

Assembly Automation and Human Machine Interface (HMI) Implementation for Rotary Table Indexing Machine

Chiranth C. V.¹, Sree Rajendra², Dr. Channakeshava K. R.³

¹Final year student, PG-IAR, Dept. of Mechanical Engineering, Malnad College of Engineering, Hassan, Karnataka, India.

²Associate Professor, Dept. of Mechanical Engineering, Malnad College of Engineering, Hassan, Karnataka, India.

³Selection Grade Lecturer, Dept. of Mechanical Engineering, Smt. L.V. Government Polytechnic, Hassan, Karnataka, India.

Abstract - Many industrial plants are automated without operator-machine interface. These interfaces are either expensive or difficult to adopt for small plants. Automated systems without graphical user interfaces make it hard for the operator to realize the machine status and instant steps needed to take up for clearing any malfunction happening in the plant. This decreases production and increases overhead cost of plant. In this work, consideration is given to the design, fabrication and development of low cost and user-friendly Human Machine Interface (HMI) for an automated wheel assembly unit. The back wheel assembly unit for kids swing car is considered for automation. The wheel assembly is carried out using a five station automated rotary index table. Electro-mechanical elements such as proximity sensors, pneumatic cylinders, solenoid valves and stepper motors are used for automating the rotary table. The machine control units are developed using low cost Arduino controller and general purpose touch screen display is used for HMI. USB serial port cabling is employed for communication. Arduino IDE is used for developing the machine control programs. This gives real-time monitoring of the automated system and reduces troubleshooting duration for culpability and also ensures safety in operation. The designed HMI may be adapted to any manufacturing unit having automation system.

Key Words: HMI, solenoid valves, Arduino controller, optical sensor, assembly automation

1. INTRODUCTION

In recent years, automation plays a very important role in manufacturing industries to optimize any process. The Human Machine Interface (HMI), controller and software involved in carrying out automation is crucial. Industries such as SIEMENS SEMATIC [6], ABB, Emerson Process Management, Rockwell Automation, Schneider electrics etc. are leading automation industries. The automation devices of these companies are of high cost and it makes unaffordable for small scale industries. To overcome these, a user friendly and open source Arduino with CIMPLICITY HMI automation is used. This helps to control and display the operations of kids swing car wheel assembly line in HMI screen.

Arduino board is being a small and compact electronic circuit board containing UNO/AT-MEGA microcontroller and other electronic components [2]. Arduino IDE (Integrated Development Environment) is employed for programming the assembly line [2]. Assembly automation is performed by sequence of operations to assemble multiple components in to a single unit [5]. This single unit (wheel assembly unit) is a subassembly of the kids swing car. Rotary table is one of the critical components in assembly line automation. Thus, it is considered for automation implementation. Rotary table automations are best suited for assemblies having eight parts or lesser and being completed in 12-13 stations [5]. In the present study, five parts and five stations are considered. The floor space required for rotary systems is comparatively lesser than linear indexing systems. Initially rotary systems are used because of product simplicity and low volume, but if the product complexity and volume increases then later it can be migrated to linear systems.

Normally the problem faced in the small scale automation industries are high cost of controller software and its maintenance, miss orientation, and miss insertion of components because of hardware part failure in the assembly automation machines.

The main objective of this work is to reduce the cost of the controller, HMI and software used for automation without compromising productivity, accuracy and safety. Further this will be helpful for automating the small scale industries with low capital investment.

2. DESIGN AND DEVELOPMENT

CAD design of the product wheel assembly unit and rotary indexing table assembly automation are designed as per the design consideration for automated production line [5]. The wheel assembly unit consists of five parts namely wheel (base part), ball bearing, central shaft, mounting cap-1 and mounting cap-2. These components joined one at a time and final assembly is done progressively.

In the initial stage product wheel assembly unit parts are CAD modeled as shown in figure 1 and developed by 3D printing the parts such as wheel, mounting cap-1 and

mounting cap-2 as depicted in the figure 2. Commercially available parts such as ball bearing and central shaft are bought and used as per the requirement for this project.

Rotary indexing table assemblies are CAD modeled and some parts were 3D printed. Design for availability is considered while designing the assembly due to limited availability of raw material. For design and development both hardware as well as controls with software is required in this work and it is described in the next paradigm.

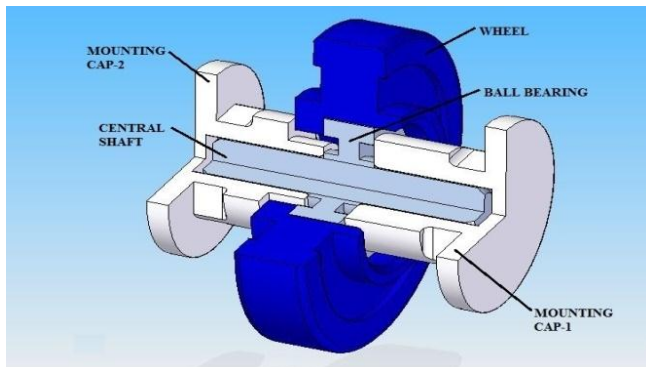


Fig -1: Cut section of wheel assembly unit 3D model showing all 5-components.

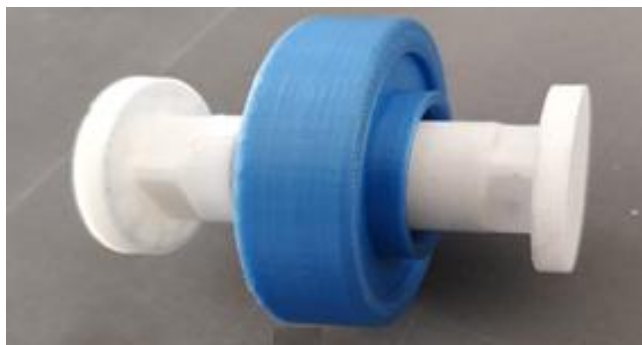


Fig -2: Actual wheel assembly unit 3D printed.

2.1 Assembly sequence

As depicted in figure 3 there are five parts which are shown in exploded view before assembly. Prior assembling the planning of these part design and parts to be assembled in a sequence is as per the design consideration of the general rules for the product design for automation by Geoffrey Boothroyd assembly theory is considered [9]. In the present work the assembly of parts sequence is as follows, part number 1 wheel is considered as base part, to this base part number 2 ball bearing part is press fitted with $\varnothing 22$ H7/p6 in to the inner diameter of wheel, next part number 3 central shaft is light press fitted $\varnothing 8$ H7/p6 in to the inner diameter of ball bearing, next part number 4 mounting cap-2 is inserted on to the central shaft and all these parts are automatically assembled. The part number 5 mounting cap-1 is manually assembled on to the central shaft from the bottom of the wheel while unloading the wheel assembly unit in the last station that is station number 5.

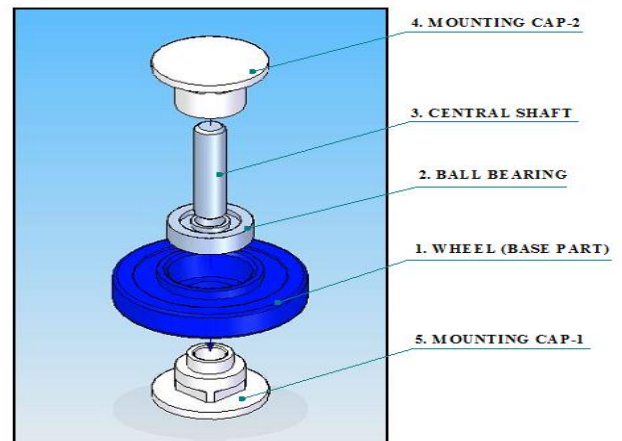


Fig -3: Wheel assembly unit exploded view with their assembly sequence and part number.

2.2 Hardware

Indexing plate and gravity feeder: For assembling the components dial (indexing) type assembly configuration [5] is considered where wheel as base part is nested in the rotary index plate.

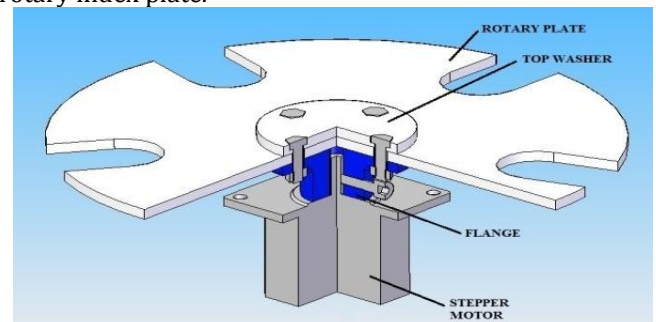


Fig -4: Cut section of rotary indexing plate assembly 3D model with different components.

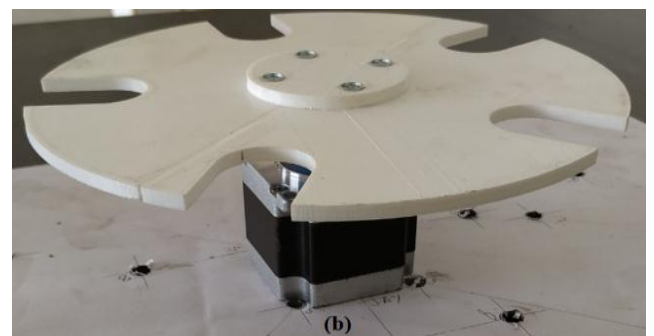


Fig -5: Rotary indexing plate actual assembly.

This rotary index plate designed, 3D printed and fastened it with the top washer and bottom flange. This rotary index plate assembly is directly mounted on to the stepper motor shaft having one of the flat edges and fastening the flange and motor shaft with a grub screw. This rotary plate assembly is as depicted in figure 4 and 5. Rotary index plate assembly rotates at 72° for each of the 5 station operations for a period of time to complete each station operations.

After completing 360° rotation of rotary indexing plate one wheel assembly unit is completed.

There are five stations having respective operations in this work as shown in figure 6 and 7 which are Station-1: gravity feeding the wheel and nesting the wheel on the slot provided in rotary index plate. Station-2: gravity feeding the ball bearing and press fitting outer diameter of bearing in to the wheel. Station-3: gravity feeding the central shaft and light press fitting the outer diameter of the shaft in to the inner diameter of the bearing. Station-4: gravity feeding the mounting cap-1 and inserting the same on to the central shaft. Station-5: unloading the wheel assembly unit and inserting mounting cap 2 manually on the other side of the central shaft.

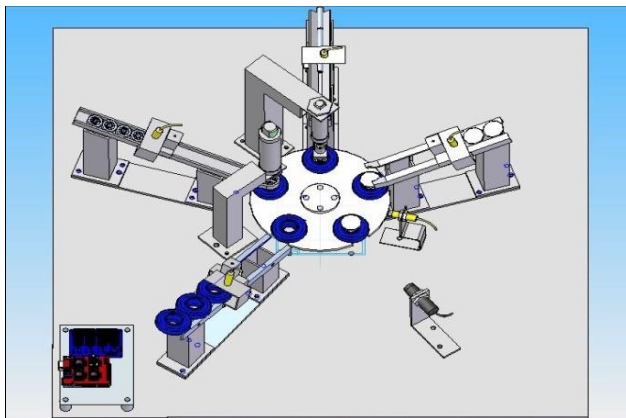


Fig -6: Rotary indexing table assembly 3D model with 5-stations.

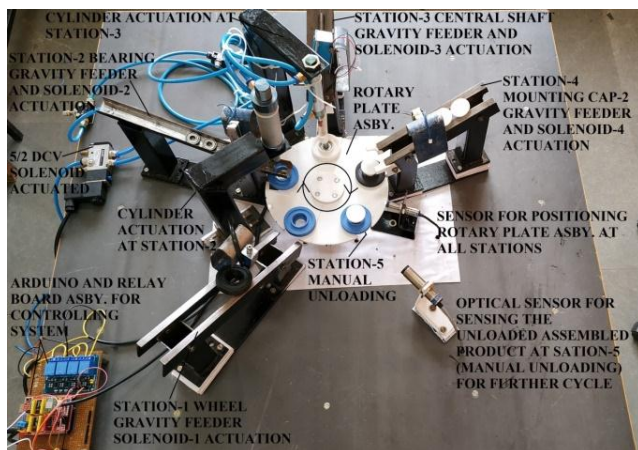


Fig -7: Rotary indexing table actual assembly.

Stepper motor produces rotation through equal number of step angle for each pulse supplied to its input. In this work a hybrid (variable reluctance and permanent magnet motors) form of stepper motor is employed and its specification are Nema 23 stepper motor with holding torque 10kg-cm, compatible with 2-phase stepper drivers, rated voltage 3.2V, phase current-2Amp, step angle-1.8°, 4-wire bipolar. The step angle of 72° is controlled by controlling the phase current.

PNP Proximity sensors are used in the present work to detect the presence of the object without any physical contact on the gravity feeder. It is also used exactly in between station-4 and station-5 to stop the rotary indexing plate for all the station operations to carry out. An NPN optical sensor is also used in the present work to make sure the object is removed from the rotary indexing plate.

For actuation of linear solenoid with push pull and double acting pneumatic cylinders are employed in this work. Solenoid actuation is used for stopping the parts in the gravity feeder and also employed for light press fitting the ball bearing, central shaft and mounting cap-1. Electro-pneumatic valves should be used if pneumatic cylinders are employed for actuation in press fitting.

3. CONTROLS AND SOFTWARE WORKING

In this work Arduino UNO [11] board is used for controlling the automation. The UNO [11] is a general purpose microcontroller board and most commonly used board in the Arduino clan [11]. It has 14 digital IO pins, 6 analog inputs, a 16MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button [11]. The Arduino UNO board is programmed with the Arduino software IDE (Integrated Development Environment) [11].

HMI software used in this work is GE's CIMPLICITY [12] which gives real time client-server envision and control from one machine to different plant locations bridging the world serving to manage operations and in making better decision [12]. From decades of GE's research and development, CIMPLICITY is the HMI and SCADA of choice for the world's largest organizations, manufacturers and utilities [12]. For applications of all sizes, software can help deliver faster response, reduced cost, and increasing the profit [12].

3.1 Block diagram of the control system

The block diagram as depicted in figure 8 shows the actual working of the control system logic adopted in the project work for effective working condition. As soon as the program prepared in the Arduino IDE software is uploaded from the system to the Arduino board using a universal serial bus (USB) cable the control system and all the equipment's connected to it starts to work. The actual work which is going to be done is as per the block diagram shown in figure 8. While as the project is in working condition then only CIMPLICITY HMI workbench can be started. The saved project in HMI can be opened in which the developed HMI screen as depicted in figure 9 is started that is by pressing run (start) button on HMI screen. As soon as the run button is started as depicted in block diagram rotary indexing plate which is connected to stepper motor starts to rotate. The proximity sensor which is placed in between station-4 and station-5 senses the aluminum metal foil which is pasted exactly in between all stations on the periphery of the rotary

plate and this sensing results in stopping the plate for 5s (depends on the cycle time). During this time all the respective station operations gets activated. The respective station operations are explained in next section that is 3.2.

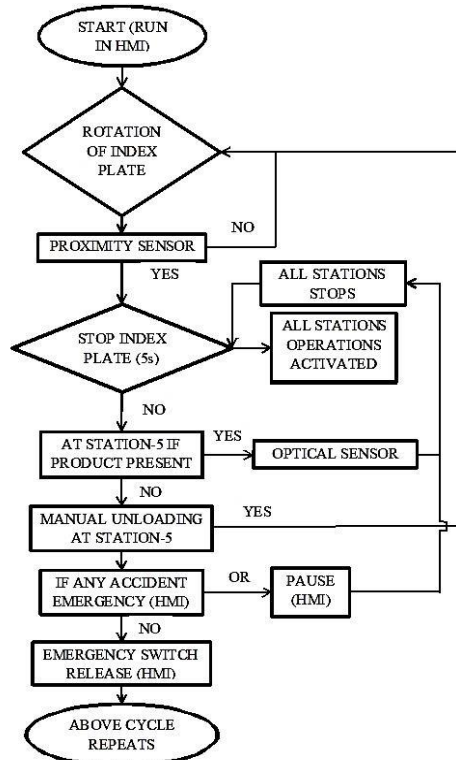


Fig -8: Working block diagram of the control system.

At the same time at Station-5 the completed product is unloaded manually. As shown in the block diagram at station-5, if and only if the assembled product is unloaded manually then the rotary plate indexes to the next station otherwise it will pause the machine and will not allow for next operation. Since because the optical sensor is placed at station-5 which will get to switched off condition then only the rotary plate indexes to the next station. Even if there is any accidents occur at any stations or on the rotary index plate an emergency switch is provided on the developed HMI screen and can be used. Or also the pause button can be used for stopping the machine for the required time, later the run button on HMI screen can be used to start the machine. After releasing the emergency switch on the HMI screen and also pressing the reset button at the same time in the Arduino board the machine starts normally otherwise the rotary plate will rotate continuously. At the end of the block diagram it is mentioned that the above cycle repeats since because this is a mass production machine.

3.2 Developing HMI

Developing HMI to an automated system which provides information to an operator on a screen with this operator can monitor and controls the process [12]. Human Machine

Interface (HMI) screen is depicted in the figure 9 showing all five stations and there operations.

Proximity sensor-5 which is placed in between station-4 and station-5 stops (5s) the rotary plate assembly for all stations to operate. Optical sensor-6 senses the presence of finished product if present it stops the rotary plate and only after unloading the product it allows rotary plate to index for further stations.

Station-1: a proximity sensor-1 senses the presence of wheel if present, solenoid-1 actuates to open and allow wheel to move on the gravity feeder and on to the rotary plate nest.

Station-2: a proximity sensor-2 senses the presence of ball bearing, if present solenoid-2 actuates to open and allow bearing to move on the gravity feeder in to the wheel. Solenoid-3 and 4 actuates from bottom and as well as from top for press fitting.

Station-3: a proximity sensor-3 senses the presence of central shaft, if present solenoid-5 actuates to open and allow shaft to move on the gravity feeder in to the wheel. Solenoid-6 and 7 actuates from bottom and as well as from top for light press fitting.

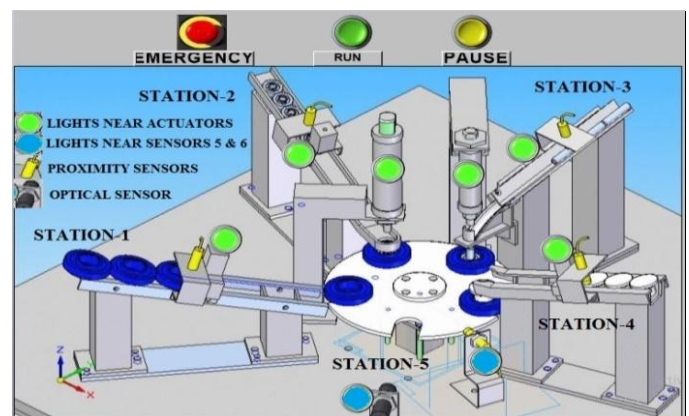


Fig -9: Developed HMI screen [13].

Station-4: a proximity sensor senses the presence of cap-1, if present solenoid actuates to open and allow cap-1 to move on the gravity feeder. Solenoid-8 actuates from top for insertion of cap.

Station-5: in this stage the completed assembled product is unloaded manually.

4. RESULTS AND DISCUSSIONS

As depicted in the figure 10 is the signal value of 1 or 0 of the proximity sensor observed in the HMI software having the address of 30001 in the program uploaded (A0 pin in Arduino) and fluctuations in the graph line can be seen because of the indexing of the rotary plate at each station. This value changing observation helps in developing the HMI

screen and also sensor performance. In the same way the other hardware devices signal performance can be observed in the quick trends window of CIMPLICITY HMI software.



Fig -10: Quick trends performance of A0 in HMI [13].

As depicted in the figure 11 is the signal value of 1 or 0 of the optical sensor observed in the HMI software and sensor having the address 30002 in the program uploaded (A3 pin in Arduino UNO board). Fluctuations in the graph line can be seen in the figure 11 is because of either assembled product presence or absence at station-5. Signal value normally will be 1 without any object at station-5, if there is any object present at station-5 it will be changed to 0 and in the graph line this can be observed which will be moving along zero line. Whenever the graph shows zero line then the machine will be in paused state, until the product is unloaded the machine will not start. This cycle is repeated for each cycle of the product assembly. This value changing observation helps in developing the HMI screen and also the optical sensor performance can be observed periodically.

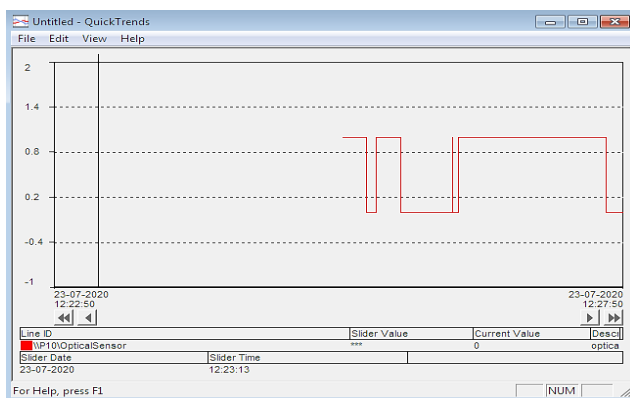


Fig -11: Quick trends performance of A3 (optical sensor address 30002) in HMI [13].

The time study method is considered for performance study. Figure 12 shows the actual performances of actuators and sensors with reference to time. The programmed actuations and sensing information are comparable with the actual operations.

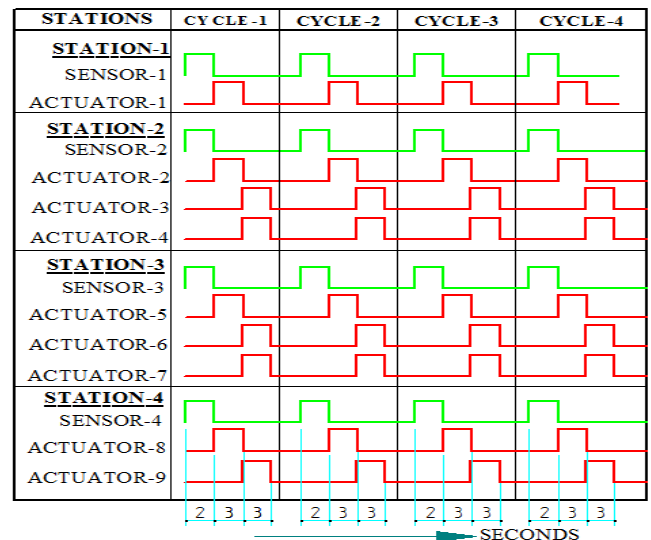


Fig -12: Performance study of developed automation system.

Each station an operating cycle of 10 seconds, including buffer time of 2 second. Inbuilt timer of micro second accuracy is used. The actuations and data acquisition system work appropriately as programmed.

5. CONCLUSION

The open source hardware and software is used for automating the assembly line. This makes the automation affordable to even small units and automating the assembly lines. Proposed automation can be justified on the basis of economy grounds. It is also showed that, small scale industry having the fewer assembly station can be automated with HMI to increase productivity by upholding safety.

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BIOGRAPHIES



CHIRANTH C. V.

DEPT. OF MECHANICAL ENGG.,
MALNAD COLLEGE OF ENGG.,
HASSAN, KARNATAKA, INDIA



SREE RAJENDRA

DEPT. OF MECHANICAL ENGG.,
MALNAD COLLEGE OF ENGG.,
HASSAN, KARNATAKA, INDIA



DR. CHANNAKESHA K. R.

DEPT. OF MECHANICAL ENGG.
SMT. L.V. GOVT. POLYTECHNIC,
HASSAN, KARNATAKA, INDIA

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