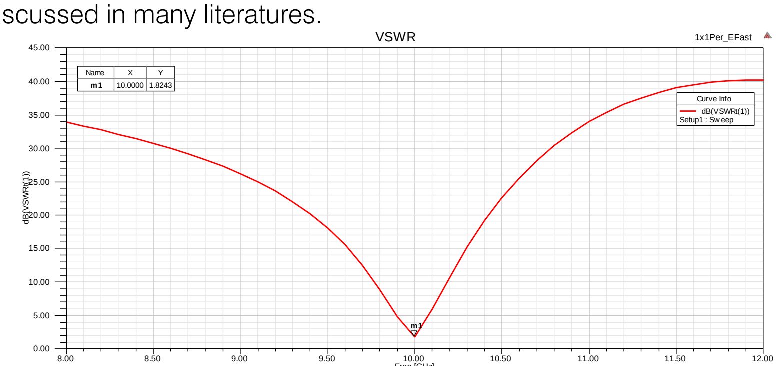


Fig. 5: VSWR versus frequency plot of proposed RMPA

d) Gain and Directivity

The gain of an antenna is the measure of the antenna efficiency, and describes how far signals can travel through space, while the directivity of an antenna measures the ability of the antenna to radiate energy in a particular direction. The higher the gain, the farther signals will travel. The 3D polar plot of the simulated antenna design is shown in fig. 6 and fig. 7 below.

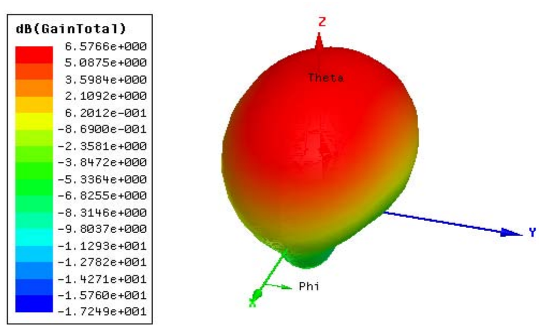


Fig. 6: 3D Gain plot of simulated RMPA

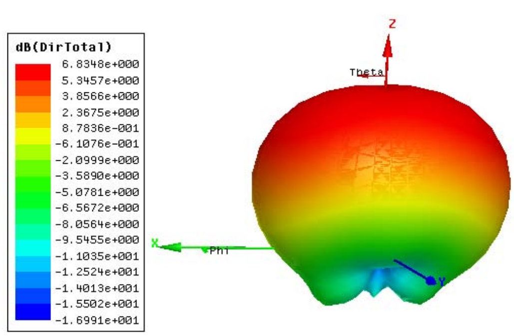


Fig. 7: 3D Directivity plot of simulated RMPA

From the 3D polar plot shown in Fig. 6 and Fig. 7, the gain and directivity of the designed RMPA are 6.58dBi and 6.83 dBi respectively, at the resonant frequency of 10 GHz. Thus, the proposed RMPA is relatively suitable for long communication, as it is less prone to interference and fading, and maybe improved when used in array for improved signal reception in wireless communication system.

e) Radiation Pattern and Beamwidth

Radiation pattern and beamwidth of an antenna describes the shape and direction of the beam of electromagnetic wave from antenna. The measured far-field radiation patterns of designed RMPA antennas are shown in Fig. 8below. The radiation pattern shown in Fig. 8 shows the E-plane (phi=0deg, x-zplane) and H-plane (phi=90deg, y-zplane) radiation pattern of the designed RMPA in polar plot. The radiation pattern of the proposed antenna is omni directional with minimum side lobe.

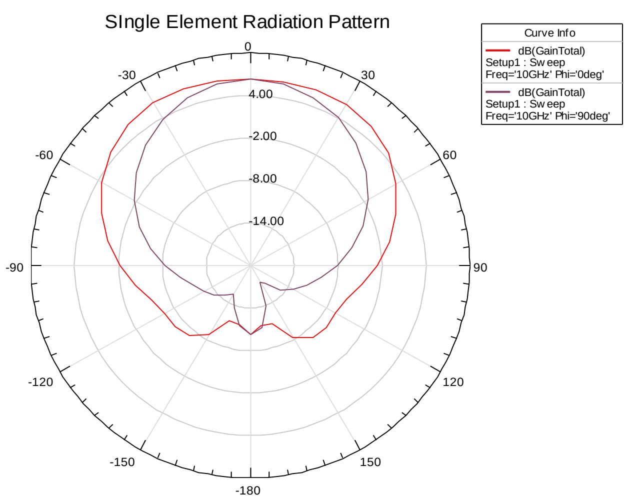


Fig. 8: Radiation pattern of designed RMPA in polar plot

When considering the beamwidth of the designed RMPA, the -3dB Half power Beamwidth (HPBW) of the designed RMPA is 115.2°. The designed RMPA therefore, supports a wider beamwidth, with less directed main-beam and a high chance of receiving interference due to its low gain. Thus, the designed RMPA can be used for WLAN and X-band application.

f) Power Radiated (Tx) and Power Received (Rx)

The power radiated or received by an antenna is an important parameter that characterizes the performance of an antenna, and determines the antenna performance efficiency. The power received by an antenna is expected to be higher than the radiated power by an antenna, as a result of ohmic losses on transmission lines or losses in the dielectric surrounding the patch antenna. In this research work, the power radiated and received by the designed RMPA are tabulated in table 3. As can be seen, the 9.891mW power received by RMPA is higher than the 9.320mW power radiated. This indicates that the proposed RMPA radiates 93.2% of its power received, and absorb less than 6.8% of received power as losses.

Table 3: Comparison of RMPA power radiated & received

Number of Elements	Power Radiated(mW)	Power Received (mW)
Single Element	9.320	9.891

g) Antenna Efficiency

The antenna efficiency of the designed RMPA in this research work, is an important parameter that expresses the ratio of the total power radiated, to the net power received by the antenna. In this research work, the radiation efficiency of the designed RMPA is 94.2%. This high antenna efficiency of 94.2% achieved by the proposed RMPA is therefore good for practical purposes as it is slightly above the 80-90% efficiency noted by Alsager (2011) for most microstrip patch antennas.

V. Summary of Simulation Results and Analysis

The summary of the simulation results of the designed RMPA in this research work is shown in Table 4. This table presents the performance parameters of the designed RMPA in this research work, using the basic antenna parameters characteristics such as resonant frequency, return loss (S_{11}), VSWR, Bandwidth, Gain, Directivity, Half Power Beamwidth (HPBW) and Efficiency.

Table 4: Summary of simulated results of RMPA Design

No. of Elements	Resonant Freq. (GHz)	Return Loss (dB)	VSWR	-10dB Bandwidth (MHz)	Gain (dBi)	Directivity (dBi)	HPBW (Deg)	Efficiency (%)
Single Element	10	-19.61	1.82	226.2	6.58	6.83	115.2	94.2

VI. Conclusion

In this research work, the design and simulation of a microstrip patch antenna for improving signal reception in wireless communication system has been presented. An innovative single element Rectangular Microstrip Patch Antennas (RMPA) resonating at 10 GHz has been successfully designed and simulated using HFSS (v.15) software. The antennas performance characteristics such as return loss, bandwidth, VSWR, gain, directivity, beamwidth and radiation efficiency were obtained in the simulation. The simulation results of the proposed RMPA resonated at 10 GHz, with a return loss of -19.61 dB, bandwidth of 2.26%, VSWR of 1.82, gain of 6.58 dBi, directivity of 6.83 dBi and an antenna efficiency of 94.2%. The novel designed antennas can be used for commercial WLAN, WiMAX, radar and satellite wireless applications in the X-band range of wireless communications.

VII. Future Works and Recommendations

Antenna design is a vast field for researchers and engineers. Future works and recommendations will be to use the single element RMPA to design and simulate a microstrip patch array antenna that improves the antenna performance of the proposed design. As antenna designed in this work is a single band antenna, it would be possible to also extend this work to a multiband design which can operate at multiple frequencies for multiple applications.

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Machine Learning in Public Health: A Review

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Abstract- In recent years Machine learning has been used for disease diagnosis and prediction in the public healthcare sector. It plays an essential role in healthcare and is rapidly being applied to education. It is one of the driving forces in science and technology, but the emergence of big data involves paradigm shifts in the implementation of machine learning techniques from traditional methods. Computers are now well equipped to diagnose many health issues with large health care datasets and progressions in machine learning techniques. Researchers have been used several machine learning techniques in public health. Several methods, including Support Vector Machines (SVM), Decision Trees (DT), Naïve Bayes (NB), Random Forest (RF), and K-Nearest Neighbors (KNN), are widely used in predictive model design research, resulting in effective and accurate decision-making. The predictive models discussed here are based on different supervised ML techniques and various input characteristics and data samples. Therefore, the predictive models can be used to support healthcare professionals and patients globally to improve public health as well as global health. Finally, we provide some problems and challenges which face the researcher in public health.

Keywords: machine learning, prediction, classification, public health, disease.

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MACHINELEARNINGINPUBLICHEALTHAREVIEW

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Machine Learning in Public Health: A Review

Md. Asadullah [α], Mamunar Rashid [σ], Priyanka Bosu [ρ], Emon Ahmed [Ѡ] & Sabeha Tamanna [¥]

Abstract- In recent years Machine learning has been used for disease diagnosis and prediction in the public healthcare sector. It plays an essential role in healthcare and is rapidly being applied to education. It is one of the driving forces in science and technology, but the emergence of big data involves paradigm shifts in the implementation of machine learning techniques from traditional methods. Computers are now well equipped to diagnose many health issues with large health care datasets and progressions in machine learning techniques. Researchers have been used several machine learning techniques in public health. Several methods, including Support Vector Machines (SVM), Decision Trees (DT), Naïve Bayes (NB), Random Forest (RF), and K-Nearest Neighbors (KNN), are widely used in predictive model design research, resulting in effective and accurate decision-making. The predictive models discussed here are based on different supervised ML techniques and various input characteristics and data samples. Therefore, the predictive models can be used to support healthcare professionals and patients globally to improve public health as well as global health. Finally, we provide some problems and challenges which face the researcher in public health.

Keywords: machine learning, prediction, classification, public health, disease.

I. Introduction

Machine learning, a method of developing a prototype that learns to enhance its quality through experience, belongs to the context of artificial intelligence and is increasingly being used in various fields of science [1]. Such algorithms can be applied to help track the progress of a person, what variables make their symptoms worse, predict how long they would take etc. [2]. It is likely to deliver technically superior results, but it is not going to be perfect. While machine learning can deliver technical performance, inequities can be compounded [3]. The intervention was particularly among the group with a moderate likelihood of participation. Targeting the results of the prediction model using the machine-learning method has been identifying suitable intervention targets [4]. Traditional machine-learning approaches have been successful because the complexity of molecular interactions has been reduced by investigating only one or two dimensions of the molecular structure in the feature descriptors. Several different ML classifiers are experimentally validated into the data set in the present study [5]. Machine learning is involved in many of these, but streaming data is only addressed in a few plays. The machine learning library consists of common learning algorithms such as classification, clustering, collaborative sorting, etc. useful when dealing with problems with machine learning [6].

Machine learning typically extends these methods to cope with high dimensionality and nonlinearity, which in wearable sensor data is of particular importance. It overlaps with artificial intelligence, but traditional biomedical statistics usually recognize the problems it seeks to solve. Extraction of the function renders machine-learning traceable because it reduces the number of data dimensions [7]. These techniques can help enhance the ability to discriminate by combining multiple metabolites' predictive abilities. However, these methods are monitor, and therefore, various validations are key factors in preventing over fitting [8]. In this paper, a new approach is proposed to automatically identify fund us objects. The method uses pre-processing techniques for images, and data to improve the performance of classifiers for machine learning [9]. Machine learning techniques are applied to these data, which are useful for data analysis and are used in specific fields [10]. Recently it can use to analyze medical data, and for medical diagnosis to identify various complex diagnostic problems. We can improve the accuracy, speed, reliability, and performance of the diagnosis on the current system by using machine learning classification algorithms for any particular disease [11]. It is used to estimate vegetation parameters and to detect disease, with less consideration give to the effects of disease symptoms on their performance [12].

II. Machine Learning in Public Health

Machine learning plays a role in the healthcare field and it is rapidly apply to healthcare, including segmentation of medical images, authentication of images, a fusion of multimodal images, computer-aided diagnosis, image-guided therapy, image classification, and retrieval of image databases, where failure could be fatal [15]. Statistical models developed using machine-learning methods can view in many ways as extensions from epidemiology and health econometrics of more conventional health services research methodologies [16]. Given the wide availability of free packages to support this work, many researchers have been encouraged to apply deep learning to any data mining,

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and pattern recognition topic related to health informatics [17]. In medical fields, machine learning has also shown promise when the aim is to discover clusters in the data, such as therapeutic choice imaging research. Here, the new features can check with a radiologist or neurologist expert assessment which varies from the prediction environment where observed marks exist in the data [18]. Screening and prognosis of patients with cancer use methods for pattern recognition and identification such as machine learning [19].

The repository should highlight the specifications of clinical machine learning tasks and motivate the ML community by providing a platform for the publication, collection of data sets, benchmarking of statistical evaluators, and methods for challenging machine learning problems [19]. The main of applying the classification method is to allow healthcare organizations to provide accurate medication quantities [20]. At every stage of development and application of machine learning in advancing health, ethical design thinking is essential. To this end, honesty and innovation physicians will work closely with software and data scientists to re-imagine clinical medicine and foresee its ethical implications. It is crucial that data from mobile health and consumer-facing technologies be systematically validated, especially when dynamic intervention is provided [22]. Three developments in machine learning may be of interest to public health researchers and practitioners [25]. Machine Learning techniques have shown success in the prediction and diagnosis of numerous critical diseases. Some sets of features use in this strategy to represent each instance in any dataset [26]. Research comparing the quality of different prediction methods to predict disease, disease etiology, or disease subtype is minimal. For many types of medical diagnoses, a good machine learning approach to classification will apply [27].

III. Challenges in Public Health

Overall, health systems face multiple challenges: rising disease burden, multimorbidity, and disability drove by aging and epidemiological transition, increased demand for health services, higher social expectations, and increased health spending [3]. Healthcare offers unique machine learning challenges where the requirements for explaining ability, model fidelity, and performance, in general are much higher than in most other fields. Ethical, legal, and regulatory challenges are unique to health care since health care decisions can have an immediate impact on a person's well-being or even life [28]. The primary focus in health informatics is on computational aspects of big data, including challenges, current Big Data Mining techniques, strengths and limitations of works, and an outline of directions for future work. A challenge is pose the high volume of healthcare data, the need for flexible processing, and support for decentralized queries across multiple data sources. Global health as an approach to the current situation and challenges, and the use of digital health as an ideal way to address health challenges associated with conflict-affected environments [30]. There are several ways in which the proposed models of machine learning can help address public health challenges. The regularity, reliability, and granularity of available data is a challenge in tracking population health. Model estimates can play a role in strategic decision-making if they can achieve sufficient precision, and machine learning models can provide a route to this required level of precision [31]. Several writers describe different challenges in public health.

Table 1: Public health Challenges

Challenges	Description	References
Development	Challenges in the acquisition of talent and growth capital	[64]
Data schema	Increasing the burden of disease, multimorbidity and disability driven by aging and epidemiological transition	[3]
Ethics, laws and regulations	Health care choices can have an immediate impact on a person's well-being or even life.	[28]
Epidemic	Social health inequalities, a small number of local healthcare professionals, and a weak infrastructure for healthcare.	[13]
Big Data	Data mining methods, advantages and weaknesses of current works and recommendations for future work	[29][32][19][61]
Treatment effect	Treatment of patient outcomes in order to select the correct treatment	[16]
Clinical Data	Real clinical information environment, incomplete and erroneous data.	[65]
Data regularity, timing and reliability	The regularity, pacing and granularity of available data is the control of population health.	[31]
Characteristics identifying	The features of communities, ecosystems and policies are defined in population health	[47]

Health Tackling	Health as an approach to the existing situation and challenges.	[30]
Dataset imbalance	Forming an ensemble of multiple models with matched numbers of positive and negative slides trained on data subsets.	[66]
Biomarkers identify	Build diagnostic, prognostic or guided therapy predictive models	[19][59]
Screening	The area of early detection of cancer is packed with highlighting cautionary tales.	[67]
Diagnosis	The nuanced essence of the disease and its patient heterogeneity	[68][69]
Image data	Modern imaging technology will surpass the capabilities of human pattern recognition	[70]
Diagnosis, treatment and monitoring	The growing number of patient data in the form of medical images	[9]
Decision making	Prediction of disease is one of the most important medical problems because it is one of the leading causes of death..	[26]
Monitoring of disease	The progression of the disease and the estimate of the level of fibrosis of the patient	[71]
High- dimension image data	Imaging evidence was a problem in the treatment of diseases based on brain imaging.	[72]
Accurate prediction	Things that recur within a binary outcome	[69]

IV. Problem Statement

In public health, they are reducing constraints such as lack of resources (human and logistic) in healthcare centers, high population dispersion, and lack of infrastructure. One problem with the concept of "data health" is the lack of a practical idea of effective and efficient healthcare programs: each insurer has sought effective strategies through trials and errors [4].The main problem is the unstructured of the medical reports. High complexity and noise issues result from the multisource and multimodal nature of healthcare data. Additionally, the high-volume data also has problems with impurity and missing values. These issues are to handle in terms of both size and reliability, although a range of methods has developed to improve data accuracy and usability [29].Machine learning methods are the leading option for achieving a better result in classification and prediction problems. In a wide range of machine learning (ML) problems, classification plays a role. Another major issue with the collection of data is the potential lack of label accuracy. Overfitting is a potential problem in machine learning. The general problem is that several existing datasets are difficult to use in terms of permission [34]. Table 2 displays the numerous public health issues facing them.

Table 2: Problem Statement in Public Health

Problem	Description	References
Classification	The situation was linear in nature for all armed and unarmed group datasets	[57][33][42][50][19][5][21][55][73][74][60][75][76][77][69]
Scalability	Exists with two of the most widely used interpretable machine learning models	[28]
Lack of infrastructure	Lack of resources in health care centers (human and logistic), high population dispersion	[13]
Effective and Efficient	Through trial and error, every insurer tried effective strategies	[4][78]
Exchange health information securely	Scientists and clinicians across institutional, provincial, or even national jurisdictional boundaries across a given healthcare organization.	[29]
Overfitting	Because of its storage limitation, it may not be appropriate for very large datasets with high dimensional features	[29][32][17][34][24][79][80]
Data Imbalanced	Which are commonly used to resolve big data clinical databases.	[29][81][27]]82][83]
Clinical unstructured notes	The multisource and multimodality of health care data leads to high complexity and noise problems	[29]
Impurity and missing	The high-volume data also has problems with impurity and missing values	[29]
Missing variables	This results in the normal multivariate methods, while	[16]

	machine-learning approaches can still be appealing for other reasons	
Prediction	The computer is equipped with a set of data to improve the classification model after it can be used for future predictions	[33][82]
Mobility	The problem of visual, hearing, flexibility also affects the disease.	[50]
Dose management	Use machine learning approaches to the SCD drug problem	[20]
Segmentation	That pixels can be marked as belonging to a particular segment or category	[84]
Multicollinearity	Reduction of measurements and management of experimental data	[73][80]
Dimensionality	Less likely than other classifiers to suffer from this problem.	[60][11][72]
Class imbalance	The number of samples from one class outweighs the other classes significantly	[59][83]
Sampling	Data collection is a possible lack of label accuracy	[7]
Scoring	Functions for use in models of prognosis estimation	[85][82]
Diagnosis		[86]
Missing data and Class imbalance	For the context, the performance metrics selected are most often inappropriate.	[46]

V. Dataset

To generate the most effective results, machine learning algorithms use to analyze data repeatedly. Machine learning currently provides the machine for scrutinizing imaginative information. Today, medical clinics very well equippe with fully automatic machines, and these machines produce tremendous amounts of data, then collect, and exchange these data with information systems or doctors to take the necessary steps. Machine learning methods can used to examine medical data and various technical diagnostic conditions in medical diagnosis. Using machine learning, systems take patient data as an input such as symptoms, laboratory data, and some of the at tributes and produce reliable diagnostic results. Depending on the reliability of the test, the computer must determine the information for the future reference will be used as a learning and qualified dataset [11]. Different Authors are used to several data determine the quality of the proposed classifiers which display as.

Table 3: Summary for data used in various research paper

Data Description	References
Patient data	[2]
Parkinson's Disease Data	[35]
Clinical Data	[3][87][88][55][24][89][10][71][90][91][38][92]
RGB-D Data	[8]
Diabetes Data	[54][93][52][81][23][36][86][43]
Malaria Data	[1]
TB Data	[13]
Health Data	[4][29]
Biomedical Data	[94]
Heart Disease Data	[62][95][48]
EMR data	[16]
Chronic Disease Data	[96]
Breast Cancer Data	[33][42][46]
Stress Data	[65]
S1,BRFSS & ACS Data	[31]

Cleveland Data	[47]
GDS Data	[50]
EHR Data	[97][18][39][98][56][99][100][77]
Medical Data	[30][20][75][24][61][11]
Meta Data	[66][19]
Image Data	[101][84][102][103][34][104][70][9][105]
TCGA Data	[67]
CKD Data	[5][51][106][26][69]
Physiological Data	[107][53]
Health Care Data	[6][108][79]
OASIS Data	[44]
Sensor Data	[40][7]
IMU Data	[74]
ADNI Data	[60][59]
RNA Data	[68]
UCI Cardiac Data	[41]
CAD Data	[85]
AF Data	[109]
Metabolites Data	[57]
MRI Data	[110][111][72]
Social Media Data	[112]
Thyroid Data	[76]
Dengue Case Data	[113]
NHANES Data	[80]
Dementia Data	[37]
DIARE-TDBI Data	[58]
ECG Data	[114]
Wisconsin Breast Cancer Data	[115]
SW Data	[116]
Genomics Data	[82]
Clinical & Image Data	[117]
PH^2 Data	[118]
WBC Data	[119]
Spectral Data	[120]
ISIC Data	[72]
ILPD Data	[83][45]
NHA-NES Data	[121]

VI. Classification Technique

In many real-world issues, classification is one of the most decision-making techniques. The higher number of samples selected for many classification problems, but does not lead to higher classification accuracy [35]. Supervised machine-learning algorithms are mainly use for classification or regression issues where the patient sample class label is already available [19]. Classification tasks are found in a various decision-making tasks in various fields such as medicine, science, industry, etc. Several approaches are suggest in the literature on how to solve classification problems [5]. In the medical context, the identification quality of commonly used machine learning models, including k-Nearest Neighbors, Nave Bayes, Decision Tree, Random Forest, Support Vector Machine, and Logistic Regression [36]. In this research paper, we conclude various research papers in a tabular form (Table-4) showing different methodologies and compare the accuracy

Table 4: Techniques are used in Public Health

Technique	Disease Name	Highest Accuracy	References
SVM,RF,KNN,DT	Parkinson's	SVM=97.22%	[2]
NB,KNN,C4,5DT,RF,SVM	Liver Disease	KNN=98.6%	[57]
LR,Adaboost,SVM,DT,	DB	SVM=94.4%	[54]
SVM,ANN	Malaria	SVM=89%	[63]
DNN	Diabetes	DNN=83.67%	[62]
MLP, KNN, CART, SVM, NB.	Breast cancer	MLP=96.70%	[33]

NB,LS-SVM,Adabag,Adaboost, RF,SVM,Logit,LDA	Breast cancer	Adaboost=99.08%	[42]
BN,LR,MLP,SMO,DT	Liver cancer	SMO=93.33%	[50]
NB,SVM,RF,LR,ANN	Heart disease.	SVM=97.53%	[39]
MLP,SVM,KNN,C4.5,RF	Cancer	RF=99.45%	[5]
LR,NN,VM	Chronic kidney	VM=97.8%	[51]
,FR,MVS,NNKAdaboost	Heart Disease	95.24=FR%	[21]
,MVS-ACP,NNK-ACP EM-PCA-Fuzzy Rule-Based	Breast Cancer	EM-PCA-Fuzzy Rule-Based93.6=%	[73]
SVM, GEPSVM, TSVM	Alzheimer's	TSVM=92.75%	[44]
SVM,L1-Logistic,L2-Logistic,RF,RUSRF	Alzheimer's	SVM=73.33%	[59]
RF,SVM,AB,BT,GL	Diabetes	RUSRF=90.60%	[52]
LR,RF,SVM,SGB	Heart Disease	RF=89.97%	[41]
LR,KNN,BaggedTree,CNN	CHD	LR=86.51%	[85]
SVM,KNN,DT,NB,LR	Diabetes	KNN=85.29%	[23]
SVM,RF,ANN	Post-Traumatic stress	LR=77.61%	[109]
RF,C5.0,SVM,KNN	Glaucoma	RF=97.17%	[89]
RF,NB,SMO,RBF,MLPC,SLG	CKD	RF=98.00%	[26]
NB,KNN.ANN,DT	Diabetes	RF=99.35%	[36]
BN,NNK	Thyroid	NB=88%	[10]
PLM,NB,BN,BNB,FR,RL,MVS	Dementia	93.44=NNK%	[37]
NNK,BN,MVS,4.5C	Breast Cancer	73.98=MVS%	[115]
FBR,MVS,BN	Suspicious Thyroid	95.99=BN%	[91]
MVS,BN,NNK,NN	Brain Tumor	83.92=FBR%	[111]
MVS,NNK,FR,BN,RL	Diabetes	98=MVS%	[100]
TD,NNK,MVS,NNA	Skin Lesion	98=FR%	[118]
MVS,BN,RL	Kidney	92.50=NNA%	[38]
TRL-4,tsooBadA,MVS,RL	Heart diseases	76.70=MVS%	[77]
MVS,BN	Liver Disease	82=MVS%	[45]
BN,FR,TD,MVS,NNA	Cancer	79.66=MVS%	[92]

VII. Cross-Validation Technique

The predictive performance of the models is evaluated using the Cross-Validation technique to estimate how each model performs outside the sample to a new dataset also identified as to test data. The reason for using the cross-validation techniques is to fit it into a training dataset when we fit a model [33].Cross-validation was applied to achieve the best results to measure the numerical performance of a learning operator [10]. This was not achieved to properly isolate and compare the performance of the different methods concering the weighting of the propensity score. Through several steps, we measured the quality of the various propensity score matching methods [53].The classifier's accuracy calculation is the average accuracy of k-folds. Subsampling is done in bootstrap validation with equivalent substitution from the training dataset [59]. Effective use of the 10-fold cross-validation was found to be a good and reasonable compromise between offering accurate performance estimates and being computationally feasible and preventing overfitting [57].

Table 5: Summary of validation Technique in Public Health

Disease Name	Validation Methods	References
Parkinson Disease	10 fold	[35]
Liver Disease	10 fold	[57][45]
Diabetes Disease	10 fold	[54][52][23]
Malaria Disease	5 fold	[1]
Heart Disease	5 fold	[7]
Breast cancer Disease	10 fold	[33][73][115]

Breast cancer Disease	5 fold	[42]
Liver cancer Disease	10 fold	[50]
Heart disease	10 fold	[39][41][77]
Cancer Disease	5 fold	[5]
Chronic kidney disease	10 fold	[51]
Heart Disease	5 fold	[21]
Alzheimer's Disease	10 fold	[44][59]
CHD	5 fold	[85]
Post-traumatic stress Disease	10 fold	[109]
Glaucoma Disease	10 fold	[89]
CKD	10 fold	[26]
Diabetes Disease	5 fold	[36]
Thyroid disease	10 fold	[10]
Dementia Disease	10 fold	[37]
SuspiciousThyroid Disease	5 fold	[91]
Brain Tumor Disease	10 fold	[111]
Diabetes Disease	5 fold	[100]
Skin Lesion Disease	10 fold	[118]
Kidney Disease	5 fold	[38]
Cancer Disease	10 fold	[92]

VIII. Model Evaluation Technique

After the estimation, the performance of the predictive models is evaluate in terms of accuracy, accuracy, and recall of unseen data using the k-fold cross-validation technique to test their abilities [33]. Classification performance is evaluating the precision, sensitivity, and specificity of each system as it is a widely accepted tool of classification performance evaluation and generalization error estimation [60]. It is mention that the F1 score can be affect distorted class ratios when used as a quality indicator. Both AUC and F1 scores are compared using paired t-tests to updated Bonferroni inference thresholds [59].Here we can summarize different methods of performance evaluation as below,

Table 6: Summary of Performance Evaluation Methods

Performance Evaluation Method	References
Specificity, Sensitivity, F-Measure, Accuracy, Precision, Cohen-Kappa Statistic	[8]
RMSE,ROC	[10]
Specificity, Sensitivity, F-Score,Accuracy,ROC,K-S Test	[18]
Accuracy, Precision, Recall	[24]
MSE,MAE,NMSE	[44]
RMSE,RSE,RAE,MSE	[45]
Specificity, Sensitivity,PLR,NLR,DP.PPV,NPV	[57]
Specificity, Sensitivity, Accuracy	[60]
AUC, Specificity, Sensitivity,F1-Score,Precision,Recall	[61]
Specificity, Sensitivity,ROC	[63][68]
Fishers Exact Test	[64]
ROC	[69][115][98][75]
Accuracy, Recall, Precision, TP rate, Precision, NPV, FP rate, RME, F1-measure, G-mean	[70]
MAE,RAE,RMSE,RSE	[71]
FROC	[74]
Accuracy, Specificity, Sensitivity, Precision, (ROC)	[75]
F1 score, Precision, and Recall,NPV	[81]
DR, Specificity, Sensitivity	[95]
RRSE,Accuracy	[96]
RMSE,R-Square	[114][91]

IX. Limitations

While the application of machine learning approaches to healthcare problems is unavoidable given the complexity of processing massive amounts of data, the need to standardize standards of interpretable ML in this field is critical [28]. Although very broad, these data sets can also be very limited (e.g., system data can only be accessible for a small subset of individuals). Several machine learning methods effectively address these restriction but are still subject to the usual sources of bias commonly found in experimental studies [62]. The limitation of using SVM is its interpretation, computational costs for larger datasets, and SVM is essentially a binary classifier. A Simplified decision tree with four attributes for a multi-class decision problem [16]. A model that is overfitted is more complicated than the data can explain. For a genuine disease-related structure, an overfitted model may have too many free parameters and thus risk confusing random noise or another confounding in the training data. This is a pervasive problem in numerical machine learning because it is often possible to set the complexity of the model as high as required to achieve arbitrarily high prediction accuracy [7]. Some limitations of traditional medical scoring systems are the presence of the input set of intrinsic linear combinations of variables, therefore they are not able to model complex nonlinear interactions in medical domains. In this study, this weakness is addressed by using classification models that can implicitly detect complex nonlinear associations between independent and dependent variables as well as the ability to identify any potential correlations between predictor variables [63].

X. Conclusion

To inform clinicians and policymakers, systems powered by machine learning will have to deliver results of interest in action through clinical trials or real-world performance observations. Eventually, classification approaches such as clustering and artificial neural networks would require a complete set of experiments. Most of the researchers used the traditional machine learning algorithm to analyze public health data like SVM, RF, NB, LR, NN, KNN, ANN, and DT and 10-fold cross-validation provide the better results. But in public health, the challenge is pose the high volume of healthcare data. As a result, the challenge in public health to handle big data. Besides, there are a lot of public health researchers facing problems. Most of that found in a different research paper are classification problems in public health data. Overfitting and data imbalances are problems in public health. In our review paper, we find some challenges which keep in mind every public health researcher because most of the research paper discussed these problems, and most of the researchers have faced these problems.

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Enhancement of Electricity Supply in Port Harcourt using Distributed Generation (DG) Technology

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Abstract- Distributed Generation (DG) is a form of energy generation that services a customer on-site and supports a distribution network. The DG is attached at the voltage of the delivery system. The energy used for DG should ideally be sustainable. DG may be used as a backup generator. It contributes to the delivery network's increased reliability. If the DG unit is placed optimally in the delivery network, the increase in reliability will be greatest. The system of installing disconnects at parts forming a junction in the distribution network affects the reliability changes attributed to DG communication with the distribution network. Therefore, there is a need to enhance Distributed Generation in Port Harcourt.

Keywords: *generation, electricity, energy, enhancement.*

GJRE-F Classification: *FOR Code: 090699*

ENHANCEMENTOFELECTRICITYSUPPLYINPORTHARCOURTUSINGDISTRIBUTEDGENERATIONDGTECHNOLOGY

Strictly as per the compliance and regulations of:

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Engr. Adebayo Adeniyi D [α] & Dr. Chinedu James Ujam [σ]

Abstract- Distributed Generation (DG) is a form of energy generation that services a customer on-site and supports a distribution network. The DG is attached at the voltage of the delivery system. The energy used for DG should ideally be sustainable. DG may be used as a backup generator. It contributes to the delivery network's increased reliability. If the DG unit is placed optimally in the delivery network, the increase in reliability will be greatest. The system of installing disconnects at parts forming a junction in the distribution network affects the reliability changes attributed to DG communication with the distribution network. Therefore, there is a need to enhance Distributed Generation in Port Harcourt.

Keywords: generation, electricity, energy, enhancement.

I. Introduction

Generators that are linked to the distribution network are known as distributed generators (DG or embedded generators). Their benefits include the potential to minimize or eliminate waste. When transmission and distribution infrastructure is strategically placed, the opportunity to minimize technological losses within transmission and distribution networks, as well as overall improvements in power quality and system efficiency, can be postponed. Among the several issues in developing country nations like Nigeria is the lack of a valid and predictable power supply; this has caused several factories to close down, and others to depend on personal power generation, driving up production costs. Nigeria's power supply needs range from 50,000MW to 70,000MW, with less than 10MW coming from the electrical grid, resulting in many load sheddings and the outage of some businesses for an extended amount of time.

So many studies have suggested ways to boost the grid by implementing Distributed Generation (DG). The recommendations for DG were focused on taking electricity closer to customers, reducing power loss, and thereby lowering maintenance and delivery costs. DG also lowers emissions, provides renewable electricity, and lowers installation costs. These variables have given DG a significant advantage over other forms of power generation in recent years, particularly in rural areas. Since it accounts for more than 70% of global energy consumption, DG has been suggested as the possible alternative. Germany, for example, uses DGs to meet more than 55 percent of its electricity demand, while the United States uses them to meet more than 45 percent (Shasha et al. 2018Installing DGs into a network does not ensure the system's stability or reliability, particularly when faults occur due to a lack of load or generation. These faults may cause the system to adapt, resulting in a variety of issues such as voltage breaches, increased actual and reactive power losses, a decrease in potential excess power when more load is taken into account, and so on. Knowledge of these factors would help in proper network management for optimum utilization; however, failure to consider these factors could result in system instability, which could result in system collapse.

The majority of studies have focused on device stability, using indexes that are dependent on future behavior predictions that do not fully represent the system's actual future behavior in the near future (Anumaka, 2016). As a result, the current system's stability in relation to potential behaviour was examined in this study. The job regarded as a fraction of the Nigeria Network for successful research (Port Harcourt Network). The analysis of reliability can be approached from a variety of perspectives, including system stability, line losses, generation losses, and so on.

Most scholars have suggested too many methods with respect to the activities recognized when analyzing a system's reliability and stability. The research used in this dissertation would reveal the system state by looking at voltage stability, actual and responsive transmission loss, system loadability, and related indices. Power flow analysis, continuation power flow analysis, and measured indices can be used to do this. The machine will be investigated using power flow analysis, which will display the state of the network under constant load. The machine will be investigated further under load increment and at full loading using continuation power flow analysis. This will demonstrate that the infrastructure is on the verge of collapsing, while the stability indices will look at how the network reacts

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when a fault causes DG failure. To stop a server failure or crash, this will show which areas need further work.

a) Statement of the Problem

Device faults, which result in either a loss of load or generation, are one of the issues with the Port Harcourt power system. The lack of generation has a greater effect on the network and has the potential to bring the grid down. After the loss of DG, the machine can become unreliable. As a result, improving the power grid in Port Harcourt seems to be such a big issue over time that it has drawn so many researchers and investors. The issue is mostly caused by a lack of generation capacity and transmission line improvements. Though there have been proposals to use DGs as an additional source of power to increase current generation, there is a need to checkmate DG positioning in the network to ensure voltage reliability, minimize actual and reactive power losses, and effectively handle more load.

b) Aim and Objective of the Study

The main aim of this dissertation is to enhancement electricity supply in Port Harcourt using Distributed Generation (DG) Technology. The specific objectives are:

1. Investigation of the condition of the present Port Harcourt network.
2. Reliability study considering faults leading to loss of DG.
3. System maintenance based on reliability indices result.

II. Review Related Literatures

Anumaka (2016) presented a work on fundamentals of reliability of electric power system and equipment. The author stated that in recent days power system consists of complex interconnections that can prone a network from different network to various difficulties, which mitigate against network reliability inadequate planning and reliability check. This could lead to high failure rate of the power system installations and consumers equipment, transient and in transient fault, symmetrical faults etc.

The reliability study considered in power system according to the author is the measure of power interrupted load connected, frequency of interruption, amount of consumers and duration of interruption. The indices highlighted for measuring reliability are the Customers Average Interruption Duration Index (CAIDI), System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Momentary Average Interruption Frequency Index (MAIFI). Equipment failure and component failure follows a similar pattern which is described in the curve in fig 2.1. The curve shows three distinct regions or phase in the total life duration of the equipment. The equipment passes through three stages which also affects their efficiency. The first stage is the infant equipment. Failure rate is high due to manufacturing fault, design fault, misuse, misappropriation and other specifiable problems. The next stage is the useful life or normal operation region which is an interesting time period of the life of an equipment failure are minimized in this stage and failure could happen due to poor operating maintenance. The last stage which have a very high rate of failure is the wear out or old age region. High failure rate at this period of time could be decreased by changing the component parts, and the wear out stage could be avoided if proper maintenance is followed in the useful life stage.

Hussien et al (2010) considered a work on assessment of distributed generation (DG) impacts on Distributed networks using Global performance index, considering high penetration of DGs. According to the author(s), power injection from the DG can change the network power flow modifying energy losses and the voltage profile. The author stated that the reason is that proper location could bring DGs closer to the consumers thereby reducing line losses which in turn could optimize the energy output thereby accepting more consumers. The indices defined by the authors are Voltage Profile Index (VPI), Real and Reactive Power Loss Index (ILP and ILQ), Voltage Regulation Index (IVR), Current Capacity of Conductors (ICC) Index, Transformer Loading Index (ICT), three-phase and single-phase-to-Ground short circuit Index (Isc_3, Isc_1) and harmonic Index.

$$ILP = \frac{P_{LDG}}{P_L} \tag{2.1}$$

$$ILQ = \frac{Q_{LDG}}{Q_L} \tag{2.2}$$

$$\mathrm{VPI} = \max_{T=2}^{N}\left[\frac{V_1 - V_i}{V_1}\right] \tag{2.3}$$

$$\mathrm{IVR} = \max_{T=2}^{N}\left[\frac{V_{iLmin} - V_{1Lmax}}{V_{1Lmax}}\right] \tag{2.4}$$

$$ICC = max_{i=1}^{ml}\left[\frac{|S_i|}{|S_{ci}|}\right] \tag{2.5}$$

$$ICT = max_{t=1}^{mT}\left[\frac{|S_t|}{|S_{ct}|}\right] \tag{2.6}$$

Where P_{LDG} is the real power losses using DG, P_L is the real power losses without DG, Q_{LDG} and Q_L are the reactive power losses with and without DG, V_1 is the root voltage V_i is the bus i voltage, V_{iLmin} is the bus i voltage magnitude loaded with minimum demand, V_{iLmax} is the voltage magnitude at bus i loaded with maximum demand, S_i is the MVA flow in line i, S_{ci} is the MVA capacity at line i, S_t is the transformer loading in MVA, S_{ct} is the maximum transformer capacity and mt denotes the number of transformers. The author could only analyze the data with only one value.

Mehdi et al (2011) considered a quantitative assessment of DG benefits to improve power system indices. In addition to the indices proposed above, the author included a new indices called the greenhouse gasses effective reduction index, which account for pollution into the environment. Simulation was done on Zanjan Regional Electric company (ZREC) using Dig SILENT software. The result indicated benefits of DG on the Network which include the improvement in the line losses, voltage profile, environmental impact and relieved transmission and distribution congestion. Also the result shows that increasing the numbers of buses with DGs will create a greater impact.

Hassen et al. (2011) used genetic algorithm (GA) for optimization of DG location and capacity for enhancing voltage profile and reducing losses. The author(s) suggested that DGs plays a vital advantage to the network as it could aid to reduce electricity cost, manage congestion in transmission lines, reduce line losses, improve voltage profile etc. The author also stated that DG will be the most reliable energy supply in the near future which is incorporated with artificial intelligence. GA consists of four stages; produces an initial population randomly, calculates fitness function for each chromosomes, produces new chromosomes from the ones selected (crossover) and execute mutation on the chromosomes created. Mathematically, the function is given as;

Minimize $$g = f(x) = F(x)\ldots, f_i(x)\ldots, f_K(x) \qquad (2.7)$$

Which is subject to;

$$x = (x_1, x_2, \ldots x_n) \sum X \qquad (2.8)$$

$$y = (y_1, y_2, \ldots y_n) \sum Y \qquad (2.9)$$

The results shows that applying the proposed index, there was a very huge improvement in the network using DG. Suggestions were also proffered on the best positioning of DGs for optimal usage.

Gopiya et al (2012) presented a work on planning and operation of DG in distributed networks. The work suggested that optimum sitting and sizing of DG and other compensation devices in the distribution networks are the two most important factors to get maximum performance such as technical, economic and environmental to utility and consumer. The work concentrated on different DG technologies, available capacities merits and demerits. The author(s) compared different optimization technologies on analysis of optimal placement of DGs. According to the work, one of the widely used optimization technique is the GA, but it suffers from divergence and local optima. Another efficient technique used is Particle Swarm Optimization (PSO) because it is simple, less computerized. It is used for those mathematical models that are difficult but prone to local maxima and premature convergence. For integer variables, simulated annealing, evolutionary programmable search, particle search algorithm and out of colony can proffer best solution. Tabu search is an efficient technique to achieve either optimal or sub-optimal solution in a short duration.

Shasha et al. (2018) summarized a review of reliability analysis of distributed power access on distribution network using the characteristics of analytical solution and simulation method in reliability calculation of traditional distribution network. The work suggested that DG can proffer a great help to the network, but can also lead to a lot of problems if not well managed. Distribution power supply can be affected by the access location, capacity, order different types of access and the mode of operation of the distribution system. The analytic method of solution can analyze the failure probability of the network components, consequences of expectant failure event, establish a mathematical model of the system reliability and calculate reliability indices of load point and system, and it include network way and state space way. The theoretical basis of state space is Markov process, which mainly includes state enumeration method, state space truncation, minimum cut set state method etc. State enumeration method though generally applicable, cannot be used to solve practical problems. The simulation method generally refers to Monte carol simulation according to the work, which simulates the formulation of all the random processes of the system to predict the behaviour of the network for a long time.

Kaduru and Gondlala (2015) presented a work on distribution system reliability base on consumer scattering. The work suggested that since DGs installed close to consumers will proffer better efficiency, it will be proper to scatter customers and use different DG sizes base on their load demand to supply power. This will reduce complexities caused by installing the DGs into the grid network. The work was done on size location based on customers scattering pattern, which will also affect the optimal usage and efficiency of the DG. Each system consists of nine load points and the reliability indices considered are SAIFI, SAIDI, CAIDI, AENS. Conclusions were drawn that the customer scattering and restoration time affects the optimum placement of DG in terms of system reliability.

Jaser et al. (2019) gave a specified analytical approach for optimal planning of DG in electrical distribution networks considering majorly the power losses. The author(s) stated that power losses could be affected by the location, capacity and the power factor of the DG units. The network considered a new approach to reduce the power losses which was implemented in MATLAB software and analyzed on 12-bus, 33-bus and 69-bus IEEE distributed test system. The result shows that the new approach provides a simple and accurate solution and do not require exhaustive computations, and the voltage profile will improve when DGs are optimally connected to the distribution network.

Sachin et al. (2020) presented a work on the reliability assessment of wind-solar PV integrated distribution system using electrical loss minimization technique considering electric loss minimization (ELM). The loss minimization was aimed at minimizing the consequences of real and reactive power losses in the distribution network, the technique considered a collection of renewable energy source, network redesign and enlargement and planning. Location to accommodate DGs were investigated using single and multiple DG locations which was simulated using construction-based particle swarm optimization to improve reliability, battery effects were still included in the model. The result shows that reliability was optimally improved by using DGs. The objective functions considered are the active power loss which is given as:

$$\text{Min } AP_{loss} = \sum_{i=1}^{Nbus} \sum_{j=1}^{Nbus} C_{1ij}\left[P_{real\ i}P_{real\ j} + Q_{real\ i}Q_{real\ j}\right] + G_{ij}\left(Q_{real\ i}P_{real\ j} - P_{real\ i}Q_{real\ j}\right) \quad (2.10)$$

Where $P_{real\ i}P_{real\ j}$, $Q_{real\ i}Q_{real\ j}$ are the active and reactive power at i and j buses respectively and N bus i is the number of buses and nodes C_{ij} and G_{ij} . Also, the reactive power loss and the reliability indices expressed in the equation below as;

$$RP_{loss} = \sum_{i=1}^{Nbus} Q_{geni} - \sum_{i=1}^{Nbus} Q_{demi} \quad (2.11)$$

Reliability indices $C_f(X_p, RT)$ where Q_{geni} and Q_{demi} are the reactive generation and demand at ith bus Xp is the failure rate and RT is the repair time. Constraint considered are the equality and inequality constraint, power flow, DG capacity, bus voltage and branch current.

Abdulaziz (2012) evaluated reliability of distributed systems containing renewable DGs using Monte Carlo simulation algorithm. The network considered three DG sources; PV, wind turbine (WT) and gas turbine (GT). The supply was done using islanded micro grid operation. The power output from the PV can be expressed as:

$$P_{out} = \begin{cases} \frac{nc}{R} * S * I(t)^2 & 0 < 1(t) \le k \\ \eta C * S * I(t) & I(t) > k \end{cases} \quad (2.12)$$

When $\eta C$is the efficiency of the PV system while K is a threshold, and I(t) is the hourly solar isolation. The solar isolation can be affected by several factors such as cloud, temperature and relative humidity. The predicted PV output power can be seen as the summation of the actual output power and change in output power.

$$P_{PV} = P_{out} + \Delta P_{out} \quad (2.13)$$

The correlation between the output power and wind velocity can be expressed as:

$$f(x) = \begin{cases} 0 & 0 \le V_t \le V_{CT} \\ A + Bvt + CV_t{}^2 V_o \le V_t \le V_r & \\ P_r V_r \le V_t \le V_{co} & \\ 0 & V_c \ge V_{co} \end{cases} \quad (2.14)$$

Where

$$A = \frac{1}{(V_{ci} - V_r)^2}\left[V_{ci}(V_{ci} + V_r) - 4V_{ci}V_r\left(\frac{V_{ci} - V_r}{2v_r}\right)^3\right], \quad (2.15)$$

$$B = \frac{1}{(V_{ci} - V_r)^2}\left[4(V_{ci} + V_r)\left(\frac{V_{ci} + V_r}{2V_r}\right)^3 - (3V_{ci} + V_r)\right] \quad (2.16)$$

$$C = \frac{1}{(V_{ci} - V_r)^2}\left[2 - 4\,(4V_{ci} + V_r)^3\right] \quad (2.17)$$

And C are constants as a function of cut-in wind speed (V_{ci}) and rated wind speed (V_r). V_{CO} is the cut-out wind speed and P_r is the rated power output. The load point i can be predicted using equation (2.18);

$$P_i(t) = W_h(h) \times W_h(m) \times P_{Li} \quad (2.18)$$

Where $W_h(h)$ is the hourly weight factor, $W_m(m)$ is the monthly weight factor and P_{Li} is the peak load for load point i.

III. Methodology

- Load flow analysis using Newton Raphson method.
- Port Harcourt distribution network Power flow simulation using MATLAB version 7.9.
- Placing of DGs and evaluation of its impact

a) Voltage Profile Improvement Index (VPII)

DG installation usually results in enhanced voltage profile at different buses. The Voltage Profile Improvement Index determines the enhancement of voltage profile (VP) with DG. It is expressed as;

$$VPII = \frac{VP_{wDG}}{VP_{woDG}} \quad (3.45)$$

The following attributes are based on these expressions:

$VPII > 1$, DG is non advantageous,

$VPII = 1$, DG has no effect on the system voltage profile

$VPII < 1$, DG has upgraded the system voltage profile

Where VP_{wDG} and VP_{woDG} are the system voltage profile with and without DGs approximately. VP is generally expressed as:

$$VP = \sum_{i=1}^{N} V_i L_i W_i \quad \text{with} \quad \sum_{i=1}^{N} W_i = 1 \quad (3.46)$$

Where V_i is voltage magnitude at bus i in per unit, L_i is load described as complex bus power at bus i in per unit, W_i is weighting factor for bus i, and N is total number of buses in the distribution system. Weighting factors are selected based on the relevance of various loads.

As outlined, the formulation for VP gives a chance to express and aggregate the value, quantity and voltage levels in which loads are provided at different load buses of the system. This formulation is used after making sure that the voltages at all load buses are within permissible lowest and highest limits, commonly within 0.95p.u. and 1.05p.u. beginning with comparable weighting factors, thereby implementing changes. Acceptable voltage profile can be chosen after evaluating the simulation results which are continually done after each weighting factor modification. If all load buses are weighted equally, the value of W_i is given as shown below:

$$W_1 = W_2 \dots = W_n = \frac{1}{N} \quad (3.47)$$

In this instance, all the load buses are given equal value. DG can be mounted almost anyplace in the system in reality. Generally, highest amount of VPII implies the foremost position for the DG installation in terms of boosting voltage profile (Ajay et al, 2008; Ochoa et al, 2006).

b) Real and Reactive Power Loss Indices (ILP and ILQ)

Other leading performance offered by installation of DG is reducing the electrical line losses (Victor et al, 2006). Line currents can be decreased by installing DG, thereby reducing electrical line losses. The real and reactive power loss indices are given below:

$$ILP = \frac{[P_{LDG}]}{[P_L]} \quad (3.48)$$

$$ILQ = \frac{[Q_{LDG}]}{[Q_L]} \quad (3.49)$$

Where PL_{DG} and QL_{DG} are the total real and reactive power losses of the distribution system with DG while ILP and ILQ are the total real and reactive system losses without DG in the distribution system. In terms of reducing loss accumulated to DGs placement and sizes, the lower the amount, the better the benefits.

The following attributes are based on this definition:

$\mathrm{ILP} / \mathrm{ILQ} < 1,$ DG has decreased the electrical line losses

$\mathrm{ILP} / \mathrm{ILQ} = 1,$ DG has none effect on the line losses

$\mathrm{ILP} / \mathrm{ILQ} > 1,$ DG has increased electrical line losses

These indices can be used to determine the best placement to position the DG that maximizes electrical line loss decrease. Obviously, minimal amount of ILP and ILQ correlates to the best DG positioning assumption with respect to the electrical line loss decrease.

c) Excess Power Loss Index (EPLI)

This accounts for the excess power obtained through CPF, also known as loading factor (λ), loss as a result of fault leading to loss of DG. The percentage EPLI can be calculated as,

$$EPLI = \frac{(\lambda - EP_{wf})}{\lambda} \times 100 \quad (3.50)$$

Where EP_{wf} is the loadability when fault occurs. The implications of the index are,

EPLI < 100, DG Fault have reduced excess load,

EPLI = 100, DG Fault has no impact of excess load,

EPLI > 100, DG Fault have increased excess load.

EPLI > 0, DG Fault cannot permit extra load or system will collapse.

d) Research Algorithm and Flowchart

The algorithm below gives a detailed approach of the work as follows:

- Step 1: Enter the line data, bus data, and number of DGs
- Step 2: Run Power Flow (PF) and Continuation Power Flow (CPF) on the Network data
- Step 3: Run eigenvalue analysis to ascertain the weakest bus
- Step 4: Attach DGs to selected buses
- Step 5: Investigate network performance after adding DG
- Step 6: Introduce fault that could lead to loss of DG
- Step 7: Investigate network performance after DG loss and its reliability
- Step 8: From result suggest system maintenance priority

IV. Result

The study of power system stability and reliability using DGs in the Port Harcourt network is the focus of this research. PSAT MATLAB 7.9 was used to simulate the method, and the results of Eigenvalue analysis were used to identify the weakest buses before performing a power flow analysis and a CPF analysis to determine voltage breaches, loadability, and actual and reactive power losses. The thesis also included a stability analysis that took into account the lack of individual DGs in the network. VPII, ILP, ILP, and EPLI are the reliability indices considered.

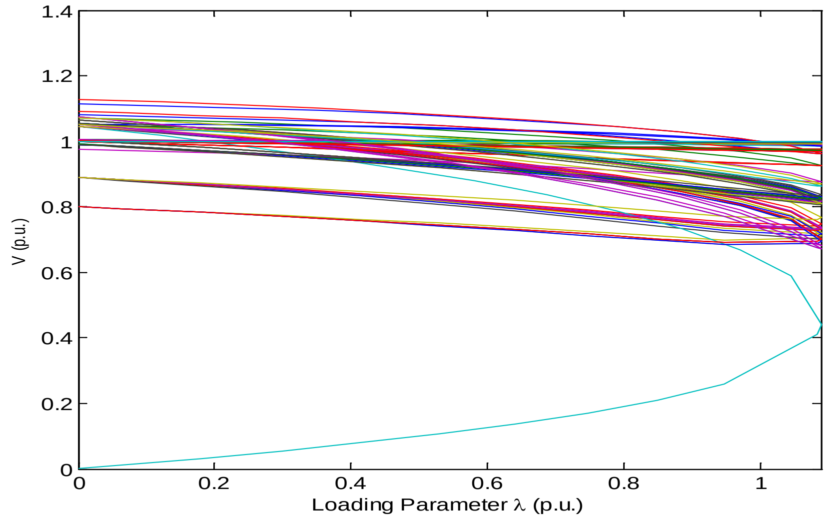

Figure 1: V-P curve for loss of DG at Bus 5

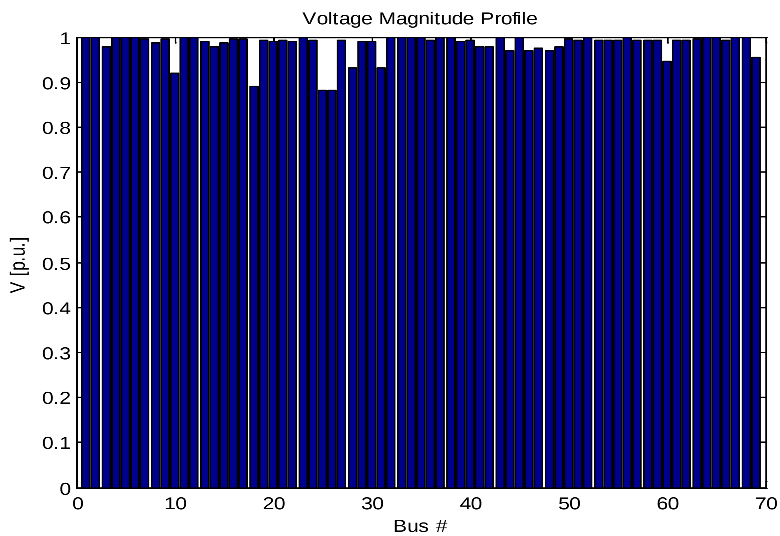

Figure 2: Voltage profile for loss of DG at Bus 6

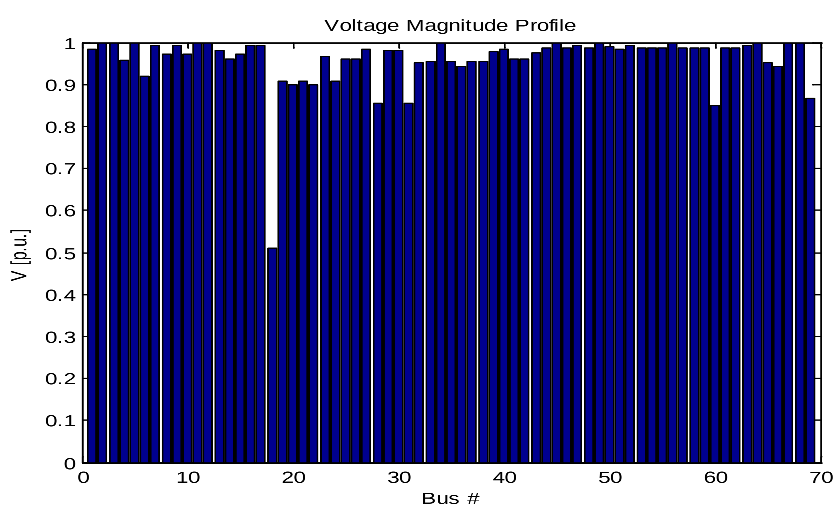

Figure 3: Voltage profile at collapse point for Bus 6

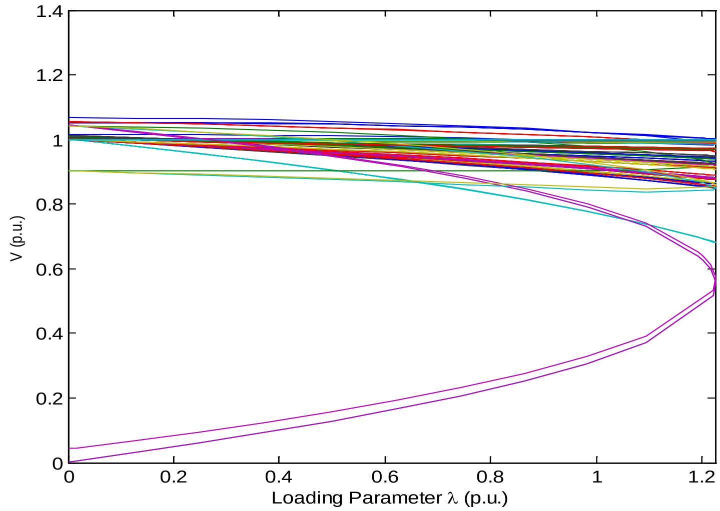

Figure 4: V-P curve for loss of DG at Bus 6

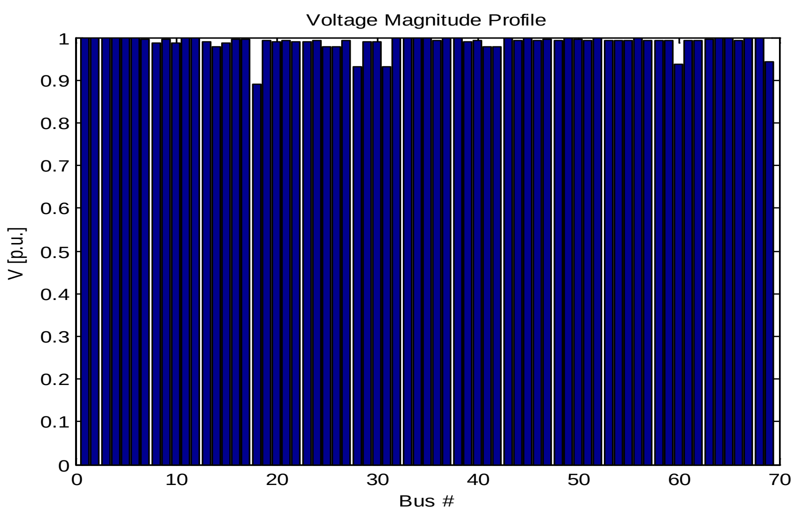

Figure 5: Voltage profile for loosing DG at Bus 7

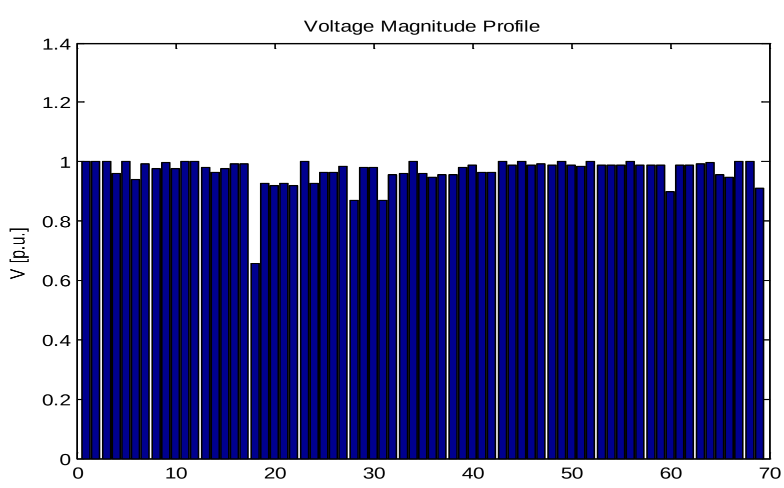

Figure 6: Voltage profile at collapse point for loss of DG at Bus 7

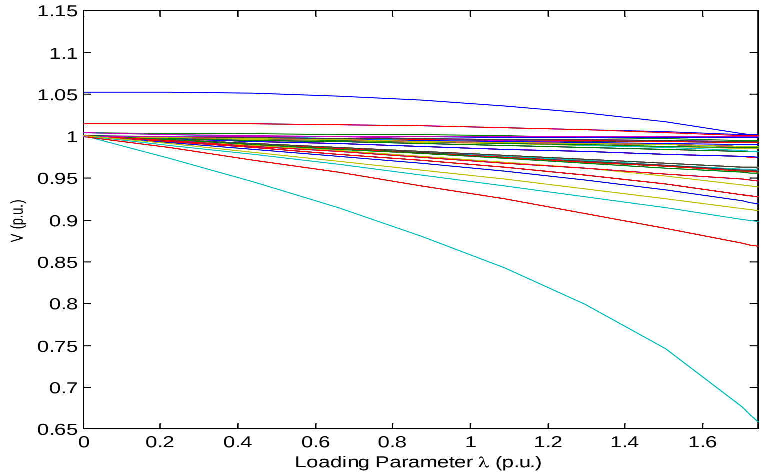

Figure 7: V-P curve for loss of DG at Bus 7

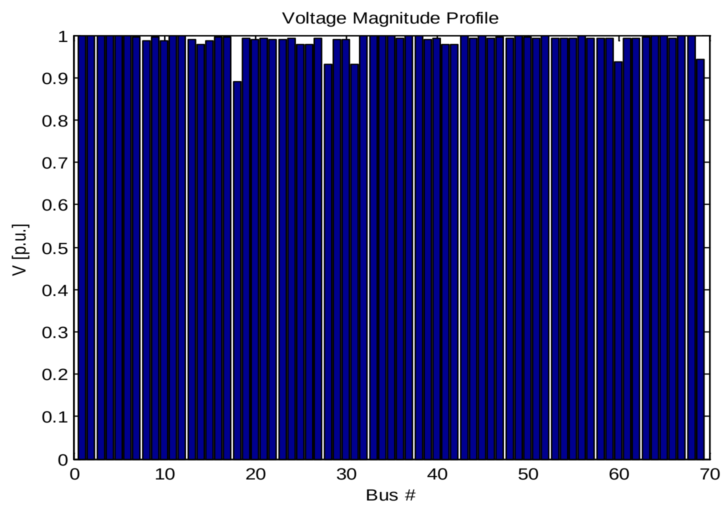

Figure 8: Voltage profile for loosing DG at Bus 65

Table 4.3: Power Flow and Continuation Power Flow Result Summary for Loss of a DG

	VV	RPL	RePL	Loadability	CVV	CRPL	CRePL
3	5	0.08235	0.8838	1.8968	8	0.11923	1.4295
5	7	0.10470	1.2561	1.0529	12	0.21241	1.9895
7	5	0.09345	0.9845	1.6756	7	0.12142	1.7204
65	4	0.08032	0.8212	1.9998	6	0.10998	1.2993
10	5	0.09148	1.0004	1.9024	8	0.13452	1.3675
11	9	0.15641	1.8758	-	-	-	-
12	10	0.12411	1.8672	-	-	-	-
13	7	0.11202	1.3564	0.9738	13	0.18529	2.2424
14	8	0.13680	1.3648	1.0003	13	0.20021	2.2876
6	6	0.09768	1.2425	1.2468	11	0.18162	1.7845
2	6	0.08868	1.1878	1.4241	10	0.19186	1.6261
19	8	0.11261	1.5987	0.7696	14	0.2529	2.3729
4	5	0.09263	0.8576	1.3752	8	0.14112	1.3241

Table 4.4: Reliability indices for loss of DG unit

	VPII	ILP	ILQ	EPLI	CVPII	CILP	CILQ
Normal	1	1	1	0	1	1	1
3	0.6000	0.8605	0.9014	8.80	0.6250	0.8968	0.8440
5	0.4256	0.6768	0.6342	49.37	0.4167	0.5034	0.6063
7	0.6000	0.7583	0.8089	19.43	0.7143	0.8807	0.7012
65	0.7500	0.8822	0.9701	3.85	0.8558	0.9723	0.9248
10	0.6000	0.7746	0.7963	8.53	0.6250	0.7949	0.8821
11	0.3333	0.4530	0.4247	100	0	0	0
12	0.3000	0.5709	0.4267	100	0	0	0
13	0.4286	0.6326	0.5873	53	0.3846	0.5771	0.5380
14	0.3750	0.5180	0.5837	51.90	0.3846	0.5341	0.5273
6	0.5000	0.7254	0.6412	40.05	0.4545	0.5888	0.6760
2	0.5000	0.7991	0.6707	31.53	0.5000	0.5573	0.7418
19	0.3750	0.6293	0.4983	67.00	0.3571	0.4228	0.5084
4	0.6000	0.7650	0.9289	33.88	0.6250	0.7577	0.9110

V. Discussion

Power flow analysis was conducted and indices calculated using the values of voltage violations, real and reactive power losses both for normal system and that at the collapse point and the maximum loading for the voltage violation as demonstrated in figures 4.6 - 4.37 and Table 4.3 and 4.4. The maximum violation was seen when DG is lost in Bus 11 and Bus 12 with the lowest indices of 0.3333 and 0.3000 respectively, there is no much significant impact when DG is lost in Bus 65 with a violation indices of 0.75. At the collapse point, the greatest impact is seen when DG is lost at Buses 19, 13, and 14 with voltage violation indices of 0.3571, 0.3846 and 0.3846 respectively. The best result was also seen when DG is lost in Bus 65 with voltage violation indices of 0.8558. No account for voltage violation for DG loss at Buses 11 and 12 since no additional load can be included to the network or a collapse will be encountered. Generally, much negative impact was not seen when DG is lost in Buses 65, 3 and 4, while worst impact was seen in Bus 12 (Rumuola feeder), Bus 11(Rumuodumaya), Bus 14 (T/Amadi) and Bus 19 (Onne feeder), while Bus 11(Rumuodumaya) and Bus 12 (Rumuola feeder) removed could lead to system collapse when considering voltage violation indices.

For real power indices, the worst case was seen in Bus 11 (Rumuodumaya) with the real power indices of 0.4530, while the best result was seen in loosing DG in Bus 65 (Agip base). For the continuation power flow to ascertain more load to be added to the network, the worst case was seen in bus 19 (Onne feeder) with real power indices of 0.4228, while the best was seen in removing DG in bus 65 with real power indices of 0.9723, though no result for bus 11 (Rumuodumaya) and bus 12 (Rumuola feeder) showing that a collapse will be encountered on the network when more load is added after losing the DGs attached to them.

Aside bus 11 (Rumuodumaya) and bus 12 (Rumuola FDR) which cannot accept more load or collapse, the worst case was seen in loss of DG at bus 19 (Onne FDR) also and the best was seen in removing DG at Bus 65 (Agip base) considering reactive power indices of 0.5084 and 0.9248 respectively. For normal system, the worst case was encountered at the removal of DG at Bus 11 (Rumuodumaya) with reactive power indices of 0.4247 and the best was seen at loss of DG at Bus 65 with reactive power index of 0.9701.

The percentage loading factor which accounts for percentage of loading parameter lost at the loss of a DG unit shows that all excess load is lost when DG is lost in bus 11 (Rumuodumaya) and bus 12 (Rumuola feeder). Smaller fraction of the excess load is lost when DG unit is lost in buses 65 (Agip base), bus 10 (T2A 24) and bus 3 (PH 24) with loadability indices of 3.85%, 8.53% and 8.80% respectively. Higher lost in excess power was also encountered in loosing DG unit in buses 19 (Onne FDR), bus 13 (Oyibo) and bus 14 (T/Amadi), with loadability lost percentage of 67%, 53% and 51.90% respectively, which is more than half of the excess load.

VI. Conclusion

This study considers the impact of DG installation in the Port Harcourt Network and what happens if a failure occurs, which could result in the loss of a DG device at every place where the DGs are located. According to the findings, DGs should be installed at Buses PH (Z2) (buses 2), PH (Z4) (bus 3), T2A (ZA) (bus 4), T3A (Z2) (bus 5), T1A (Z2) (bus 6), T1B (Z4) (bus 7), T2A (Z4) (bus 10), Rumuodumaya (bus 11), Rumuola FDR (bus 12), OYIGBO (bus 13), (bus 65). With reduced actual and reactive power losses, the system maintains reliability and can accept additional load with 5 voltage violations.

The possibility of missing a DG device was also investigated in order to see how stable the network would be if the DG went down. The results show that losing DG units at Buses 11 (Rumuodumaya) and 12 (Rumuola FDR) may have a significant impact on the network, raising the number of breaches, actual and reactive power losses, and overall excess load losses of 67 percent, 53 percent, and 51.9 percent, respectively. Apart from the impact on buses 11 (Rmuodumaya) and 12 (Onne FDR), bus 19 (Onne FDR) registered the worst case in terms of voltage violation at collapse stage (Rumuola feeder).

When DG was lost at bus 65 (Agip Base), which gave the best overall result, there was little impact. This demonstrates the importance of taking strict steps to protect the DG units on buses 11 (Rmuodumaya) and 12 (Rumuola feeder), as they decide the network's power to a large degree.

VII. Recommendation

After the study, the following recommendations could be proffered;

- Proper positioning of the DGs in Port Harcourt could aid in maximizing the power output and considering more load.
- Constant maintenance of the most affected area of DG lost could be of great relevance as it largely determines the state of the network.
- DGs could be considered as alternative for the weak power supply in Nigeria.

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Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- o Explain the value (significance) of the study.
- o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

Index

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