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IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Design and Development of an Integrated Automation Simulation System

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DOI: https://doi.org/10.30880/ijie.2019.11.08.006
Received 28 January 2019; Accepted 15 September 2019; Available online 15 December 2019

Abstract: An effective simulation process enable engineers and research practitioners for successive trialing, experimentation, and validation of process, system design, and configuration. This paper highlights the design and development of an Integrated Automation Simulation System which consists of testing, drilling, clamping, and ejecting modules. The conceptualization of the design undergone project specification with the use of Computer Aided design (CAD) to hypothesize the physical hardware. After the fabrication, the development tests was perform using the identified quality characteristics in terms of accuracy, consistency, speed optimization, and the product quality evaluation (ISO 25010). Results show that thru the help of the rendered CAD designs the actual prototype was effectively realize. Results further illustrated that it has met all the quality characteristics test and product quality requirements. The implication of this findings elucidated the pedagogical applications of this prototype in relation to the manpower adaptation into the current trends of Industry 4.0.

Keywords: Automation Simulation, Manufacturing, Processing Simulation System, CAD, Quality Characteristics

1. Introduction

Efficient manufacturing can be described as the capacity to produce quality goods and products within a given specified resources. To achieve optimum efficiency, firms have developed into a very structured organization and systems with advanced machineries that is able to address the changing product demands of the end users. Because of these dynamic product changes, big firms thought of having a versatile process and machineries that can easily adopt with the product variations and survive 21st century competition in the market, these concept of retrofitting manufacturing equipment as a specific opportunity for sustainable manufacturing was developed and later collectively renown as Industry 4.0 [1]. Well renowned innovation firms who have already integrated Industry 4.0 into their operations have heavily invests in research and development which focuses on foreseeing the changing market demands and improved product quality. The impact of the novel technologies contrast with existing technologies lead to new formations of firm's suppliers, linkages, and customers [2**].** The manufacturing value production within mostly first industrialized countries emphasized that new firms should also gear towards the Industry 4.0 as competition drives them to further innovate or face a losing market.

This advancements paves way for numerous opportunities and the realization of sustainable fabrication of machineries capable of producing versatile goods and commodities. Subsequently, the enactment of these stage of industrialization also provides opportunities for the engineers, technologist, specialists and maintenance personnel to also enhance and adopt 21st century technologies and fused-in their current capabilities to drive the manufacturing process. Through technological sustenance it is certain that employees be able to realize their full potential and manage work changes imposed by the firm's top executives and management [3]. In the top management's perspective, adopting to these current trends in manufacturing sector, also requires them to do intervention on the manpower side. Since machines eventually gets outdated, it is then replaced with new and complex devices which might affect the performance of the worker if not taken well. These creates a need for a balance between machine upgrade and manpower training. An HR

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system focused on human capital enhancement affects manpower operational performance in terms of productivity, machine efficiency, and customer alignment linking human-capital-enhancing HR systems with a quality manufacturing strategy. [4]

2. Literature Review

2.1 Simulation Systems

Industrial simulation is significant to improve the understanding of a process. Engineers perform different simulations to maximize trialing of the product, predict flaws, improve ergonomic aspects, and reduce operational cost for experimentation. It also enables them for multiple recreation of the design before it is made available and construct new and robust plans. Thru simulation, topographical alterations become easier and appropriate as manufactured models came from different models of simulations. These simulation techniques enable rapid view from design or process design made available for modifications. [5] A similar simulation system can be related to a press station simulator that can be used for technical skills upgrading was effective as a method for reducing capital requirements for technology adaptation. [6]. Simulation based researches are effective as it contributes to

2.2 Computer Aided Designs (CAD) and Computer Aided Manufacturing (CAM)

In a manufacturing setup, the continuous assembly of re-modification of machineries where modeled thru computer-based environments to speed up the process of modelling, testing, and validation of process concepts. The use of CAD does not only save duty cycle time but also reduces operational cost of manpower training, and different in-efficiencies of the model when installed in physical setup. The successful implementation of models can be effectively realized thru the application of CAD model-based simulation for virtual assembly prototyping, planning, and training. [7] With the arrival of CAD/CAM technologies, models may now be swiftly manufactured from three-dimensional topographical designs. There are many diverse rapid prototyping (RP) technologies available, these current technologies also has their own strengths and weaknesses. Some of these flaws were more concerned on some usual process constraints such as layer thickness, system accurateness, and rapid rate. [8] The use of CAD constitutes the use of finite element modelling that is highly popular in effectively predicting the performance of a device when exposed to disturbances like changes in temperature. [9]; cracks analyses [10]; and Acoustics [11], this in turn enables the optimization process on the design.

2.3 Automation systems

These systems were the by-product of the innovations from the iterative manual manufacturing process. The advent of industrialization cemented the foundation on the creation of electro-mechanical devices that speeds up the manufacturing time and development cost. Numerous levels of automation (LOA) improved the levels of human control associated with the dynamic control tasks thereby improving inclusive human/machine enactment. Automated systems have conventionally been discovered as selective function; either one, the human or the machine is dispensed to a prearranged duty. More recently, halfway stages of automation have been discoursed as a way of maintaining worker involvement in system enactment, leading to advancements in work-environment consciousness and decreases in out-of-the-loop process problems. [12]

2.3.1 Programmable Logic Controllers

These electronic devices use a microcontroller for data and signal processing. It also uses a programmable memory for the internal storage of instructions by implementing specific functions such as logic sequencing, timing, counting, and arithmetic to control, through digital or analog input/output modules, various types of machines or processes. [13] These controllers were necessary in the automation process as it directs the actions taken by the output devices from the input devices by means of a program. These programs can be altered in any given thus, manufacturing flexibility is achieve thru these alterations.

2.3.2 Pneumatics technology

This technology predominantly uses air as a medium of work. Compressed air being generated from the pumps, were routed into pipelines or hoses and controlled via valves making the actuators move. The use of these technology is usually partnered with electronic control to direct the valves. Since air is free compared to hydraulic and electrical control, it provides several manufacturing benefits in the production of goods. A similar practical application can also be related to the use these technology in the sports by means of launcher as an effective throwing device. [14]

2.3.3. Electric motors and control

Several devices move thru electrical motors. In a manufacturing setup, these industrial motors drive conveyors, CNC machines, cranes, pumps, and fans. It can also be noted that motors have different types and capacities so it is important for a plant personnel to familiarize the technical design and control techniques in using industrial motors especially during the ramp-up, maintenance before and after operation, and repair and troubleshooting. The observance to different machine failures constitutes the optimization of electrical parts to make the process more efficient in terms of energy savings. [15]

2.3.4 Industrial Implication of Simulation Systems

Some manufacturing firms ought to limit cost in the operational expenses related to manpower training as it delays their overall production time. But recent researches suggest that the professional insights of these technical employees improved when exposed to different enhancements of new machineries or technologies related in their work. [16] The work status research also suggests that in firms, there are younger individuals felt the need of relevant trainings as a technologies co-equally exists with them. [17]

2.3.5 Quality Model (ISO/IEC 25010)

The quality model is the cornerstone of a product quality evaluation system. The quality model determines which quality characteristics will be taken into account when evaluating the properties of a software product. The quality of a system is the degree to which the system satisfies the stated and implied needs of its various stakeholders, and thus provides value. Those stakeholders' needs (functionality, performance, security, maintainability, etc.) are precisely what is represented in the quality model, which categorizes the product quality into characteristics and sub-characteristics. [14].

3. Objectives and Significance of the Study

This research was primarily conducted to design and develop an integrated automation simulation system which consists of the following modules: rotary turret table; depth testing; clamping; drilling; and ejecting. Likewise, the study aims at creating an efficient simulation tool so as the following specific objectives were generated:

- Determine the appropriate technical project specifications for the system.
- Develop the prototype model thru the use of computer-aided designs and fabricate the automation system.
- Determine the quality characteristics of the system in terms of accuracy, consistency, and speed optimization.
- Determine the Product Quality Evaluation (ISO 25010) of the prototype

1. Methodology

In piloting these prototypes, there identified two stages identified to realize the process. The first stage is the design phase which include project specification and design. In this phase, technical specification of devices needed were identified, followed by rendering CAD models to design specific mechanical parts and assemble the whole system in the software environment. The second stage is the development phase which consist of test for quality characteristics in terms of accuracy, consistency, and speed optimization. The prototype were also subject thru product quality evaluation using ISO25010.

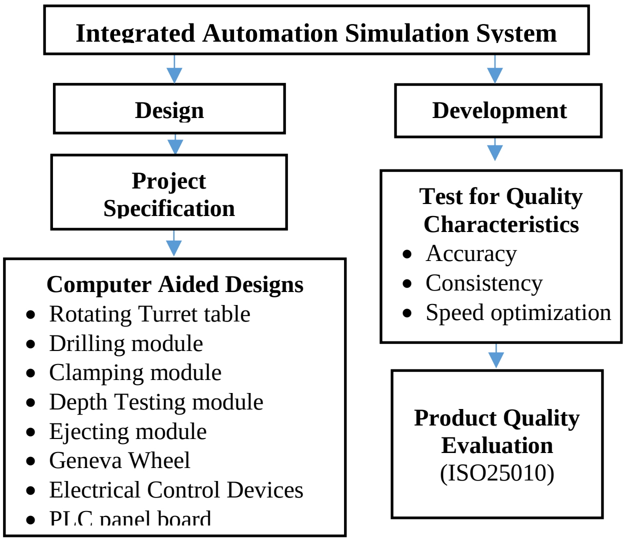


Fig. 1- Design and Development Process

4.1 Project Specification and Design

This stage of the designing phase was achieved through the series of brainstorming of the components appropriate for each process performed with the modules. The generated specifications were consulted from different automation experts to achieve a validation.

4.1.1 Project Specification

The detailed specification of the prototype components is shown at Table 1. It is composed of the main components with the following specifications. Highlighting the indicated components is important as an initial requirement to drive the prototype.

Table 1 – Specification of the Prototype Components

Main Components	Specification
Industrial Controller:	• Programmable Logic Controller-24 I/Os
Industrial Sensors:	• Diffused Photo-electric Sensors, 24V • Reed sensors, 24V
Electronic/ Electrical Components:	• Improvised Terminal-Blocks • 4PDT relays, 24V • Terminal wires with terminated end • DC Wiper motor, 12V, 70-100W • DC Drill Motor, 5-36V • Solenoid Actuator, 24V
Pneumatic components:	• Single-acting cylinder 5mm stroke, 24V • Double-acting cylinder 8mm stroke, 24V • Single-solenoid valve, 5/2 way, 24V

4.1.2 Project Design

The development of the project design is made available with the use of CAD software to model the parts needed for each module. These modules were then assembled into a whole assembly.

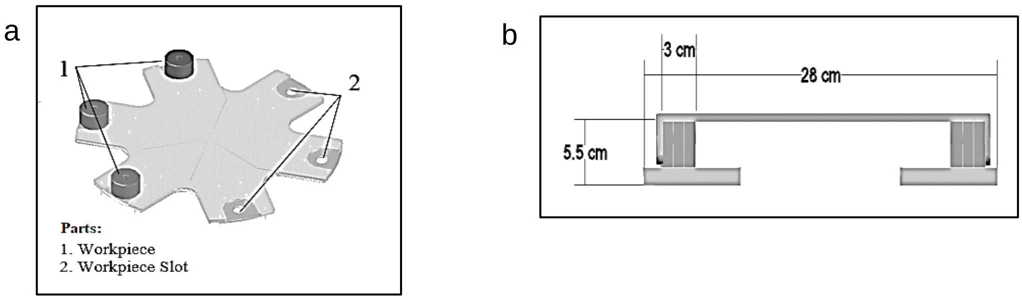


Fig. 2 – (a) Rotating Turret Table; (b) Table Base

The design shown in fig.2*(a)* was the Rotating Turret Table, the basic platform for the carriage of the workpieces. In its design, there are six rounded slots fit for the cylindrical workpieces. The rotating turret table, revolves thru the use of electrical motors and for each slot, there are sensors to detect the presence of the workpiece: the design in the fig. *2(b)* the Table base for the said rotating turret table in which it serves as primary mounting support.

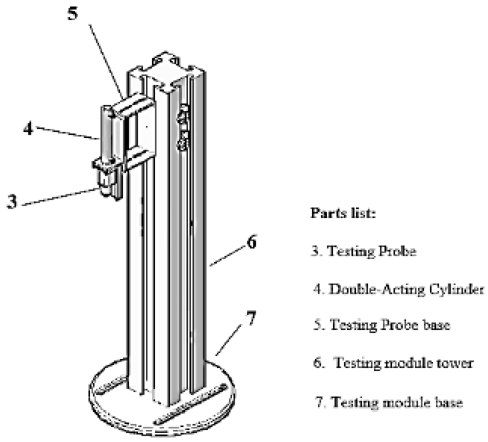


Fig. 3 – The Depth Testing Module

The module is shown in fig.3 was the Depth Testing Module, which is primarily concerned with the test of the workpiece surface. The testing probe (3) detects whether the workpiece position on the rotating turret table was placed in lying upright position or it's the reverse, it sends a signal to the programmable logic controller.

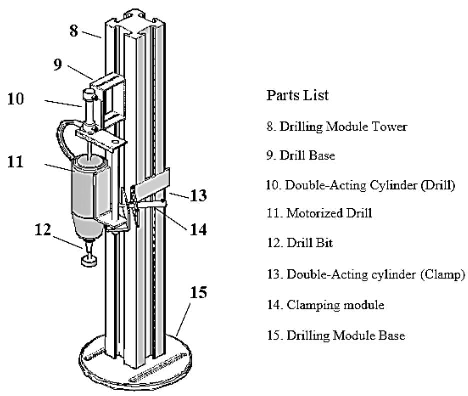


Fig. 4 – The Depth Testing Module

As shown in the fig. 4 was the Drilling module design, which consist of several parts. The said module performs drilling operation thru push and pull mechanism using pneumatic actuators and a drilling operation thru an electric motor with a tool bit hitting the workpieces. The drilling simulation were shown in this process.

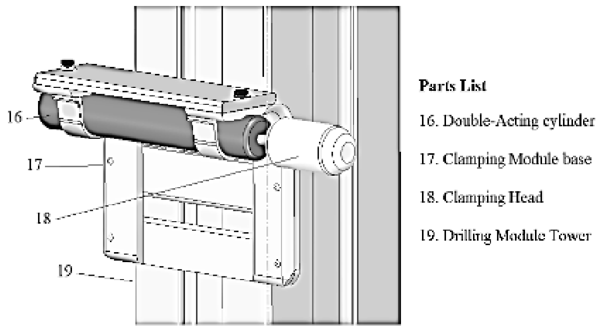


Fig. 5 – The Clamping Module Design

The design shown in fig. *5* is the Clamping module. Its main function is to perform the clamping mechanism while the workpiece is put on-hold near to the clamping head (18). Such clamping should be fit enough to prevent damage in the workpiece, provide and maintain enough grip to prevent vibration when drilling operation starts. These module uses compressed air upon its actuation. In a manufacturing process, clamping mechanism were one of the most common processes performed in the automation, as it also prevents products from unwanted movements and alterations during the concurrent drilling, bending, or pressing process. It is highly important simulation tool since the actuation needs appropriate balance in between the amount of compressed air flow in the pipelines as well as manipulation of electronic signals from the controllers.

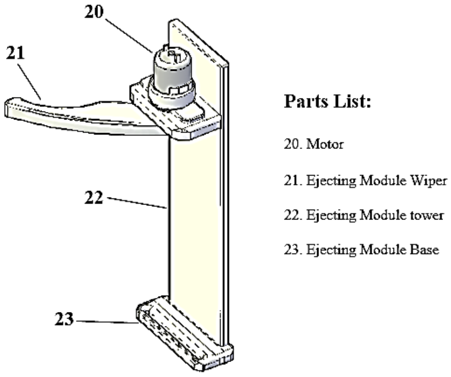


Fig. 6– The Ejecting Module Design

The design shown in fig.6, is the Ejecting module which swipes the incoming workpiece when detected, enabling its transfer to the following module for another processing operation. It uses motor to drive the wiper and controlled via electronic signals coming from the controller.

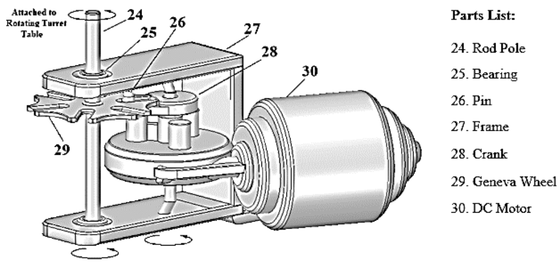


Fig. 7 – The Geneva Wheel Design

Another design shown in fig. 7 is the Geneva Mechanism whose main function is to convert the continuous motion of a DC motor (30) into six angular halts subdivided into testing, drilling, and ejecting modules respectively. The rod (24) is attached to the rotating turret table as shown in figure 1 and drives and angular motion coming from the mechanism. The bearings (25) provides a smooth circular transition of torque transfer going to the rod (24). The pin's (26) main function was to drive the Geneva wheel (29). The frame (27) provides mounting support of all devices present in the figure presented. The crank (28) was the part that connects the pin (26) to the motor and provides pull when torque was generated. The Geneva Wheel (29) was the mechanical part that determines the number of halts going to the attached rotating turret table. The DC motor (30), an electrically driven device that is when energized by a direct current source performs circular mechanical movement thereby driving all the components present in the figure.

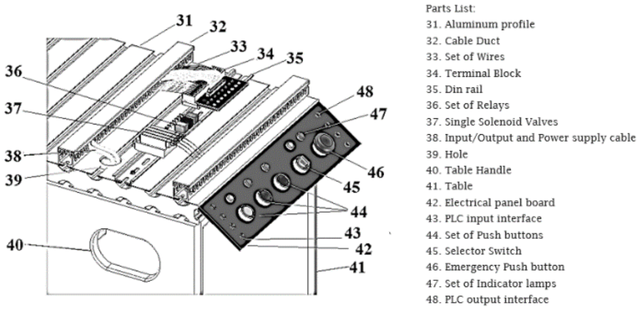
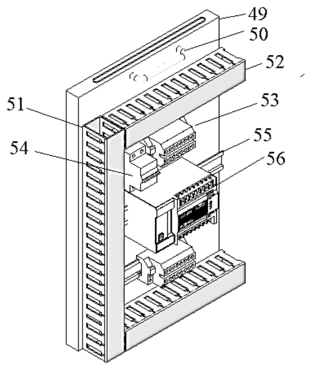


Fig. 8 – The Electrical Control Devices

The automation simulation system has many electrical and electronic devices as depicted in fig. *8*. These parts were the hardware devices were the human operator actuates switches to manipulate the operational sequences and perform trials. The aluminum profile (31) serves as a retrofit base for all components present. The cable duct (32) secures all electrical wirings to prevent from being hit and loosen during the mechanical movements — the electrical wirings (33) made of a solid wire #23AWG, used as a means for transporting power and signal to the electrical control devices. The Terminal block (34) with LED indicators was used as an interface for the input and output devices to shorten the number of cables going to the Programmable Logic Controller or PLC. The Din rail (35) provides flexible mounting for some of the Electro-pneumatic components present.

A set of relays (36) were also used to control the switching of a large amount of current from the PLC going to the DC motor (30) and also for the solenoid valves (37). The solenoid valves (37) was also incorporated in the design to control the pneumatic components in the testing and drilling modules. The I/O and Power supply cable (38) is responsible for delivering signals and power to the terminal block (34) and PLC. A hole (39) was also provided as a route for the devices associated in the table (41) below. Also, a slot for a table handle (40) was incorporated to have an ergonomic grip to the table (41) during its mobility. The table (41) is the overall carrier of all devices present in the design. The Electrical panel board (42) serves as the mounting for the devices: PLC input interface (43), Set of Pushbuttons (44), Selector Switch (45), Emergency Pushbutton (46), Set of Indicator lamps (47), and another PLC output interface (48).

The Programmable Logic Controller panel board as shown in fig.9, is composed of: a PLC panel (49), which serves as a platform for the associated devices present, Panel handle (50) which is the provides grip for the human programmer when the panel board is detached from the lower part of the table. There were also a Vertical cable duct (51) and Horizontal Cable duct (52) that secures the electrical wirings connection. The PLC external terminal block (53) provides an interface for the electrical wiring to the PLC to prevent direct connection of wires and inhibit deformity in the screws when detaching wires is frequent. A Circuit breaker (54) was also added in the design since for electrical safety. A Din rail (55) provides flexible mounting to the devices present. Lastly, the Programmable Logic Controller (56) was incorporated to control the operational sequences of the devices. As shown in *figure 4(b)* was the isometric view of the completed design of the Integrated Digital Automation Simulation System with Depth Testing, Drilling, Clamping, and Ejecting Modules.



Parts List:

49. PLC Panel
50. Panel Handle
51. Vertical Cable duct
52. Horizontal Cable duct
53. PLC External Terminal Block
54. Circuit Breaker
55. Din rail
56. Programmable Logic Controller

Fig. 9 – The Programmable Logic Controller (PLC) Panel Board

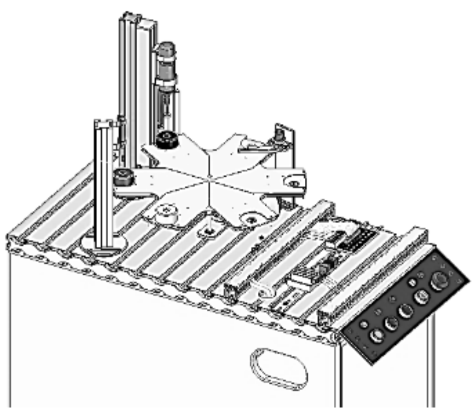


Fig. 10 – The Completed Design of the Integrated Automation Simulation System

4.2 Quality Characteristics

This stage shows the criteria for defining the quality characteristics of the prototype. To check its efficiency, the prototype is evaluated through a series of trials in term of its accuracy, consistency, speed, and overall product Quality.

4.2.1 Test of Accuracy

The use of digital dial indicator was used as a tool for measuring mini-offsets from the mechanical movements. The digital indicator tool is also commonly used in robot arm calibration using ISO 9283 namely path accuracy and repeatability.

Table 2 – Likert Scale of Consistency Ratings

Numerical Scale	Descriptive Rating
4.21-5.00	Highly Consistent
3.41-4.20	Very Consistent
2.61-3.40	Consistent
1.81-2.60	Fairly Consistent
1.00- 1.80	Not Consistent

4.2.2 Test of Consistency

An invited panel of experts composed of ten (10) members consist of engineers and specialists in the field of automation and mechatronics were invited to validate the consistency ratings thru optical inspection of the different quality criteria set forth by ISO/IEC 25010. The evaluation procedure employed is the Likert Scale presented on Table 2 above.

4.2.3 Test of Speed Optimization

The device has undergone speed optimization trials by comparing the operating the sequence in four operational times and observing if the operation has found successfully *met* or *not met.* The category that shows all operations met will have the fastest speed optimization time. In this manner, a stopwatch timer was used to measure the time for each trials and determine speed optimization values.

4.2.4 Product Quality Evaluation

The experts composed of ten (10) who quality characteristic also assessed the product quality evaluation set forth by ISO 25010. The highest possible rate for each characteristic was three (3), and one (1) was the lowest. Three (3) meant at very high extent, two (2) meant at an average extent, and one (1) meant at a low extent of product quality.

2. Results and Discussions

This section presents the project designs versus the actual image of the modules presented. It also discusses the results gathered for the test for quality characteristics and the product quality evaluation.

5.1 Project Design versus the Actual Image

Computer Aided Design (CAD) relatively provided relief on the researcher’s composition of ideas in terms of the mechanical aspects of the prototype. The CAD-generated designs were found to be generally similar to the fabricated hardware modules and thus, it has successfully met all the requirements thru virtual, physical modelling, and assembly of the prototype. It can be gleaned at fig *10* that the actual module did not significantly differ from the CAD rendered designs in terms of its size and specifications..

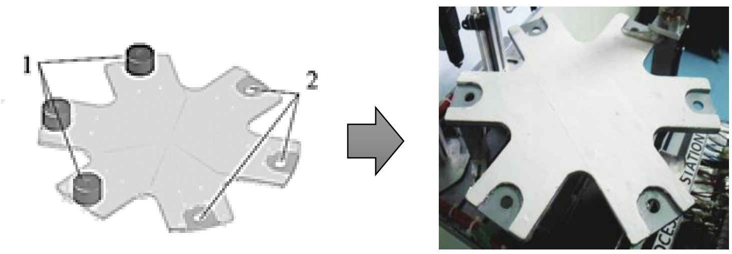


Fig.10 Rotary Turret table’s actual image

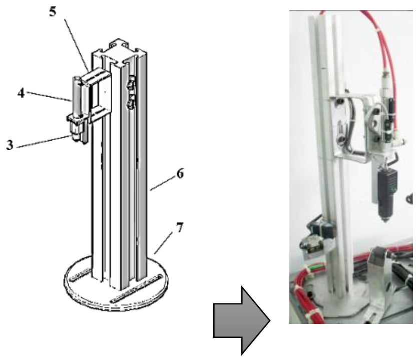


Fig. 11- Depth Testing Module's actual image

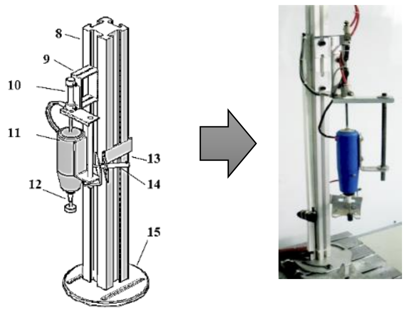


Fig. 12- Drilling Module's actual image

The image shown at *figure 12* shows the drilling module along with its conceptual model. When retro-fitting parts, the mechanical design is fit to the available materials present and has been successfully installed.

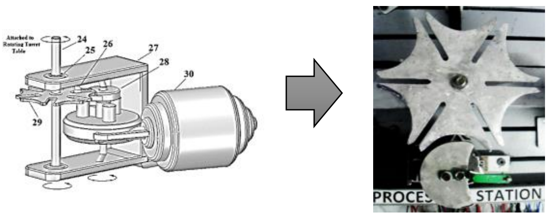


Fig.13- Geneva Wheel Mechanism's actual image

The motion performed by the Geneva wheel mechanism is very important in driving the whole system. In this manner it should have a very precise topographies as it will cause offsets in the angular positioning of the driven rotary turret table. Thru the use of CAD software, those offshoots in measurements was lessen.

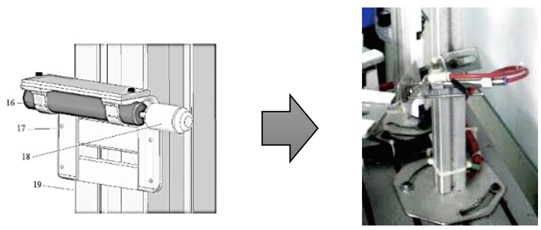


Fig. 14- Clamping Module's actual image

The clamping module shown at fig.14 also did not significantly differ from the CAD rendered designs and it is important for workpiece to be aligned properly during the operation process.

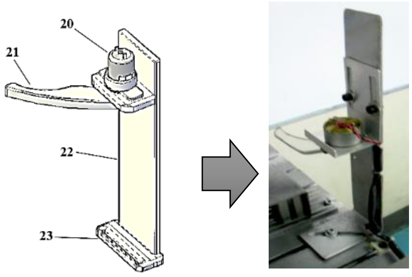


Fig.15 - Ejecting Module's actual image

The ejecting module shown in *figure 15* has some slight variation at the base. As observed in the design, the base has fell short making it unstable for the attached heavier parts in its upper portion. To address its weight balancing issue, the base is extended co-equally on the swivel part above for a stable actuation upon its dynamic process.

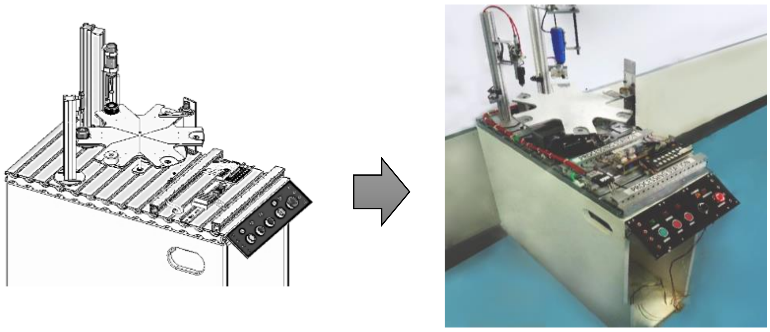


Fig.16- Integrated Automation Simulation System's Actual image

5.2 Quality Characteristics of the Integrated Automation Simulation System

5.2.1 The Test for Accuracy

The test conducted for the Depth Testing Module was the workpiece alignment offset value in mm units and the workpiece detection in random placement with value representation of 1 for upright and 0 for not upright workpieces. As described in *Table 3*, results revealed that the workpiece alignment was found have 0.590mm offset value, and this can be interpreted a very minimal value for misalignment. Other findings showed for testing the accuracy of the detected the workpiece position in either upright or not upright placement. It has successfully detected the type of workpiece placement in the five trials.

Table 3- Depth Testing Module- Accuracy Test

Trial No.	*Workpiece alignment offset value (mm)*	*Workpiece detection in random placement (upright-1/ not upright-0)*
1	0.010	0-0
2	0.961	1-1
3	0.980	0-0
4	0.044	1-1
5	0.955	1-1
Average:	0.590	0-0 /1-1

Table 4 - Drilling Module- Accuracy Test

Trial No.	*Drill Depth (mm)*	*Hole width (mm)*	*Speed (rpm)*		
			Low Speed	*Medium Speed*	*High Speed*
1	5.02	3.01	862	1733	2602
2	4.95	2.97	859	1731	2599
3	5.01	2.98	857	1733	2597
4	4.95	3.00	862	1729	2598
5	5.03	2.95	864	1730	2601
Average:	**4.99**	**2.98**	**861**	**1731**	**2599**

For the test conducted for the drilling module as described at *Table 4*, the drilled workpieces have an average drill depth of 4.99mm from its center top in which it was found to be accurate having a minimal offset of only 0.01mm. In the context of drill width, the average value was found to be 2.98mm of also a minimal offset value of 0.02mm. For the speed of the drill, it has a low-speed average of 861rpm, medium speed average of 1731rpm, and a high average speed of 2599rpm respectively. The accuracy test of the clamping module as described in *Table 5*, were done thru a five trial observation with the ten (10) panel member's optical inspection. Summative findings were suggested that it has consistently clamped the workpiece effectively and thus making the subsequent drilling operation more secured. The clamping operation performed smoothly, and the workpieces were properly fit in the clamping probe. Also, proper tightness was observed to prevent damage to the workpiece.

Table 5 - Clamping Module- Accuracy Test

Trial No.	*Is the workpiece securely clamped? Decision (yes/no)*
1	Yes
2	Yes
3	Yes
4	Yes
5	Yes
Average:	Yes

Table 6 - Ejecting Module-Accuracy Test

Trial No.	*Is the workpiece ejected properly? Decision (yes/no)*
1	Yes
2	Yes
3	Yes
4	Yes
5	Yes
Average:	Yes

A similar method done thru the ejecting module's accuracy test by the panel members and it was also found to have successfully ejected the workpiece during the five trials conducted as shown in *Table 6.*

5.2.2 The Test for Consistency

The following data were obtained from a panel composed of ten (10) members, and the consistency ratings were done thru optical inspection during the demonstration of the device as rated by the panel members shown in *Table 7*. It was found out in the test that for all five trials conducted, the overall ratings was 4.5 which has a descriptive meaning of *Highly Consistent.* With this result, it has been consistent for the operations for the two workpiece positions.

Table 7- Consistency Test Ratings

The position of the Workpiece	***Trial no.***	***Panel member Decision** (Did the depth testing, drilling, clamping, and ejecting module successfully operated its five trials consistently?)*										***Mean***
		1	2	3	4	5	6	7	8	9	10	
Upright	1	4	4	4	4	4	4	4	4	4	4	4
	2	3	5	3	5	5	5	5	3	4	5	4.9
	3	5	4	4	5	5	5	5	5	5	5	4.8
	4	5	5	4	4	5	5	5	5	5	5	4.8
	5	3	5	5	5	4	5	5	5	4	4	4.6
Not Upright	1	5	4	5	5	5	4	4	4	5	5	4.6
	2	4	5	5	5	5	5	5	5	4	3	4.6
	3	5	5	4	4	5	4	4	4	5	5	4.5
	4	5	5	5	4	4	4	4	3	4	3	4.1
	5	5	4	5	4	5	4	4	4	4	4	4.3
											Overall Mean	**4.45**
											Interpretation	Highly consistent

5.2.3 The Test for Speed Optimization.

The device's optimization trial as described in *Table 8* operates all the working modules present in the device. There were four (4) trials made to execute the operations. In trial 1, it has performed with 8 seconds operational time; there were four operations not met because it has not performed well due to fast movements and misaligned movements. At trial 2, with 10 seconds operational time, there were two operations not met. In trial 3, it has significantly improved but still has shown one operation not met. All of the operations were found to have successfully met all the requirements only in the trial 4 with 15 seconds operation time.

Table 8 - Speed Optimization Test

Operations	***Panel Members Decision*** *Are the operations successfully performed? (met/not met)*			
	Trial 1 (8s)	*Trial 2 (10s)*	*Trial 3 (12s)*	*Trial 4 (15s)*
• Rotating Turret Table	Not met	Not met	Met	Met
• Depth test process	Met	Met	Met	Met
• Clamping process	Not met	Met	Met	Met
• Drilling process	Not met	Met	Met	Met
• Ejecting process	Not met	Not met	Not met	Met
Average:	**Not met**	**Met**	**Met**	**Met**

5.3 The Product Quality Evaluation

The highest possible rate for each characteristic was three (3), and one (1) was the lowest. Three (3) meant very high extent, two (2) meant an average extent, and one (1) meant a low extent of product quality. As shown in *Table 9*, were the panel member's observation for the ratings of the different quality criteria set forth by ISO/IEC 25010. These indicators were describe in terms of functional suitability, performance efficiency, compatibility usability, reliability security, maintainability, and portability. Results shown at *Table 9* that the integrated automation simulation system had a high average product quality evaluation as rated by the panel members. Hence, the device developed could be recommended for utilization.

6. Conclusions and Recommendations

The design and development of an integrated automation simulation system provides hands-on automation experience through simulation. In total, the comparison between the design and the actual hardware did not significantly differ. Describing the quality characteristics namely: the test for accuracy, consistency, speed optimization, and overall product quality was determined, and it was found out that it has met all the requirements with high product quality evaluation thus, it could already be used for utilization.

Acknowledgement

This study would not have been realized without the evaluation done by the panel members namely: Engr. John Alfred Balo, Engr. Aljune Condevillamar, Engr. Ian Exclamador, Engr. Ruel Sarmiento, Engr. Paul Enrico F. Puyo, Atty. Mon-em Abangad, and our university mentors Prof. Erman S. Marajas, Prof. Cesar Gabo, Prof. Roberto Salarza, and Dean Edilberto Z. Andal, Ed.D. Special thanks were also given to our University president Dr. Nestor M. De Vera, and our research chairman Dr. Delon Ching for the presentation and publication support.

Table 9 - Product Quality Evaluation of the Panel members based on ISO25010

Characteristics	Sub-Characteristics	Rating	Descriptive Equivalent
Functional suitability	Functional Completeness	3	High
	Functional Correctness Functional Appropriateness	3	High
		2	Average
Performance efficiency	Time-Behavior	3	High
	Resource Utilization Capacity	2	Average
Compatibility	Co-Existence	3	High
	Interoperability	3	High
Usability	Appropriateness Recognizability	3	High
	Learnability	3	High
	Operability	3	High
	User Error Protection	2	Average
	User Interface Aesthetics	3	High
	Accessibility	3	High
Reliability	Maturity	3	High
	Availability	2	Average
	Fault Tolerance	2	Average
	Recoverability	2	Average
Security	Confidentiality	2	Average
	Integrity	3	High
	Non-Repudiation	2	Average
	Accountability	2	Average
	Authenticity	2	Average
Maintainability	Modularity	2	Average
	Reusability	3	High
	Analyzability	3	High
	Modifiability	3	High
	Testability	3	High
Portability	Adaptability	2	Average
	Install Ability	3	High
	Irreplaceability	3	High

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