RESEARCH ON THE DESIGN AND DEVELOPMENT OF AN EXPERIMENTAL MODEL OF A ROBOTIC SYSTEM FOR SOME PHASES OF MOLD ASSEMBLY.

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The purpose of this scientific paper is to conduct a case study on a workstation within a company and to automate it. In this context, the starting point is the manual process of assembly and the goal is to develop an experimental robotic assembly system.

1. Introduction

This scientific paper aims to present an automated alternative for the metallic inserts assembly process. The study begins with the injection process, material preparation, homogenization, manipulation of the piece from the mold, and its takeover by the operator. Then, the Poka Yoke Vision system is studied, which ensures the correct and complete assembly of the inserts on the piece. An analysis of the automation requirements is performed, along with Finite Elements Analysis (FEA) and physical analyses using a force transducer. Next, the 3D modelling part is initiated, including sketches, prototypes, and electrical schematics, and available alternatives are explored. The next stage involves the additive manufacturing of some parts and conventional manufacturing of a semi-finished product on a milling machine, through processes such as drilling, centering, and milling. In parallel, work is being done on an image analysis program aimed at recognizing certain surfaces of the piece and converting pixels to millimetres.

2. Current Stage

The chapter is divided in several components, as follows:

2.1 Image Analysis

In order to perform image analysis and precise measurements, a ruler with a fixed length of 10 cm was used as a measurement unit, along with a 6-axis Kinova Gen 3 lite robotic arm presented in both Figure 2.1.1 and Table 2.1.1, and a webcam. Photographs was taken at different camera positions, represented by different values of the arm's Z parameter, and the distance between the centre of the camera and the subject being photographed will be measured in pixels.

Fig 2.1.1- Kinova Gen 3 lite Articulated Robotic Arm [1]

Table 2.1.1. Kinova Gen 3 lite parameters [1]

Information	Values
Degrees of freedom	6
Payload weight	0.5 kg / 1.1 lbs
Total weight	5.4 kg / 11.9 lbs
Maximum reach	760 mm
Maximum speed	25 cm/s
Motor rotation range	± 155 to 160°

To calibrate the system, 30 photographs were taken, five for each value of Z between 0 and 0.25 meters (Fig 2.1.2, 2.1.3), selected using a five-point sampling method. The average number of pixels corresponding to a length of 10 centimetres were be calculated for the 30 photographs and presented in both pixel units and millimetres.

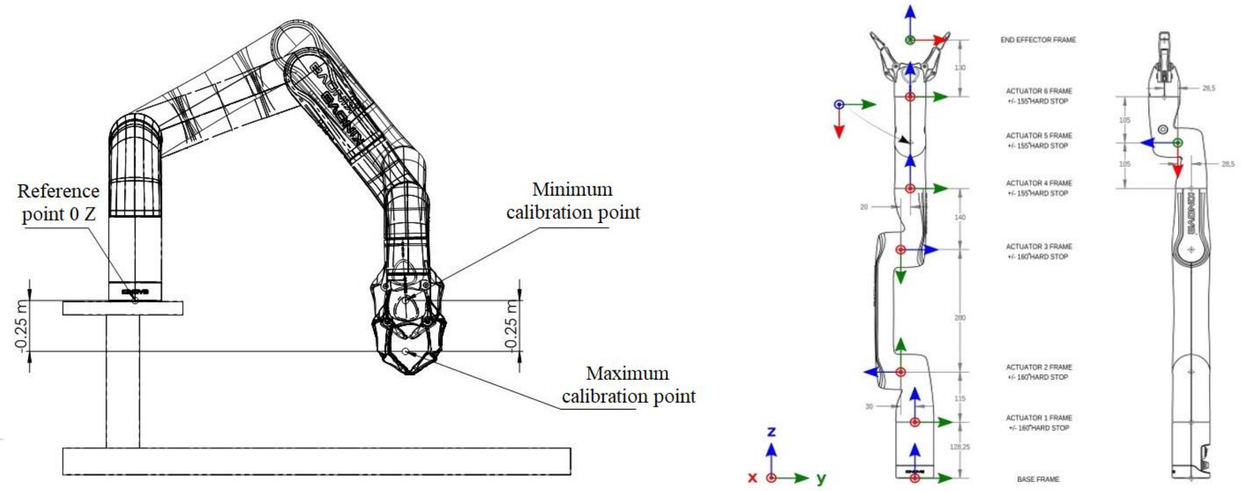

Fig 2.1.2- Calibration principle diagram [2]

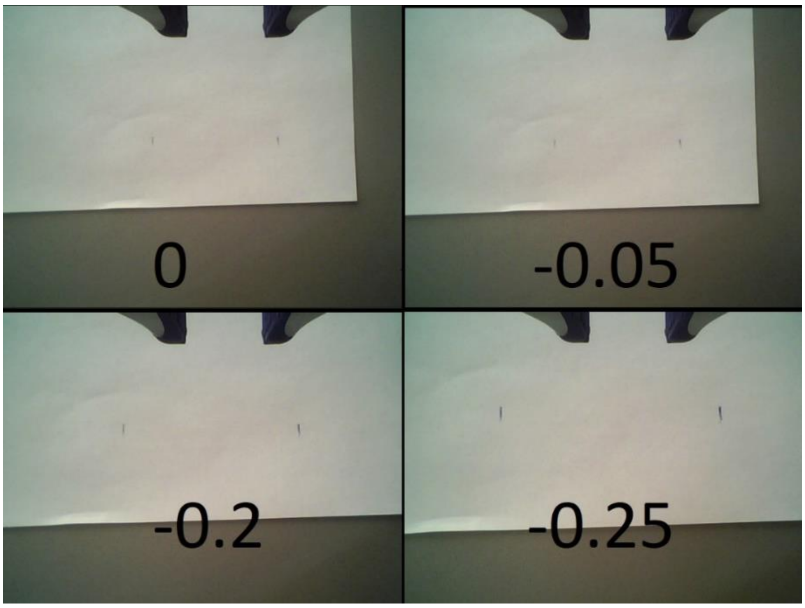

Fig 2.1.3- Images taken by varying the Z parameter

The *Measure* command from NI Vision Assistant was used to determine the distance in pixels between the two lines, as shown in the following figure.

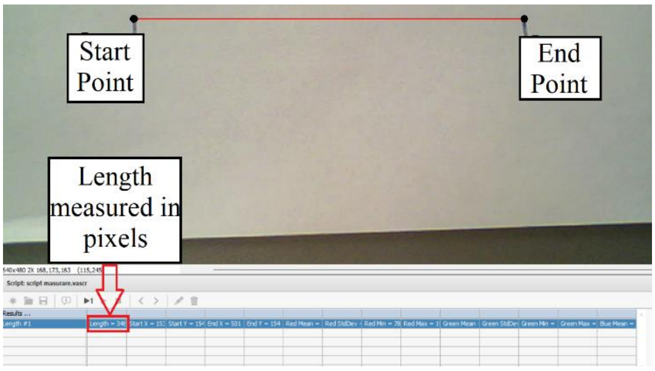

Fig 2.1.4- Pixel measurement method

The following table shows the measurement results.

Table 2.1.2. Pixels measurement results

Z	Pixels per 10cm						Pixels per mm
[meters]	1	2	3	4	5	Average	Average
0	156	155	156	157	157	156.2	1.562
-0.05	175	176	175	176	175	175.4	1.754
-0.1	198	199	199	199	199	198.8	1.988
-0.15	232	232	232	230	232	231.6	2.316
-0.2	277	279	278	279	278	278.2	2.782
-0.25	348	346	347	348	347	347.2	3.472

The equation of the line was calculated using the Curve Expert program, in order to obtain the scaling factor and transform the measurements into real length units, such as millimetres. The "Calculate a nonlinear regression" function was used to obtain the regression line equation, as the points are not arranged on a straight line (Fig 2.1.5). All available nonlinear calculation models were selected, and based on the score obtained from the analysis, the most suitable equation for our data was chosen.

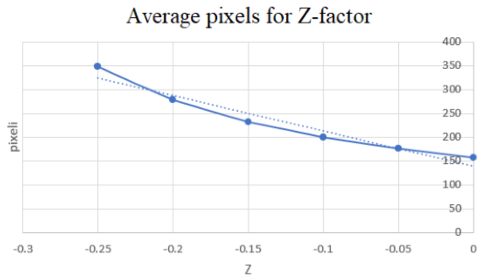

Fig 2.1.5- Nonlinear graph of pixels for the 10 cm unit.

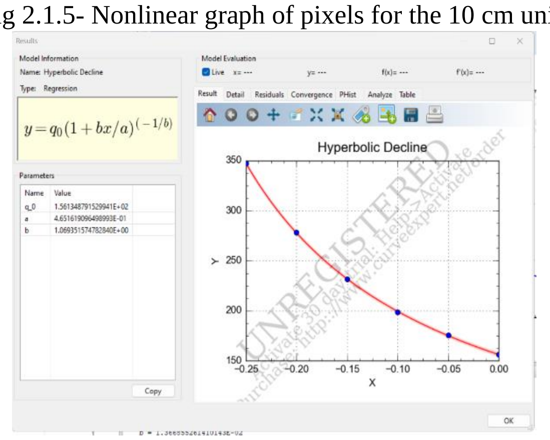

Fig 2.1.6- Presentation of the chosen function

The scaling formula was implemented in the LabVIEW programming environment so that measurements can be transformed into real length units using the "Hyperbolic Decline" function (Fig 2.1.6), which is defined by the parameters "q0", "b", and "a", and the variable "x", which represents the number of pixels. When controlling the system, the height of the object and the fixation device are also taken into account, specifically by adding the parameter "hT" to the formula.

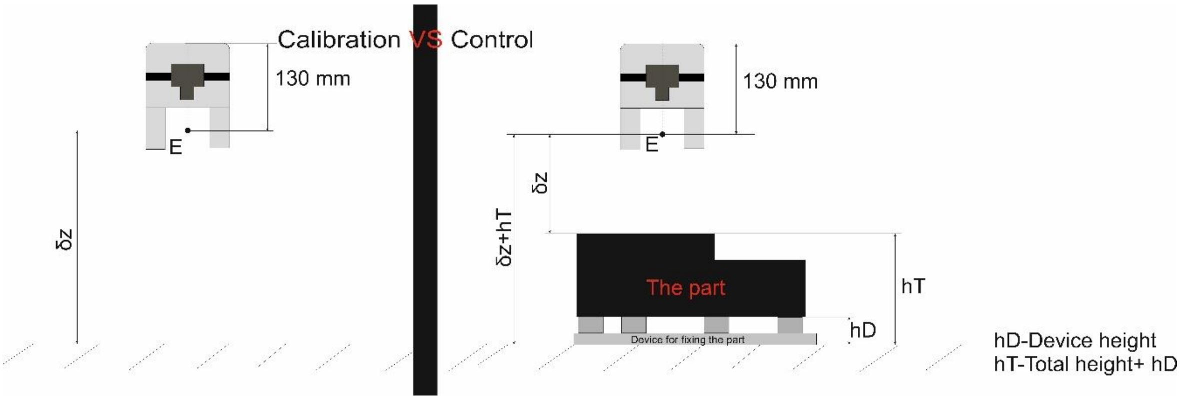

Fig 2.1.7- Calibration vs control with the part

So, image analysis becomes a simple geometry problem as shown (Fig 2.1.8), where C is the camera centre, B is the camera resolution, and D is the centre of the detected object.

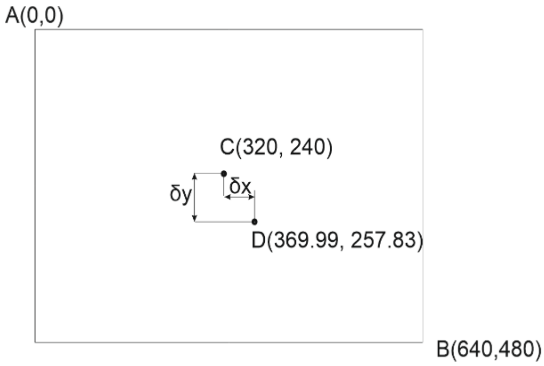

Fig 2.1.8- Converting an image into mathematic representations

Demonstration of pixel to mm conversion:

To reach the centre of the element, we need to move a certain value on the x-axis and another value on the y-axis, according to the following calculations:

The difference between the x-coordinate values of the centre of the element (369.99) and the current position x-coordinate is: $\delta x = 369.99 - 320 = 49.99\, pixels$.

The difference between the y-coordinate values of the centre of the element (257.83) and the current position y-coordinate is: $\delta y = 257.83 - 240 = 17.83\, pixels$.

Thus, to reach the centre of the element, we need to move 49.99 pixels on the x-axis and 17.83 pixels on the y-axis.

To convert the units to millimetres, we applied the conversion formula starting from the relationship of 1 ppm (pixels per millimetre) equal to 1.28666 pixels/mm. For example, to convert the displacement of 49.99 pixels on the x-axis, we multiplied this number by the conversion ratio of 1 mm to 1.28666 pixels, obtaining the value of 38.89 mm. Similarly, for the displacement of 17.83 pixels on the y-axis, we used the same formula and obtained the value of 13.86 mm.

$1\, ppm = 1.28666\, pixels/mm$ (factor calculated by the program for Z = 0 and piece height of 100 mm)

$49.99\, pixels * (1\, mm / 1.28666\, pixels) = 38.89\, mm$

$17.83\, pixels * (1\, mm / 1.28666\, pixels) = 13.86\, mm$

The next step is to move the camera centre to the gripper centre, and this is done as follows: we need to calculate the coordinates of the point E (End Effector) relative to the centre of the image sensor C.

It is known that the distance between the two points is 55 mm on the X-axis, so the coordinates of point E can be calculated using the formula:

$$E = C - 55\ mm \tag{1}$$

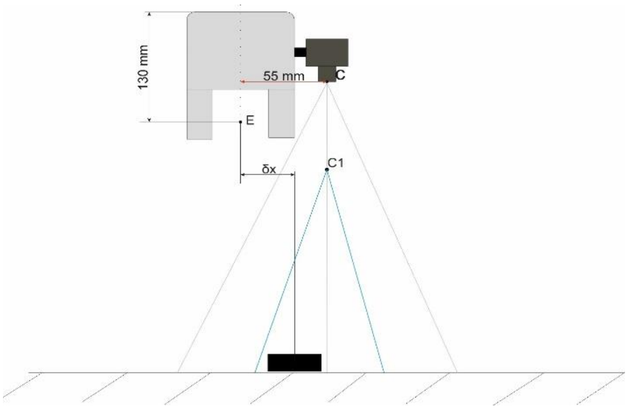

Fig 2.1.9- Moving camera centre to end effector

2.2 FEA analysis vs reality

A FEA analysis was performed using Ansys software to determine the required clamping force of the insert, while simultaneously a real test was conducted with a force transducer. The accuracy of the results obtained is 86.57%. The analysis resulted in a value of 15.149N, while the force transducer indicated a value of 17.5N. This difference is considered to be due to the material used for the insert, Ovako 51CrV4, of which the composition is not fully known.

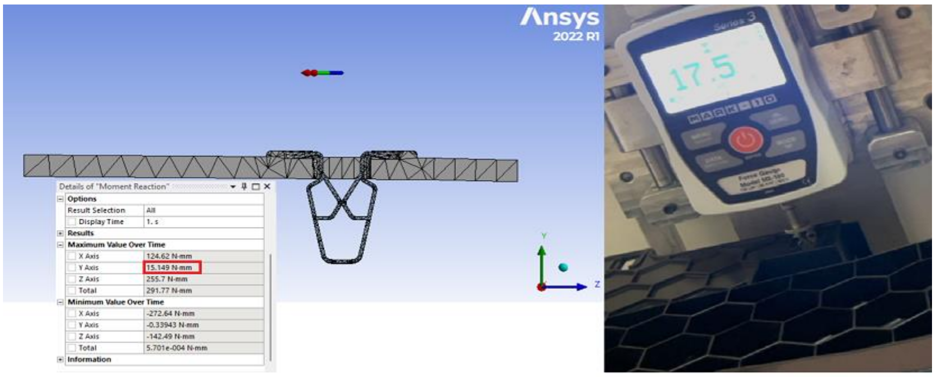

Fig 2.2.1- Interpretation of FEA analysis vs. force transducer

2.3 Device for fixing the part

A complex fixing system has been developed, which was designed through planning five production batches, each comprising 110 assemblies, in an industrial environment. This system was created by building a 3D model and a CAM model, and was successfully manufactured. The purpose of this system is to take over the degrees of freedom of the parts and fix them in a corresponding position.

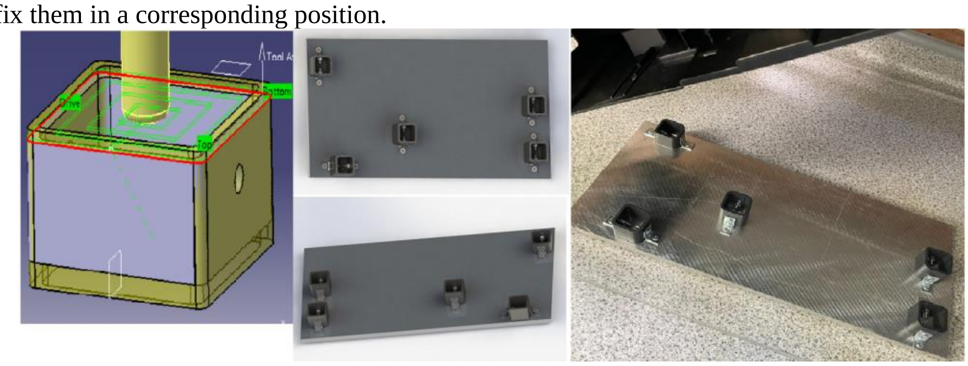

Fig 2.3.1- Device for fixing the part, CAM, rendered, real life

2.4 Inserts sorting device

A complex system has been developed that includes creating a 3D model and printing a sorting device. The purpose of this device is to facilitate the activity of the robotic arm by picking up the inserts. To activate the device, three different trigger solutions were developed: magnetic sensor, proximity sensor, and vision system.

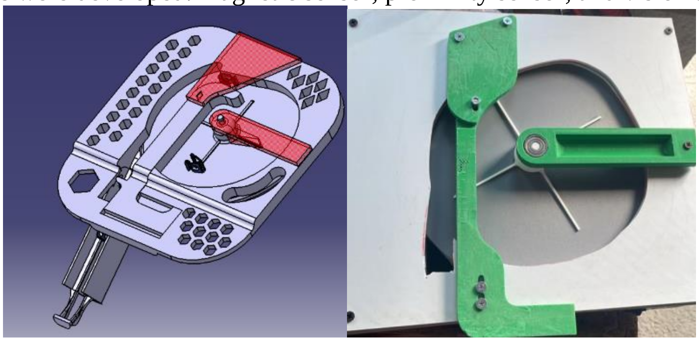

Fig 2.4.1- Insert sorting device CAD vs prototype

2.5 Protective glove for gripper

A complex system has been developed for grasping inserts that will come into contact with a rubber area of the gripper. To facilitate this activity, a special fixture has been designed which has two zones: an inner one that conforms to the shape of the effector, and an outer one that facilitates grasping the insert. This fixture will be used to protect the contact area between the gripper and the metal insert, which can cause damage or wear.

Fig 2.5.1- Protective glove for gripper VS Alternative to 3D printing, silicone mold

3. Conclusions

This research article describes the design and development of an experimental robotic system for certain phases of mold assembly. The manual assembly process is analyzed, an automated Vision system is developed to ensure correct and complete assembly of parts, and physical and engineering analyses are performed using a force transducer, 3D models, prototypes, and electrical schemes. A semi-finished product is processed through milling processes, while simultaneously, an image analysis program is developed to recognize certain surfaces of the part and convert pixels to millimetres. Future research directions may include implementing the robotic system in a real production environment, improving the image analysis program, and exploring other production methods. Additionally, machine learning algorithms can be implemented in the robotic system to improve its accuracy and efficiency.

4. Bibliography

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