

Passive Sensing Jaw for Grasping and Orienting

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Abstract

The goal of this work is to present an innovative design for a smart robotic gripper, which is able to grasp different randomly deployed prismatic and cylindrical packages and orient them through a mechanically passive alignment system with sensing capability. It consists in a new concept of end-effector combined with an ad-hoc path planning for aligning residual worst cases. The system uses gravity and an angular sensor embedded into the gripper to detect the object orientation and, if necessary, formulate a control strategy to align it before the release phase. An initial screening experiment was executed to find the parameters that most influence the alignment angle and execution time. Two worst-case packages were tested in different working conditions. The results show that the percentage of success of the system is high even in the worst operating conditions.

Index terms—

1 I. Introduction

Picking, aligning, and placing objects of different shapes and sizes is a very common task in the automation industry. The most commonly used interfaces for picking involve vacuum force obtained via suction cups and sponges or mechanical friction provided by soft and rigid jaws [1], which have the higher capability to grip objects of different shapes, volumes, and masses without changing the jaw shapes. The jaws can be designed in different configurations and actuated either by pneumatic systems, which are noisy and expensive as they require a vacuum line, or by mechanical systems.

Parallel configuration is the most commonly used for picking objects of standard geometries, since higher dexterity configurations require a complex and expensive adaptive control strategy. One example of high dexterity configuration is the dexterous hand presented in [2], [3] and [4]. Examples of the complexity of the control strategy for this kind of solutions are reported in [5] for rolling approach, in [6] for sliding approach and [7] for gaiting approach. The choice of using a parallel gripper is justified in the manufacturing field by Bracken [8], who proposed a geometrical classification of parts to be gripped into six shape categories (i.e., spherical, rectangular, cylindrical, triangular, holed and flexible) and stated that the gripper able to deal with most shapes is the parallel two-jaw gripper.

Assuming that a robotic system is composed of a robot and a mechanical parallel gripper, it is possible to solve the alignment problem with two strategies: using a high degree of freedom manipulator equipped with a gripper that has no alignment capability or performing the alignment by using the gripper rather than robot kinematics. Holladay et al. [9] demonstrated that the task can be solved in a shorter time and with a smaller work space using the second approach.

The orientation problem using only the gripper can be solved in several ways, but the most commonly used is pivoting [10]. It consists in closing the gripper jaws in such a way that the object can rotate around the axis passing through the contact points. Rao et al. [11] demonstrated the effectiveness of this orienting technique by making four degree of freedom robot to move a polyhedral part in space (along all the object's degrees of

45 freedom). This approach takes advantage of gravity to complete the alignment so that the alignment system can
46 be defined as passive. It also introduces a constraint on the gripping distance from the object's center of mass.
47 Making the realignment system to be active allows to get rid of this constraint and to control the alignment
48 angle, but the introduction of additional hardware decreases reliability while increasing costs.

49 In this paper, we propose and validate a new design with a passive realignment system to be integrated into
50 parallel mechanical grippers. In addition, in pick and place operations it can be necessary to choose if the object
51 has to be realigned or not, a problem that is addressed using a passive mechanical system integrating an angular
52 sensor monitoring in real-time the inclination of the object and synthesising an appropriate control strategy based
53 on planned actions.

54 2 II. Related Works

55 An example of a passive system is given by [12], where each jaw has a vertical V-groove cavity with a small hard
56 contact point attached to an elastic strip that orthogonally crosses the groove. When the gripping force is low,
57 the rotation is obtained by pivoting the object around the axis created by hard contact points that are free to
58 rotate. When the force increases, the strip goes into the groove, thus constraining the object. The interesting
59 feature is that the type of contact between the object and the jaw is a function of the gripping force. Although not
60 suitable for cubic objects, this solution can be retrofitted to different parallel jaws. Another possible detrimental
61 effect is that the point-like contact may damage the object surface, which is also subject to wear, and requires
62 high accuracy in sensing the object to grasp and in planning for the proper gripping point. Additionally, the
63 proper gripping force is another feature to be defined, which requires precise knowledge of the gripper-object
64 friction coefficient.

65 Two other interesting examples are available in the literature, both based on pneumatic actuation. The one
66 presented in [13] solves the problem of the correct gripping force choice by introducing an active rubber diaphragm
67 between the jaw body and the fingertip. A bearing allows the fingertip to freely rotate when the diaphragm is not
68 inflated, then the inflation allows it to stop quickly at a given angle. This design has the advantages of being fast
69 and independent on the object geometry and grasping force. Additionally, it is equipped with a rotary magnetic
70 encoder that allows for feedback control. The main limitation is the need for a pneumatic system.

71 The other solution presented in [14] uses an inflatable membrane to change the shape of the contact interface:
72 when the pressure is high, the fingers have a prismatic shape and contact is restricted to a small area (ideally two
73 points); when the pressure is low, the shape smoothly becomes a V-groove cavity, where cylindrical objects are
74 held. The advantage of this design is that it is independent of the object geometry although it is only suitable
75 to align cylindrical shapes and, again, it needs to be actuated by a pneumatic system.

76 The solution here presented is purely mechanical and passive, and integrates a sensing system. It can work with
77 a wide range of object shapes while avoiding the use of a pneumatic system. It allows for a simpler, more reliable,
78 and more cost-effective jaw design. The encoder also performs quick fault diagnosis, increasing robustness.

79 3 III. The Passive-Sensing Jaws

80 The jaws of the parallel gripper were designed with an innovative passive auto-alignment capability.

81 Each of the two jaws has a different design and accomplishes different functions in the alignment operation.
82 The one in Fig. 1 only works as a pivot to align the object, the other in Fig. ?? has three additional features: 1.
83 a v-groove cavity; 2. a counterweight at an offset to the rotation axis; 3. a rotation sensor. The v-shape, provided
84 with an elastic film, is made to better secure cylindrical objects, the surrounding planar surface is instead used
85 to improve contact with prismatic pack (E-F) releasing with the counterweight and v-shaped cavity moving
86 parallel to the ground ping the magnetic strip on a 32 mm diameter cylinder becomes 1.15° , maximum speed
87 is 16 m s^{-1} (100 rad s^{-1}). The encoder is equipped with the external LIKA IF40 converter that performs
88 interpolation and provides digital output. The angle sensor is added also with the purpose of making the system
89 able to detect faults and misalignment. It enables the robot controller to move the end-effector so that the object
90 can be aligned in the best possible way, in terms of time and final angle with respect to the vertical direction,
91 before releasing the package. In case of fault the system could drop the object and run again an alignment
92 process.

93 4 IV. Experimental Analysis on Pharmaceutical Packaging

94 The application fields of the developed system are many. In this work it has been tested for the alignment
95 of packages for pharmaceutical use. In particular, their shape can be both prismatic and cylindrical with the
96 geometric requirements of Fig. ?. As shown in Fig. ?, the average percentage (AVG) of cylindrical packages
97 out of the overall worldwide packages depends on the country. Their weight is less than 800 g.

98 The packages has to be placed in a position of maximum-stability: the cylindrical have to be placed in vertical
99 position; the prismatic maximizing the contact surface.

100 5 V. System Design

101 This section describes the important features of the hardware components and the developed software used for
102 statistical experiments. a) Hardware Components Fig. ?? shows the components used for testing.

103 6 Robot:

104 The robot is the HS-4345 4-axis SCARA robot designed by Denso robotics. It has four links connected with
105 three revolute and one prismatic joints.

106 7 Controller:

107 The RC8 controller is the interface between the robot and the PC. From a software point-of-view, the ORiN
108 middleware is used to build the client application to communicate with the controller. In this work the coded
109 client application requests a service sending a packet over TCP stream using b-CAP communication protocol.
110 Server assigns commands and responds to the client to confirm the service execution is completed.

111 Laser: Keyence LK-G157 laser displacement was used to set the position of the object's center of mass with
112 respect to the object's main axis. The repeatability of the instrument is 0.5 μm . Parallel gripper: The Shunk
113 WSG 50 parallel gripper is used to actuate prototype jaws. It is equipped with force and position sensors and
114 controlled sending commands via TCP/IP protocol.

115 8 b) Software Description

116 A state machine was designed to control the whole alignment process, whose main states, summarised in Fig. 7,
117 are:

118 Idle: In Idle state the system is waiting to receive the object information about its shape, dimensions, mass,
119 position and orientation, and if it has to be placed in maximum stability condition or only its location has to
120 be changed. For the test application presented in this paper, all these information in were provided manually as
121 input, while, in actual operative conditions, a dedicated vision system connected to a database will be used.

122 Positioning: In positioning state, the robot moves to the gripping point specified with a final end-effector
123 position in the operational space and following an optimal planned path.

124 Gripping: Here the gripper grabs the object and uses its force sensors to detect the presence of the object: in
125 case the object is lost, an error is returned and the system goes back to Idle state.

126 Lifting: The robot lifts the object and, depending on the gripping point, the object will be aligned or
127 not. The height at which the object is lifted depends on object dimension and on the gripping point. When
128 package alignment is needed, the lifting and pivoting phases show a dumped second order dynamic with different
129 characteristics for different medicine packages, as shown by the encoder signals time evolution in Fig. ?? obtained
130 with a sampling frequency of 100 Hz.

131 9 Robot Moving:

132 The robot moves the object to the release point. During this phase the gripper, with its alignment axis, must
133 always be orthogonal to the tangent of the trajectory. The direction of the robot's motion is selected such that
134 the inertial force caused by the robot's acceleration adds an alignment torque to the package (i.e. it pushes the
135 object to the mechanical stroke limit). In this way, if the object is already at the end of its stroke, the lateral
136 acceleration acts on a constrained degree of freedom and does not affect the final angle. Object Release: This
137 final phase is crucial for the success of the orientation process and only depends on the final angle at the end
138 of the motion phase. Fig. ?? shows the geometric condition for correctly releasing the cylinder in its stable
139 configuration (cone stability).

140 The critical value of θ_c , θ_{cr} , is found making the ratio between the position of the object center of mass (CM)
141 and the object diameter at the bottom surface.

142 Perception Loop: In the Perception loop the smart end effector perceives and combines information such as
143 the current gripper position P_0 , the final desired one P_p , the current object angle (θ_t), the gripping distance
144 (h) w.r.t. the center of mass (CM), the object diameter (D) and its height (H), to plan the trajectory. Those
145 information are used to realign the package using a reference alignment vertical plate if the object needs to be
146 further aligned before release.

147 In particular, by the perceived information, the robot moves the gripper to the plate at a distance based
148 on the radius of the cylindrical envelope of the package increased by a safety factor (d_f). A parametric arc
149 movement forces the gripper to be parallel to the vertical plate, Fig. 10. The path chosen in this way guarantees
150 the packages to be tangential to the wall at the final point P_p .

151 In this phase, the value of the object inclination (θ_t) is constantly checked along the planned gripper
152 trajectory to determine when the object can be correctly released.

153 In Fig. 11 it is shown the sampled signal (100 Hz sampling frequency) of the rotary sensor during a full In
154 particular, at 3.5 s the object is gripped and lifted, reaching a final angle of approximately 40° . The robot forward
155 acceleration makes the angle to stabilize around 55° at 5.5s, but this is not sufficient for having a successful release
156 because the critical angle for this particular package equals 68° .

157 As a consequence, the robot moves towards the vertical plate, that makes the final angle to be around 90
158 degrees allowing a safe release.

159 The code to manage the finite state machine for picking, positioning, aligning and releasing operations is written
160 in C language on Microsoft Windows operating system. A multi-thread application was coded to simultaneously
161 control the SCARA robot, the gripper and read the angle value, Fig. 12.

10 VI. Design of the Experiments

In this section we carry out a statistical analysis to validate the system design and present the obtained results. The design validation should verify the following hypothesis: system is able to pick up, perform pivoting and aligning of packages of different shapes and weights, in a reduced amount of time and with a low error percentage.

A first factorial screening experiment is performed in order to identify factors that have stronger influence on the pivoting capability. The response surface is then obtained and used to find the factors combination that leads to the worst final angle and the largest settling time.

In other terms, this first experiment allows to obtain the worst operating condition for pivoting success. In this condition the complete pick align-place operation is performed to check the robustness of the system with real drug packages. In this final study, the effectiveness of the system is assessed through the percentage of successfully completed alignment operations.

All the statistical analysis was performed in RStudio, an integrated development environment for R programming language. The factorial experiment is the most efficient type of experiment for screening. After obtaining the factors significance, the objective is to obtain the response surface. The factorial design is augmented with several observations at the center to fit a model linear in all factors but one, which is quadratic. If the ANOVA shows that the quadratic term is significative, then we need to augment the factorial plan to a 3 n Central Composite Design, if not, a linear 2 n model is a reliable approximation. Blocking is used to perform sequential experimentation and augment the factorial design only if the second-order model is needed [15].

The choice of factors levels comes from prior and actual knowledge of the process and is made to fit the real operating conditions of the process when performing the central composite design. The design factors chosen for the factorial experiment with their low (L), center (C) and high (H) levels are reported below. Assuming that the gripper always makes the pivoting axis orthogonal to the cylinders longitudinal axis, the only gripper degree of freedom that is varied is the position along grip ping axis, all the others are held constant. Also the vertical distance of the grip from the plane is assumed fixed because, even if there is an error in estimating the diameter of the object, the V shape helps to center the grip.

When gripping an object, the gripping force rises from zero to its nominal value with a dynamics that depends on equivalent stiffness and damping at gripping interface. Here the transient is considered negligible and the force is assumed to ideally go from zero to its nominal value before gripping starts.

Mass, volume, inertia moment, diameter, height and gripping distance are not independent factors, so it is not possible to design an experiment taking all of them as factors.

Volume V , inertia moment, gripping distance d and material type are substituted with two factors: the relative distance of gripping point from the geometrical center of mass (A) and the relative distance of the center of mass of the inner material from the geometrical center of mass of the container (D). This is non zero when the material is non-homogeneous, while it is zero otherwise. For non-homogeneous materials, we refer to the unconstrained material contained within the package, e.g., pills or powders. On the other hand, for homogeneous material we refer to uniformly constrained materials such as fully filled liquid jars or thick creams.

The response variables of particular interest to characterize the alignment process are the final angle and the settling time. The first quantifies the alignment in steady state condition, when oscillations are completely damped, the second instead takes into account the alignment dynamics.

To satisfy the statistical requirements of the independence of observations, the matrix for the final design was generated randomizing the experiment order. A set of different 3D printed cylindrical objects is used to create all combinations of geometrical factors, shown in Fig. 14. They are filled with materials of different densities in order to obtain the same mass value. In Fig. 14, the orange and the black objects are filled with homogeneous and non-homogeneous material, respectively. In the latter case, the ratio between the position of the material center of mass w.r.t. the cylinder and the cylinder height is constant.

11 i. Results

The analysis of variance is performed on the factorial design added with central points. The fitted model for angle response variable is $\text{Angle} = A * B * C * D * E * F * G + A^2$, the one for time variable is $\text{Time} = A * B * C * D * E * F * G + A^2$.

The F values and p -values of the factors are reported in Tab. 1 and Tab. 2. The quadratic term is added to check if the 2 n factorial plan has to be augmented to a 3 n Central Composite Design. The high p -value of the quadratic term in both models proves that the linear model is sufficient to describe the system behaviour.

The analysis of variance response surfaces are then obtained fitting a first order model to the factorial data added to central points. Finally, the steepest descent path is determined to obtain the combination of factors that led to the worst condition for final angle and aligning time. A visual interpretation is given here reporting the values of factors when moving down the steepest descent path at 0.5 distance from the center point and at the factors high level (distance 1 from the center point). Results are reported in Tab. These results are in accordance with the physics of the problem. The system can be modeled as a damped physical pendulum with additional energy loss caused by the bump against the stop screw. The amount of energy dissipated during the bump depends on the restitution factor. For what concerns the final angle, its value depends on the final balance between the torque of the gravity force that acts on the package center of mass and the unbalancing mass one. A short gripping distance implies a short lever arm for the gravity torque, resulting in a lower angle value. The

224 unconstrained material moves to the bottom of the Analyzing the time variable, the high gripping distance con
225 tribute to have a larger torque, while the non-constrained material adds an aligning torque to the system when
226 the package starts to rotate. The large diameter and large height makes the inertia moment, and consequently
227 the kinetic energy, to be higher. The kinetic energy is also increased by the large vertical acceleration. Since
228 a larger kinetic energy implies to have more bumps and a longer transient, the final aligning time results to be
229 longer.

230 The time needed for the entire aligning operation depends on several factors, one of the most relevant being
231 the package initial and final position and orientation. Moreover, the aligning angle and time are highly depending
232 on the robot lateral dynamics. By assuming that the robot will be operated to minimize the time of the process,
233 next experiments to validate the gripper in the whole robotic system are performed fixing only the geometric
234 conditions at their worst for the aligning angle: The worst-case drug package characteristics found for pivoting
235 in Section 5.1 are not the same as those for the re lease operation. The latter case is influenced only by pure
236 geometric considerations from the values of the position of the center of mass and the diameter of the object at
237 the bottom surface as seen in section 4.1. In contrast with the diameter, the position of the center of mass is
238 affected by uncertainty, especially if the material contained in the package is not homogeneous. We can assume
239 that the center of mass in the geometric center of gravity is a good approximation and conservative. In fact, even
240 though pharmaceutical packages contain heterogeneous material, due to the effect of gravity during rotations,
241 the inside material would go to the lower part and this would lower the center of mass increasing the critical
242 angle for stability. To have a small height and small diameter implies a lower critical angle, so another package
243 of drugs was selected to take into account the worst case for release, which is reported in Fig. 15(b).

244 In order to provide a complete analysis of the system, two test campaigns were carried out to validate the
245 robustness of final design on both worst cases with packages of Fig. 15. The centres of mass of both packages
246 correspond to the geometric centres due to the homogeneity of the material contained inside.

247 In order to take into account the most critical source of uncertainty related to the identification of the object
248 position and therefore its center of mass estimation, both the previously defined drug packages are tested randomly
249 varying the gripping point between 10% and 90% of their half eighth (Fig. 16). In both cases, 200 gripping
250 positions are generated from a uniform distribution, and the releasing success is tested for both packages after
251 pivoting only and also with the robot moving on a trajectory.

252 12 i. Results

253 The results of these experiments are presented in Tab. 5 and Tab. 6. All the incorrect alignments occurs when
254 the gripping distance is near 10%.

255 13 VII. Conclusion

256 In this paper, we have presented an innovative design for a smart robotic gripper able to grasp objects of
257 cylindrical and prismatic shapes and then orient them through a mechanically passive alignment system. The
258 gripper is endowed with sensors to detect object misalignment and, if necessary, uses an external vertical plate
259 for re-orientation. The statistical performance analysis shows that the worst condition for the pivoting operation
260 is represented by small height, large diameter packages filled with homogeneous material. Moreover, geometrical
261 considerations on object stability are made to find the worst packages characteristics for release success: small
262 height, small diameter, filled with homogeneous material. Two commercial packages representing the two worst
263 cases are tested in different working conditions. When both packages are released after the vertical motion of
264 the robot, considering also the robot lateral motion and using an additional vertical plate as backup solution to
265 complete the alignment operation, the success rate considering also the worst cases is around 99%.

266 The cases in which the alignment is not successful are those in which the gripping point is close to the center
267 of gravity. The probability of success consistently increase with a vision system that can reliably estimate the
268 position of the centre of mass. The results shows that the percentage of success of the system is high even in the
269 worst operating conditions, see Extension 1. 1 2 3 4 5

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³Year 2022 © 2022 Global Journals Passive Sensing Jaw for Grasping and Orienting

⁴© 2022 Global Journals Passive Sensing Jaw for Grasping and Orienting(a) Package 1: 520x44 mm 52 gr (b)
Package 2: 90x35 mm 175 gr

⁵<https://www.gpi.it> 2 <https://www.lika.it>

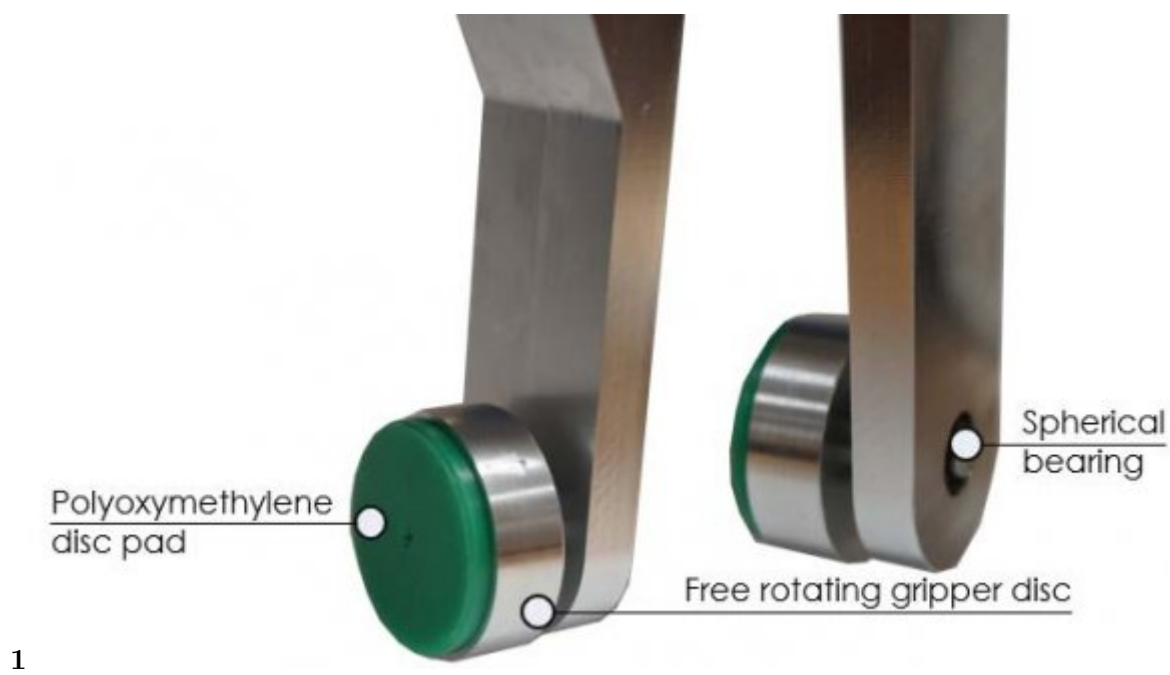
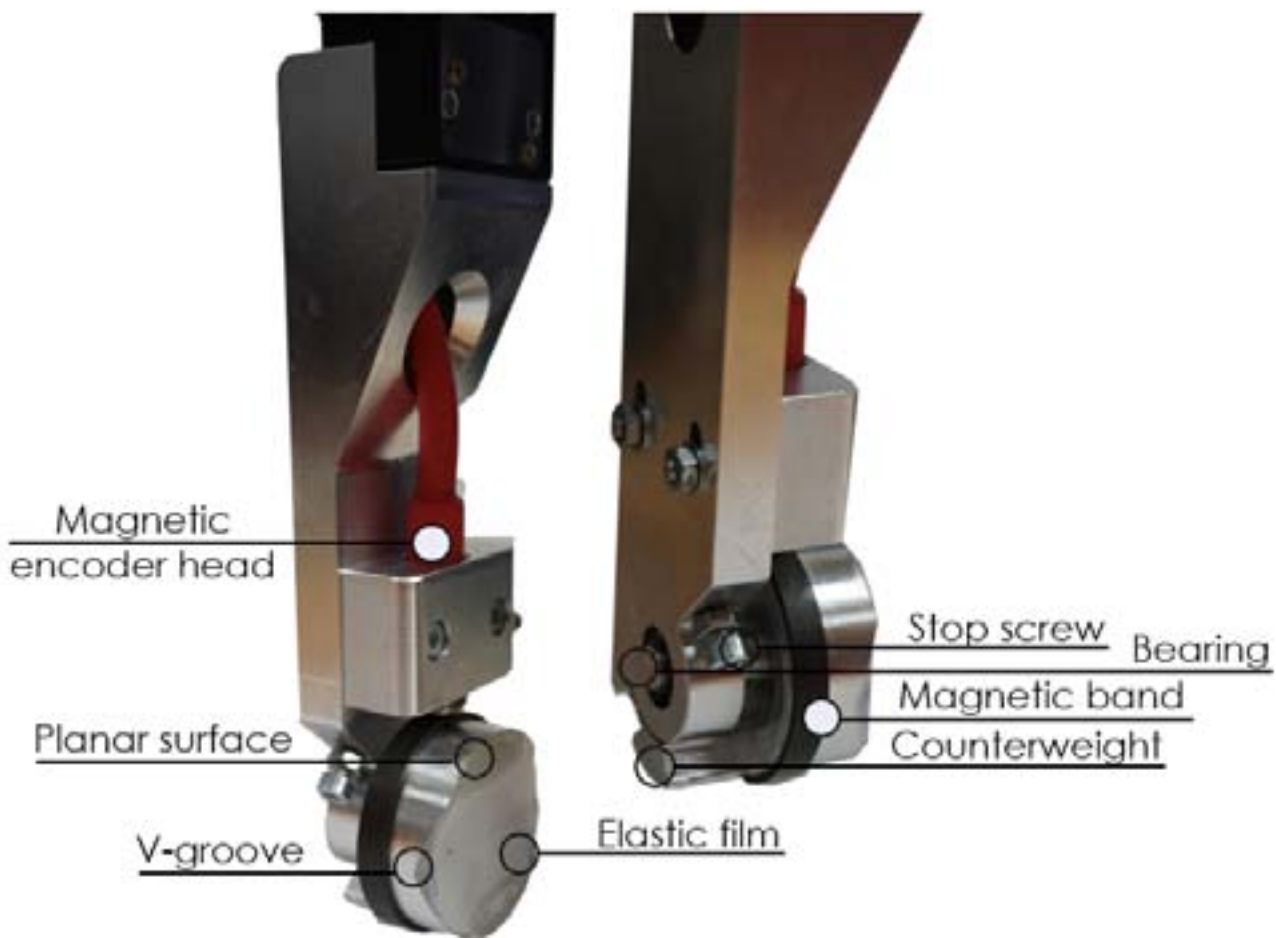
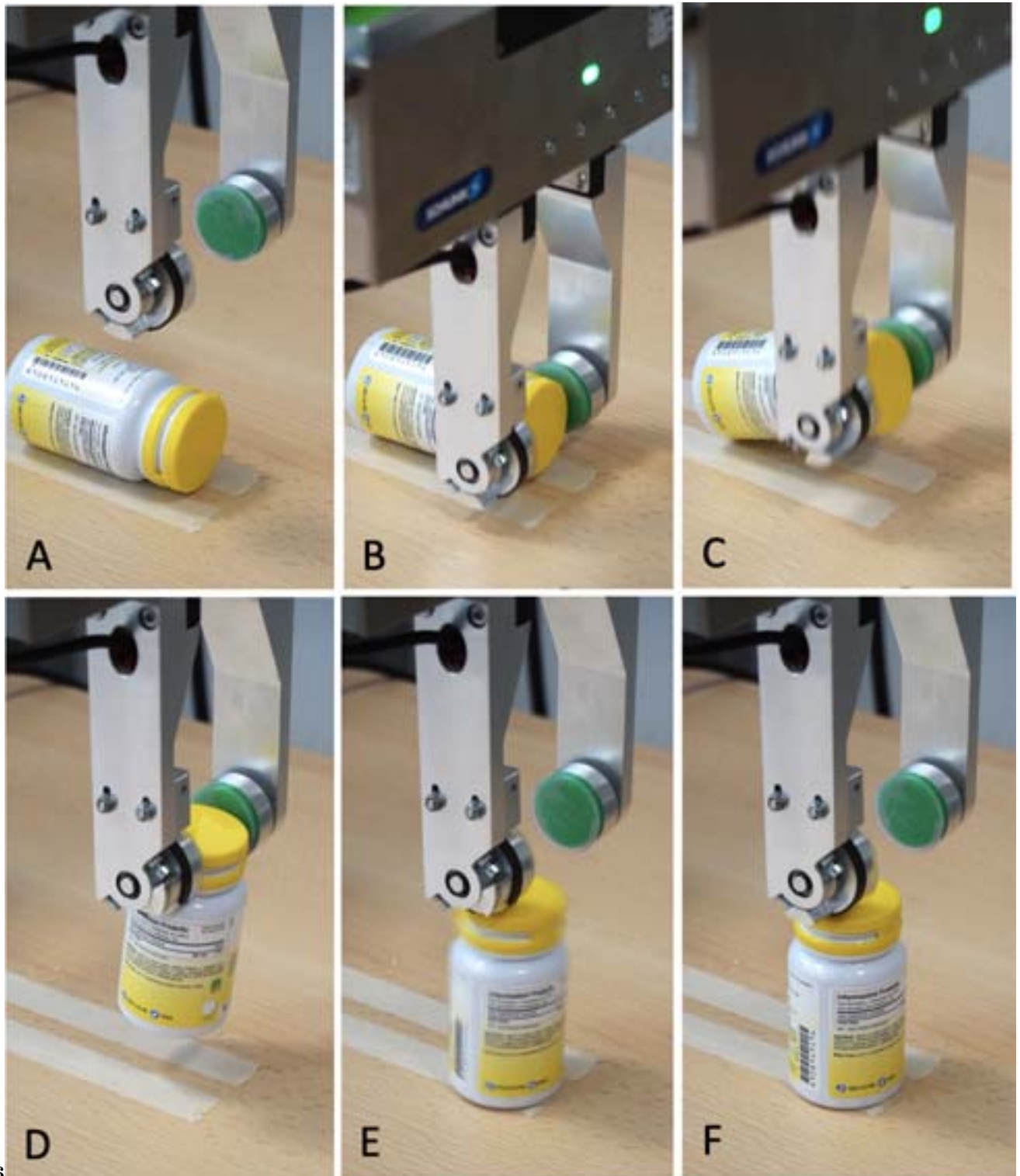


Figure 1: Fig. 1 :



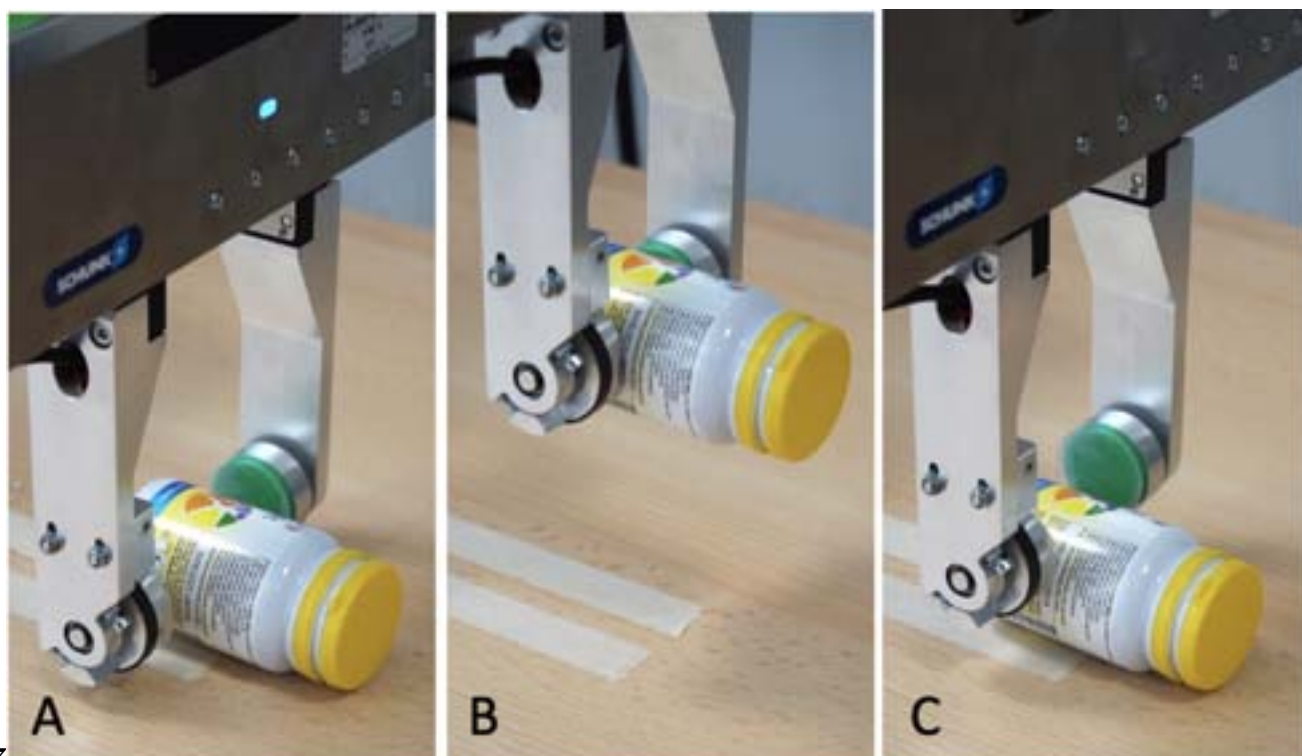
2334

Figure 2: Fig. 2 : 3 (Fig. 3 :Fig. 4 :



56

Figure 3: Fig. 5 :Fig. 6 :



7

Figure 4: Fig. 7 :

	ITALY		EUROPE		AUSTRALIA		OTHER		ALL	
	No. of pharm.: 25 Items: 82.852 Packs: 283.348		No. of pharm.: 10 Items: 25.897 Packs: 64.941		No. of pharm.: 10 Items: 13.589 Packs: 67.696		No. of pharm.: 9 Items: 15.992 Packs: 167.229		No. of pharm.: 54 Items: 138.327 Packs: 583.214	
Dimensioni confezioni	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
Width	176 mm	19 mm	170 mm	19 mm	169 mm	20 mm	174 mm	20 mm	176 mm	19 mm
Lenght	265 mm	29 mm	286 mm	37 mm	283 mm	28 mm	258 mm	31 mm	286 mm	28 mm
Height	109 mm	12 mm	113 mm	12 mm	118 mm	10 mm	108 mm	13 mm	118 mm	10 mm
3D Diagonal	315 mm	61 mm	307 mm	62 mm	335 mm	65 mm	266 mm	64 mm	335 mm	61 mm
Diam. cylinders	123 mm	29 mm	138 mm	31 mm	105 mm	24 mm	135 mm	34 mm	138 mm	24 mm
Height cylinders	101 mm	24 mm	111 mm	18 mm	118 mm	21 mm	97 mm	18 mm	118 mm	18 mm
% cylinders	0,12%	0,00%	3,48%	0,07%	33,95%	14,52%	3,19%	0,00%	33,95%	0,00%
AVG % cylinders	0,01%		0,92%		20,45%		0,71%		4,08%	

8910

Figure 5: Fig. 8 :Fig. 9 :Fig. 10 :



1112

Figure 6: Fig. 11 :Fig. 12 :

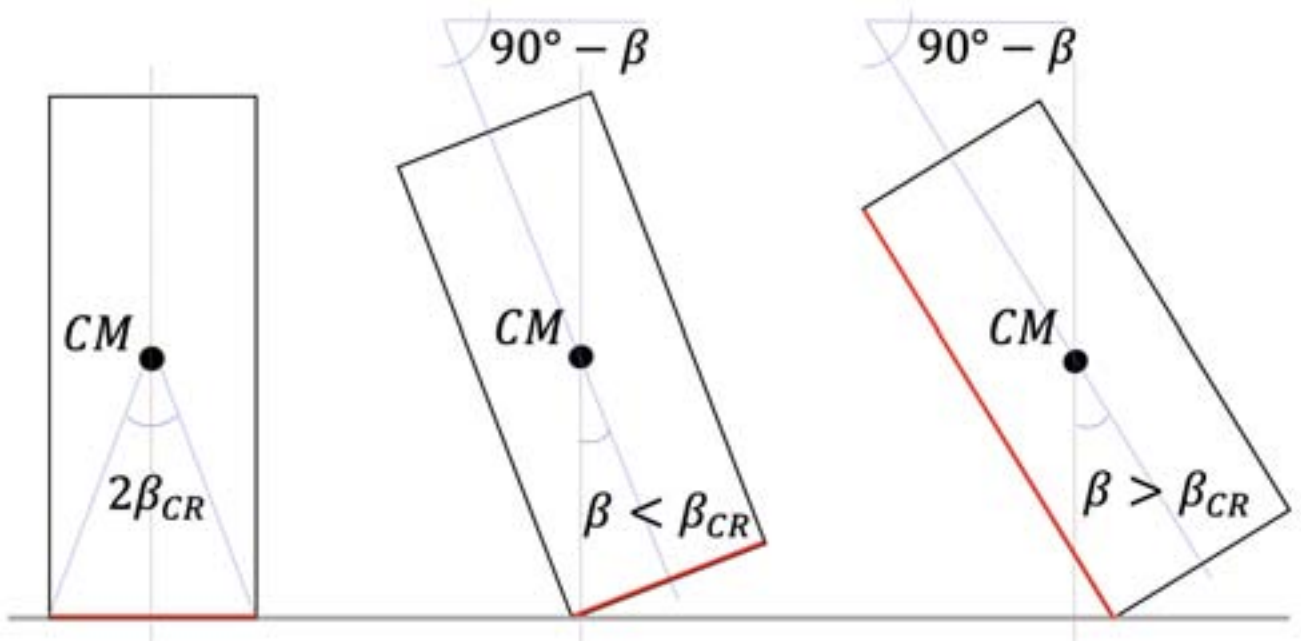
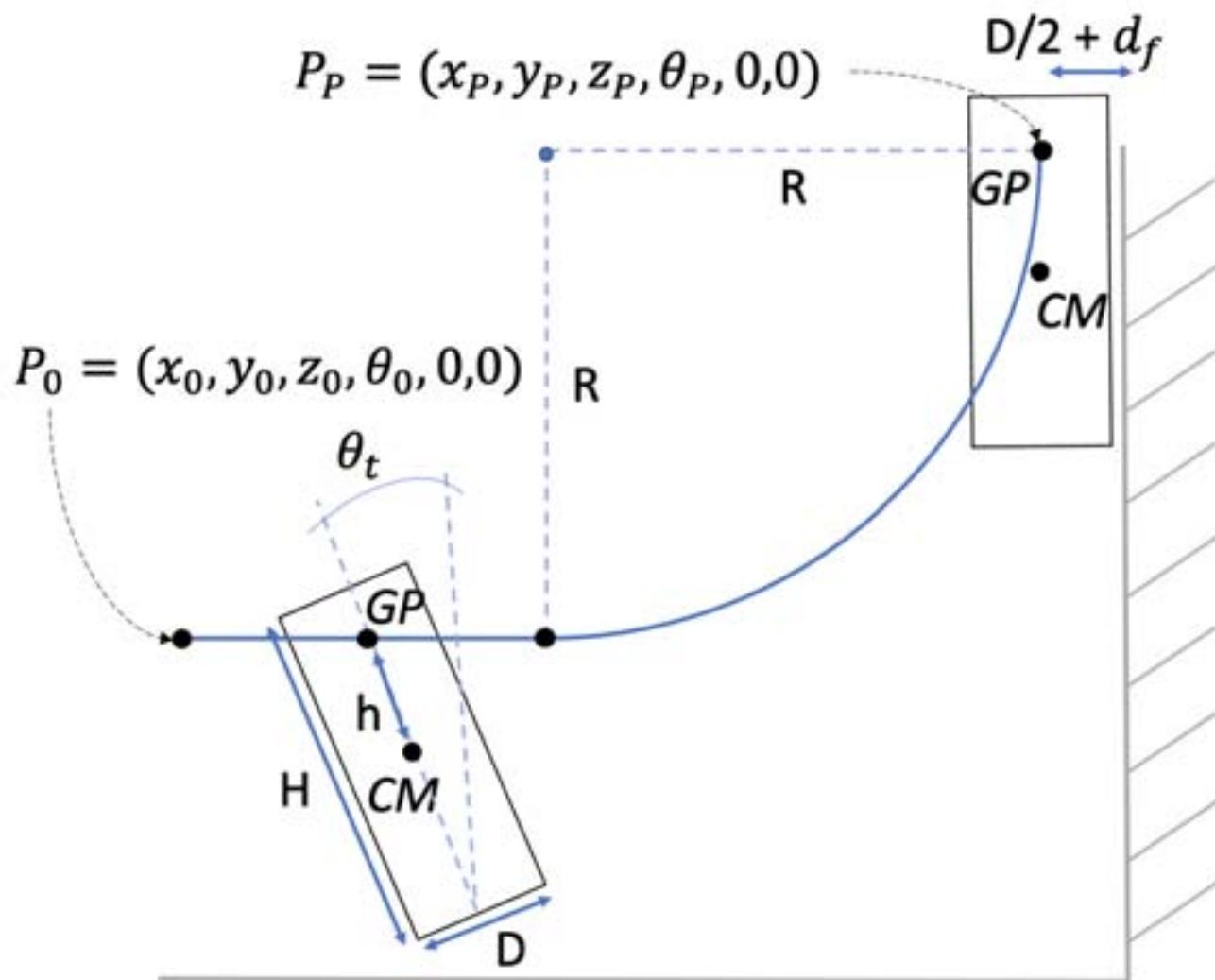


Figure 9:



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Figure 10: Fig. 15 :

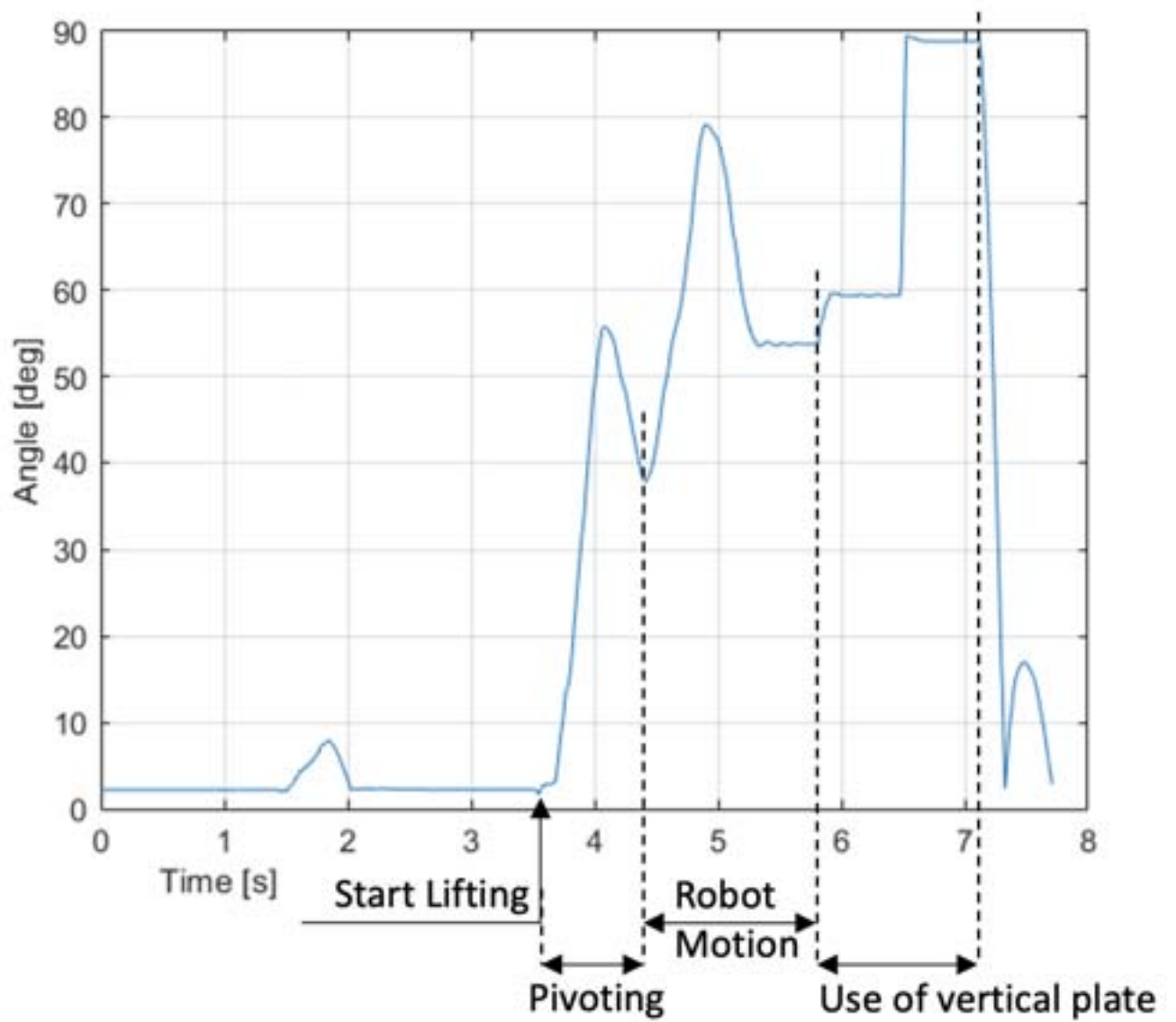
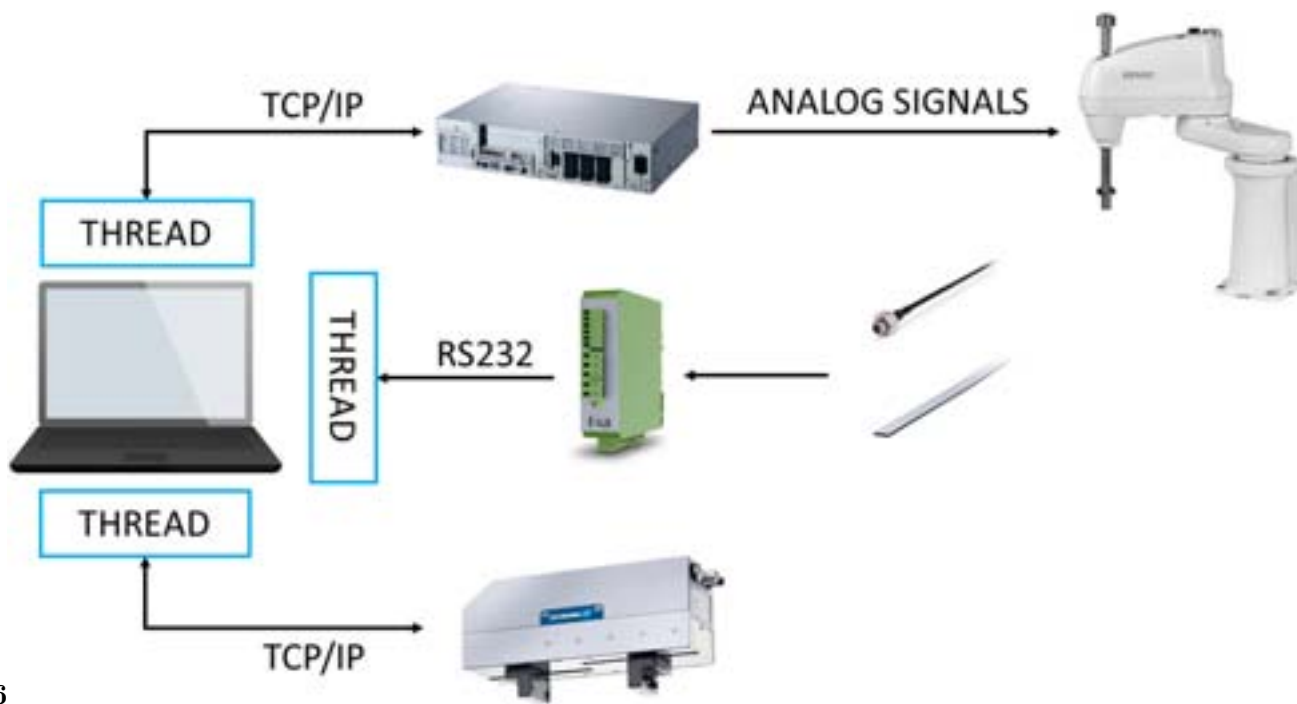


Figure 11: B



16

Figure 12: Fig. 16 :

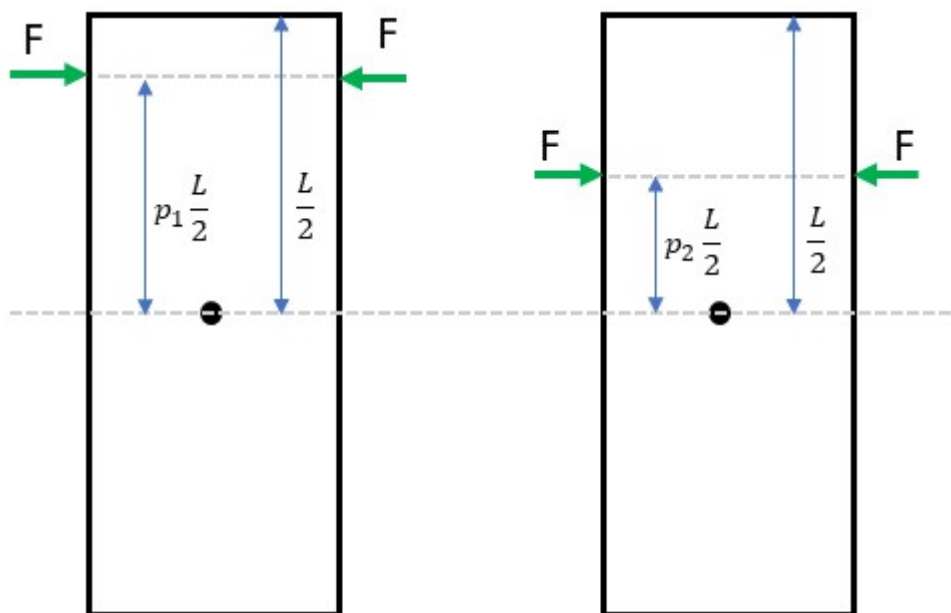


Figure 13:

1

Factor	F value	p-value
(A) Gripping distance	341.46	4.84e-13
(B) Diameter	1448.04 < 2.2e-16	
(C) Height	996.87	<2.2e-16
(D) Material	37.57	9.521e-09
(E) Vertical acceleration	5.547	0.02
(F) Friction coefficient	14.14	2.54e-4
(G) Gripping force	0.38	0.54
A 2	0.60	0.44

Figure 14: Table 1 :

2

Factor	F value	p-value
(A) Gripping distance	3157.99 < 2.2e-16	
(B) Diameter	280.32	< 2.2e-16
(C) Height	232.70	< 2.2e-16
(D) Material	15.73	1.193-4
(E) Vertical acceleration	11.31	1e-3
(F) Friction coefficient	10.71	1.36e-3
(G) Gripping force	142.88	< 2.2e-16
A 2	2.43	0.12

Figure 15: Table 2 :

3

Figure 16: Table 3 :

4

Dist.	A	B	C	D	E	F	G
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	0.23	0.28	0.27	-0.09	0.00	-0.06	-0.19
1	0.47	0.55	0.54	-0.21	0.05	-0.13	-0.35

Figure 17: Table 4 :

5

Figure 18: Table 5 :

6

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Figure 19: Table 6 :

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272
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