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Design and Fabrication of Vehicle with In-Wheel Motor

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Abstract- This dissertation is about improvement of mobility and off-road capability of state-of-art robot vehicles. The overall structure is based on tracker and wheel-type complex driving design in order to achieve the effects of ground proximity and vibration prevention during movement of robot vehicle, while the integration of tracker cantilever mechanism will enhance the off-road mobility leading to much broader range of applications in terms of task assignments. Common vehicles can only travel on common roads and slow slopes such that the scope of application has been rather limited. In this experiment we will design and develop one set of vehicle assist cantilever mechanism with high adaptability based on structural analysis with respect to the scenario of usage such that the developed vehicle can pass through rocky roads with enhanced mobility and expanded scope of investigation. Since the vehicles for military and police must not be too heavy, we select aluminum alloy as the material for such mechanism in order to achieve light weight and high mobility. This kind of tracked vehicle is bound to greatly broaden the scope of application of land-based mobile platform with market potential and mass production technology. Vehicle robot can be directly applied to various purposes such as military and national defense, handling of explosives, chemical and biological attaches, and assaults of fortified buildings. It also leads to applications in various environments of heavy mechanical and electrical industries such as high temperature, high pressure, gas leak, high radiation, and high voltage factory environments. Therefore, the purpose of this experiment is to development vehicle robots for service of mankind in response to environmental demands.

Keywords: vehicle robot, step-climbing mechanism, auxiliary cantilever, power transmission system.

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Design and Fabrication of Vehicle with In-Wheel Motor

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Abstract- This dissertation is about improvement of mobility and off-road capability of state-of-art robot vehicles. The overall structure is based on tracker and wheel-type complex driving design in order to achieve the effects of ground proximity and vibration prevention during movement of robot vehicle, while the integration of tracker cantilever mechanism will enhance the off-road mobility leading to much broader range of applications in terms of task assignments. Common vehicles can only travel on common roads and slow slopes such that the scope of application has been rather limited. In this experiment we will design and develop one set of vehicle assist cantilever mechanism with high adaptability based on structural analysis with respect to the scenario of usage such that the developed vehicle can pass through rocky roads with enhanced mobility and expanded scope of investigation. Since the vehicles for military and police must not be too heavy, we select aluminum alloy as the material for such mechanism in order to achieve light weight and high mobility. This kind of tracked vehicle is bound to greatly broaden the scope of application of land-based mobile platform with market potential and mass production technology. Vehicle robot can be directly applied to various purposes such as military and national defense, handling of explosives, chemical and biological attaches, and assaults of fortified buildings. It also leads to applications in various environments of heavy mechanical and electrical industries such as high temperature, high pressure, gas leak, high radiation, and high voltage factory environments. Therefore, the purpose of this experiment is to development vehicle robots for service of mankind in response to environmental demands.

Keywords: vehicle robot, step-climbing mechanism, auxiliary cantilever, power transmission system.

I. Introduction

In this dissertation we will improve the mobility and off-road performance of currently developed tracked robot vehicle. The overall structure is based on tracker and wheel-type complex driving design in order to achieve the effects of ground proximity and vibration prevention during movement of robot vehicle, while the integration of tracker cantilever mechanism will enhance the off-road mobility leading to much broader range of applications in terms of task assignments. The step-climbing auxiliary mechanism will be designed to improve the off-road performance and combat effectiveness. The major R&D directions include the designs of all kinds of front wheeled claw auxiliary mechanism, step-climbing mechanism, and functional mechanism (CG adjuster). There can also be customized designs with parameters adjustment mechanism in response to environmental variations and basic environmental sensing functions in addition to stability and fast-moving features. There must be enough power for the robot vehicle to take all kinds of actions to travel through tough terrain, pile of rubble, sands and weeds. On the contrary, the in-wheel motor can enhance the flexibility of vehicle while traveling on flat ground.

The application of robot is not limited to single environmental condition such as in urban or rough terrain. It has to effectively adapt to all kinds of severe combat environments and rapidly-changing battle field conditions in order to fulfill all its functions. The auxiliary front wheeled claw will be designed for robot vehicles. The analysis and design of robustness of the entire vehicle system will be generated by data collection and structural analysis/design in order to develop highly adaptive mechanical tank tracker. This kind of tracker is bound to greatly broaden the scope of application of mechanical tank with market potential and mass production technology. Highly adaptive mechanical tank can be immediately applied to various fields such as disaster site rescue, all kinds of robots, military and national defense, handling of explosives, and assault on fortified building.

II. Literature Review

The first thing first for design of tracked robot is to be fully aware of the state of the art. All kinds of design approaches proposed by predecessors will be used as the reference for consideration of the most appropriate design concepts and the application improvements. Based on the collected relevant literatures, the vehicle analysis can be classified by movement method and man structure.

a) Classification by movement method

First of all, there are two types of movement methods, tracked type and wheeled type:

i. *Wheeled type*

The characteristics of wheel-based movement approach are fast movement speed, good mute effect,

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simple structure, fast tire replacement, low operating cost, fewer parts, and better cruise capability. However, this kind of vehicle has worse off-road performance than tracked type vehicle resulting in reduced mobility or even the loss of mobility. From the perspective of step-climbing, the consideration will be based on how to improve the mechanism design of strategic wheeled type vehicle in order to travel through the obstacles with increased degree of freedom.

ii. *Tracked type*

This tracked type vehicle can be regarded as the miniaturized version of armored tracked vehicle. Most trackers are made of metals such that the noise issue is difficult to overcome. The majority of applications of such kind of vehicle are for highly dangerous area where through wireless remote control, the use of tracker can overcome most rocky terrains while carrying different weapons or camera equipments by demands. The advantages of such kind of vehicle are the strong surveillance capability and secrecy which leads to reduced casualties. However, the disadvantages of such kind of vehicle are inability to cross the trenches, noise generation, and inability to cross the obstacles with height more than twice of the wheel diameter.

b) Classification by main structure

There are three kinds of movement methods based on this classification: main structure tracked type, main structure tracked type with front auxiliary cantilever, and main structure tracked type with both front and rear auxiliary cantilevers.

i. *Main structure tracked type*

This type of vehicle can be regarded as the miniaturized version of armored tracked vehicle mainly used for areas which are either extremely dangerous or cannot be reached by human beings. Through wireless remote control, the use of tracker can overcome most rocky terrains while carrying different weapons or camera equipments by demands. The advantages of such kind of vehicle are portability, secrecy, and high mobility. However, the disadvantages of such kind of vehicle are inability to cross the trenches, noise generation, and inability to cross the obstacles with height more than twice of the wheel diameter.

ii. *Main structure tracked type with front auxiliary cantilever*

This kind of tracked vehicle is the improved version from the main structure tracked type. The additional auxiliary cantilever will enable this tracked vehicle to overcome obstacles with heights over twice of the wheel diameters. The most unique characteristic of this kind of tracked type vehicle is its step-climbing capability. This kind of tracked type vehicle has better effectiveness of surveillance in urban battle fields and misleading the enemies, while it can be used for post-disaster rescues and operations in collapsing buildings.

iii. *Main structure tracked type with both front and rear auxiliary cantilevers*

The auxiliary cantilever mechanism of this type of tracked vehicle is located on the front and rear of the main body such that it can achieve easy step-climbing from both sides, and it can also lift the vehicle to enhance the surveillance range with raised vision. Not only the obstacles can be easily crossed, the body length has also been increased and the vehicle has been effectively extended in order to accomplish the tasks of crossing the trenches and stairs without being too much affected by terrain constraints. However, the manufacturing cost has been increased due to the additional front and rear auxiliary cantilevers, while the degree of difficulty in operation has also been increased with less control of the overall weight.

III. Research Process Flow

As for the research process flow of this dissertation, the preliminary operations include confirmation of research purposes, analysis of existing vehicle structure, determination of vehicle type, and beginning of components and parts settings. After that, the mechanism type will be further designed and planned followed by the power analysis and structural analysis. The detailed description is as shown below:

- Proper definition of research purposes: understanding of research purposes and confirmation of design objectives in order to investigate current and future market demands for vehicles.
- Confirmation of mechanism type: the targeted vehicle will be the wheeled type vehicle with additional front and rear auxiliary cantilevers, while the relevant data will be discussed in order to understand the mechanism type of wheeled vehicles.
- Selection of components and parts: components and parts such as timing belt, brushless motor, all kinds of bearings, screws, and chains will be selected based on results of previous research.
- Mechanism design: the design will be based on the required functions of the robot with confirmed limitations, while the possible issues and technology bottleneck during robot manufacturing will be analyzed. Proper materials must be adopted for the design of main body framework and connecting bars in order to achieve the economic benefits. The optimal structural design and safety coefficients can be analyzed in response to the structural strength requirements of the robot. The determination of crucial dimensions will be based on the 3D graphics constructed by CAD-assisted design and Inventor 3D graphics software before they can be compared with the experimental statistics analysis.

- Mechanism assembly and actual test: the original outsourcing case will be confirmed and the designed machine will be assembled in order to test whether or not there is interference between all modular actions. All modules will then be assembled for overall test.

IV. Vehicle Mechanism Compositions

We plan to select wheeled type vehicle because of its high mobility and low noise functions in conjunction with front and rear auxiliary cantilever mechanisms such that this kind of mobile vehicle can travel in and out of designated task area without being limited by terrain variation thus leading to greatly enhanced work efficiency. The vehicle will not be limited to the height variation, where the auxiliary cantilever mechanism can be used to shift the center of gravity in order to climb over the short wall or to climb the slopes.

a) Mechanism design

Proper materials must be adopted for the design of main body framework and connecting bars in order to achieve the economic benefits. Proper materials must be adopted for the design of main body framework and connecting bars in order to achieve the economic benefits. The optimal structural design and safety coefficients can be analyzed in response to the structural strength requirements of the robot. The determination of crucial dimensions will be based on the 3D graphics constructed by CAD-assisted design and Inventor 3D graphics software before they can be compared with the experimental statistics analysis. For better efficiency, usually the manufacturing will be designed based on materials such as mid-carbon steel, aluminum alloy, carbon fiber, glass fiber, and plastics in order to complete the vehicle prototype. Due to the budget constraint and the purpose of reducing manufacturing cost, we plan to use CAD assisted design with Inventor 3D graphics software for construction 3D graphics and ANSYS software for analysis and simulation before the development of every new model in order to obtain more objective conclusion earlier and reduce the time spent on trial and error by R&D staff such that we can effectively achieve the optimal design of mechanical structure. Numerous researches in engineering industry have relied on experiences and large amount of experiments for efficiency enhancement and speedy conclusions.

The prototype of design in the place is as shown in the figure below, where tracked type auxiliary cantilever mechanisms have been installed on the front and rear of the vehicle. When this vehicle has been driven on steep slopes, roads with huge height differences, or step-climbing, its features of center of gravity shifting and auxiliary propulsion can immediately enhance the obstacle crossing capability of such robot vehicle. The active wheel of the wheeled type vehicle is located in the main body leading to high mobility and reduced body vibration during movement of robot vehicle. With the integration of suspension system, the main structural stability of the robot vehicle can be more effectively enhanced and more capable of absorbing extra vibration such that the damage to precision instruments carried by such vehicle due to vibration can be prevented as shown in Figure 4.1 and 4.2.

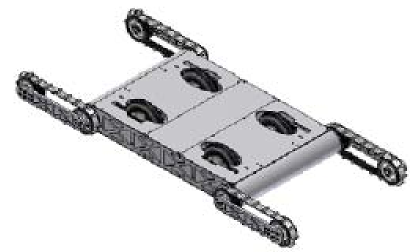

Figure 4.1 : Prototype design of vehicle with in-wheel motor

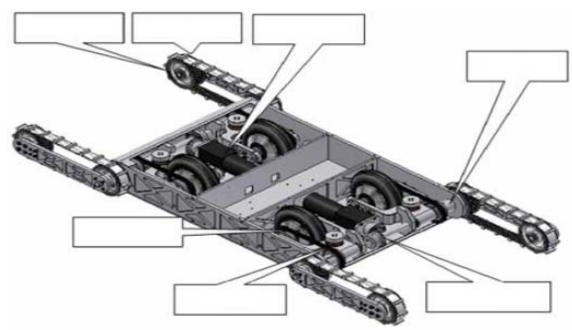

Figure 4.2 : Prototype design of vehicle with in-wheel motor (interior)

V. Analysis of Design Specifications based on Scenario of Use

The vehicles with front and rear auxiliary cantilevers can do more than crossing the short walls with ease. The integration of cantilever and tracker enables this vehicle to be feasible for all kinds of road conditions (even on muddy road). It can be difficult to enhance the speed of vehicle of flat road due to the slow movement speed of tracker. In order to avoid this issue, the vehicle will be designed to have retractable cantilevers to only allow the wheel to have contact with the ground such that the speedy crossing movement can be achieved. This approach will be less affected by terrain constraints such that this kind of cantilever design is the design focus of this dissertation. In this chapter we use the graphics software "Autodesk Inventor" to simulation various scenarios in accordance with actual 3D dimensions and corresponding to different terrains and obstacles such as "passing under obstacles", "crossing obstacles", "crossing trenches", and "step-climbing". Scenarios of different terrains will be analyzed, and the breakdown of actions of vehicle with in-wheel motor passing through different environments will be graphically simulated. The default environments are filled with obstacles such as small trenches, tree trunks, and short walls.

a) Flat ground movement mode

During the movement on flat ground, both the front and rear auxiliary cantilevers will be retracted to both sides of the active tracker in order to reduce the friction caused by front and rear auxiliary cantilevers during movement and thus leading to better mobility for turning and straight movement as shown in Figure 5.1.

Figure 5.1 : Flat ground movement mode

b) Obstacle crossing mode

When the unmanned vehicle is crossing the obstacle, the front auxiliary cantilever must be in contact with the edge of obstacle in order to lift the vehicle while the tracker is activated, and the terminals of front and rear cantilevers will be the propulsion for the vehicle. In the end the cantilevers will go around the obstacle and the vehicle body will be descended in order to quickly cross the obstacle as shown in Figure 5.2.

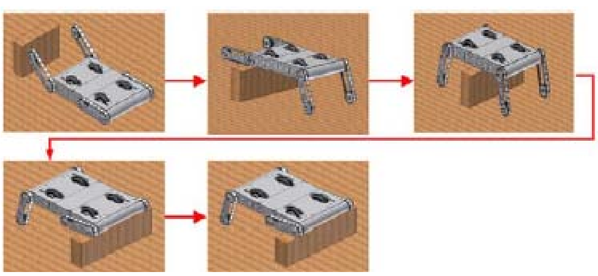

Figure 5.2 : The simulation of obstacle crossing scenario

c) Analysis and simulation of staircase obstacle

Under step-climbing mode, the front and rear auxiliary cantilevers must be kept level with the contact surface of the staircase to ensure the bulging edge of staircase is grabbed by the tracker block such that the vehicle body will not fall off due to large angle of staircase, and the step-climbing movement can be achieved as shown in Figure 5.3. The step-climbing actions of front and rear auxiliary cantilevers of the robot vehicle can be broken down into the following six steps:

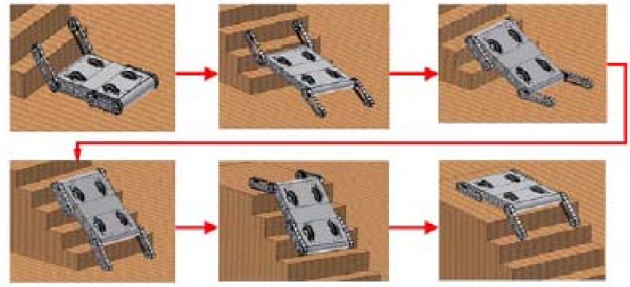

Figure 5.3 : Simulation of staircase obstacle scenario

d) Analysis and simulation of trench obstacle

The front and rear auxiliary cantilevers of the vehicle will be stretched out to be parallel to the active wheels such that the total length of the front and rear wheelbases can be as long as 1100mm. With the weight distribution ratio of the front and rear parts of the vehicle close to 50:50, this will allow the vehicle to effectively cross the trench with total length of 500mm as shown in Figure 5.4. The trench-crossing actions of front and rear auxiliary cantilevers of the robot vehicle can be broken down into the following six steps:

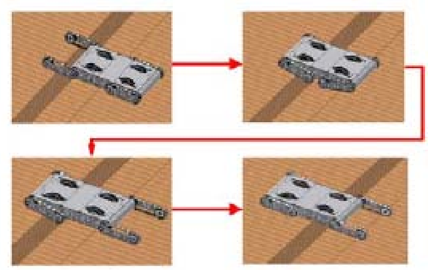

Figure 5.4 : Simulation of the trench obstacle scenario

VI. VEHICLE ANALYSIS

In this research we use ANSYS computer-aided analysis software to simulate the static analysis of main vehicle structure. The parameter settings of simplified model have been adopted for this research with the concept of simplification as described as: during the simplification process the parts can be categorized into main structural parts as the force-bearing parts and the general assembly parts (non-structural parts) as the non-force-bearing parts for the purpose of model simplification. Since this is mechanical analysis, the main structural parts will be used for structural gridding and boundary condition setting, while the stress value and displacement are observed for evaluation of material strength and structural damage.

a) Stress analysis of main framework structure

The aluminum alloy 6061-T6 is selected as the material for main framework structure with the maximum load capacity as 100Kg. The boundary conditions are: one side of main framework structure is fixed at the interior hole, while there is 100Kg evenly distributed on the surface of interior hole on the other side of main framework structure; Young's modulus of the aluminum alloy material is 70GPa, Poisson ratio is 0.3m and the density is 2700 kg/m3. Based on the analysis result, when the main framework structure is under downward force as shown in Figure 6.1, the overall deformation is 0.611 mm and the maximum displacement takes place at the edge of outer diameter. The result also indicates that the main structure has withstood 24.75MPa of stress as shown in Figure 6.2 with no structural damage. Stresses from all directions have all been within the yield strength of aluminum alloy 6061-T6 at 270MPa such that all the stresses are within the safety range.

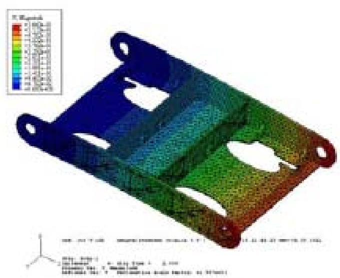

Figure 6.1 : The displacement of main structure vs. the load of 100kg

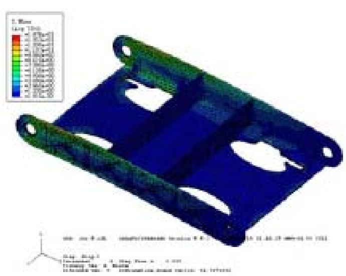

Figure 6.2 : The stress of main structure vs. the load of 100kg

b) *Stress analysis of auxiliary cantilever structure*

The aluminum alloy 6061-T6 is selected as the material for auxiliary cantilever structure with the maximum load capacity at the front end as 100Kg. The boundary conditions are: the large terminal of auxiliary cantilever structure is fixed at the interior hole, while there is 100Kg evenly distributed on the surface of interior hole on both sides of the front end of auxiliary cantilever; Young's modulus of the aluminum alloy material is 70GPa, Poisson ratio is 0.3m and the density is 2700 kg/m3. Based on the analysis result, when the main framework structure is under downward force as shown in Figure 6.3, the overall deformation is 0.881 mm and the maximum displacement takes place at the edges of both sides of auxiliary cantilevers. The result also indicates that the main structure has withstood 55.59 MPa of stress as shown in Figure 6.4 with no structural damage. Stresses from all directions have all been within the yield strength of aluminum alloy 6061-T6 at 270MPa such that all the stresses on auxiliary cantilever structure are within the safety range.

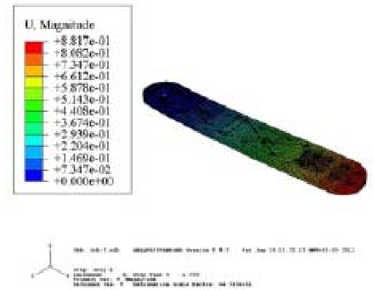

Figure 6.3 : The displacement of auxiliary cantilever structure vs. the load of 100kg

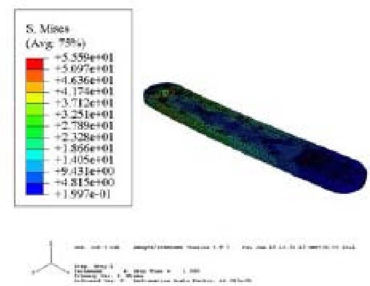

Figure 6.4 : The stress of auxiliary cantilever structure vs. the load of 100kg

c) *Stress analysis of in-wheel motor cantilever structure*

The aluminum alloy 6061-T6 is selected as the material for in-wheel motor cantilever structure with the maximum load capacity single-side in-wheel motor cantilever structure as 100Kg. The boundary conditions are: the in-wheel motor cantilever structure is fixed at the lower hole, while there is 100Kg evenly distributed on the surface of upper hole of in-wheel motor cantilever structure. Young's modulus of the aluminum alloy material is 70GPa, Poisson ratio is 0.3m and the density is 2700 kg/m3. Based on the analysis result, when the in-wheel motor cantilever structure is under downward force as shown in Figure 6.5, the overall deformation is 0.243 mm and the maximum displacement takes place at the edges of outer diameter. The result also indicates that the main structure has withstood 21.62 MPa of stress as shown in Figure 6.6 with no structural damage. Stresses from all directions have all been within the yield strength of aluminum alloy 6061-T6 at 270MPa such that all the stresses on active gear structure are within the safety range.

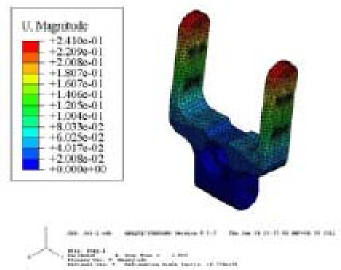

Figure 6.5 : The displacement of anti-vibration cantilever structure vs. the load of 100kg

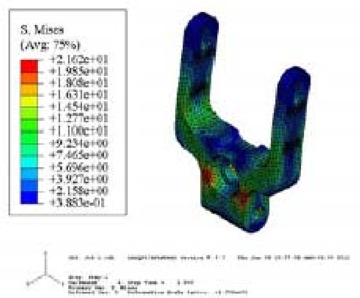

Figure 6.6 : The stress of anti-vibration cantilever structure vs. the load of 100kg

d) Vehicle model analysis

Modal analysis has been conducted with respect to main structure, auxiliary cantilever, and in-wheel motor cantilever structure in order to obtain the first ten natural frequencies and their corresponding modal shapes. The material density, Young's modulus, and Poisson's ratio will be imported first for modal analysis. In this article the boundary conditions are: the main structure is fixed at the shaft holes on both sides, the auxiliary cantilever structure is fixed at the main shaft hole, and the in-wheel motor cantilever structure is fixed at the rotary hole. Any oscillation took place among main structure, auxiliary cantilever structure and in-wheel cantilever structure during operation could lead to unexpected structural damage.

e) Results of vehicle dynamic analysis

The dynamic analysis will be set up right after the modal analysis with respect to main structure, auxiliary cantilever structure, and in-wheel motor cantilever. As for the boundary conditions, we set upward force at 490N, time of continuous load at 0.2 second, and then we observe the amplitude of variation of force application point with respect to time interval (1.5 seconds), where the analysis time for vibration attenuation process in within 1.5 seconds time frame. With the additional smooth parameter set at 0.25, the dynamic analysis can be calculated. Since there could be instant load generated when the vehicle is running on all kinds of terrains, the structural robustness of main structure, auxiliary cantilever and in-wheel motor cantilever structure can be observed by this analysis to see if the requirements of safety coefficients have been met.

From Figure 6.7 and 6.8 we find that the maximum instantaneous stress at the location of main structure element 43054 with 1.5 second interval is around 48MPa. Under this circumstance, since the yield strength of aluminum alloy material (6061-T6) is around 270MPa, the safety coefficient is set to be twice of this value such that in the 1.5 second interval the maximum stress is less than the yield strength of aluminum alloy material. Thus we conclude that the main structure should be safe. By observing Figure 6.9 and 6.10, the maximum instantaneous stress within 1.5 second interval at the location of auxiliary cantilever structure element 4965 is around 80MPa, such that the maximum stress is less than yield strength and meeting the safety coefficient. By observing Figure 6.11 and 6.12, the maximum instantaneous stress within 1.5 second interval at the location of in-wheel motor cantilever structure element 31262 is around 30MPa, such that the maximum stress is less than yield strength and meeting the safety coefficient. Therefore we conclude that there should be not safety concern for the main structure.

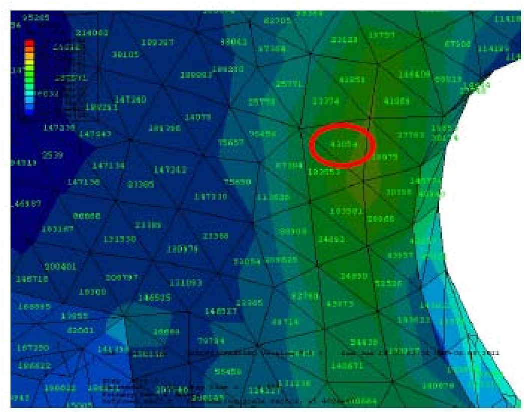

Figure 6.7 : The stress distribution at the location of main structure element 43054

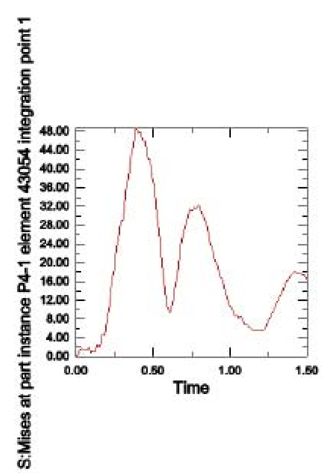

Figure 6.8 : The stress variation curve within 1.5 second interval at the location of main structure element 43054

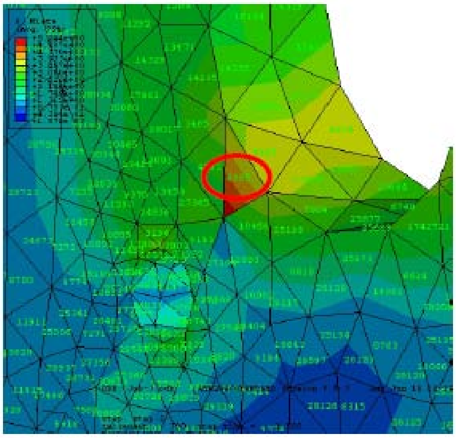

Figure 6.9 : The stress distribution at the location of auxiliary cantilever structure element 4965

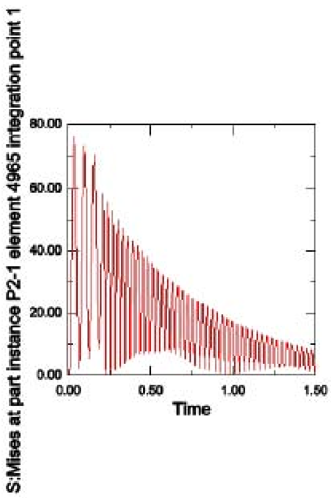

Figure 6.10 : The stress variation curve within 1.5 second interval at the location of auxiliary cantilever structure element 4965

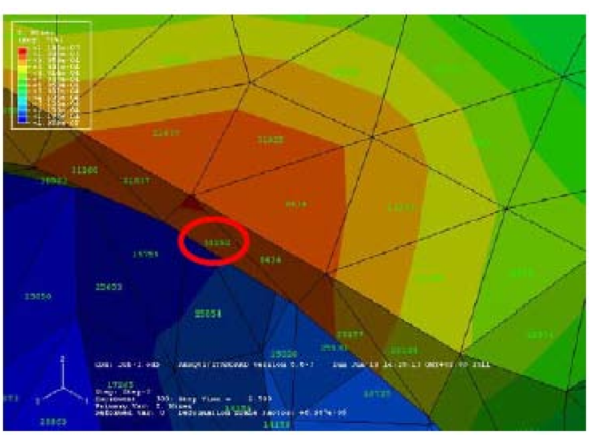

Figure 6.11 : The stress distribution at the location of in-wheel cantilever structure element 31262

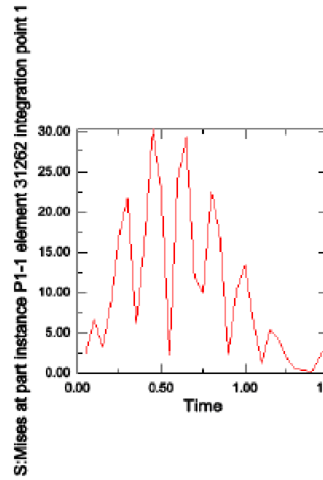

Figure 6.12 : The stress variation curve within 1.5 second interval at the location of in-wheel cantilever structure element 31262

VII. Conclusions

This research is in coordination with the technology development program of Chung-Shan Institute of Science and Technology-“Researches on design practice and power of robot vehicle”. Therefore, we first conduct finite element analysis and simulation with respect to auxiliary cantilever structure, main structure, anti-vibration cantilever, transmission gear, and wheel shaft structure, and we investigate the effects of different loads on the structure. Autodesk Inventor software is used to establish the geometric model of vehicle. In the end, the stress strain statistics is calculated by finite element software simulation, and the conclusions of experimental analysis are described below:

- In this dissertation we successfully develop the vehicle with in-wheel motor which has been proven by all kinds of obstacle experiments to achieve specific targets such as moving speed at 4m/sec, climbing of 45-degree staircase, and crossing 50-cm trench. This is the evidence that our country has owned 100% of self-development R&D technology of this self-made multi-function vehicle.
- This vehicle is based on remote control such that the scope of application can be greatly enhanced to all kinds of terrains such as staircase. This vehicle has superior mobility such that it can still be driven even if it has been rolled over. It can carry various equipments such as weapon, camera, and mechanical arms with enhanced scope of application, market potentials, and mass production feasibility. The wireless vehicle can be directly applied to various purposes such as military and national defense, handling of explosives, biological and chemical attacks, assault on fortified buildings,

factories of heavy mechanical and electrical industries, and high temperature/high pressure/gas leak/high radiation/high voltage environments which are not suitable for human operation.

- The developments of robot vehicles in US, Japan, and Germany have been leading the world, but they are also more expensive. In addition to the R&D cost, the intelligent disaster handling robot developed by our country also requires high costs of talent cultivations and regular robot maintenance and services. However, the vehicle developed in this research is based on 100% customized design and 100% self-developed technology with cost of around $10000 USD. All components are products based on domestic specifications with easy access.

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