Remotely Accessible Injection Molding Machine for Manufacturing Education: Lessons Learned

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Abstract

Many household products were produced by injection molding machines. In educational settings, injection molding machines are used to teach mold design, properties of materials and manufacturing processes. This paper describes the process of converting a manual injection molding machine to be automated and remotely accessible. The retrofitted machine was evaluated by students during lab time. Students responded positively overall to being able to remotely access the machine, to seeing how a Arduino controller can be used in a real-life application, and to seeing a automated system in action. Suggestions include giving more time to use the machine, more labs and exercises to allow them to see how the machine works, and the ability to play with the system. Future directions include expanding the system to include the automating the process of feeding raw materials into the mold, unloading parts from the mold, and continuing to make different kinds of parts. This would allow students to both use the system to create parts remotely and learn how to make a system accessible over the Internet.

Motivation

Hands-on experience is an essential part of the manufacturing education program or degree. However, the cost of industrial scale equipment, limited lab time, and large student population have hindered this desired experience. The remote lab concept was first proposed in 1991 by a researcher at Purdue University who created a remotely shared control systems lab [1]. Researchers at Georgia Tech reported work on teleoperation of manipulators in the early 2000s [2-3]. Remote labs have received more attention as Internet technology has become mainstream. Remote labs ares designed to alleviate the challenges listed above [4-8].

According to Guinn [9], since the beginning of 2011, the manufacturing industry has added over 100,000 jobs to the economy. Economists expect this trend to continue, predicting that manufacturing employment will increase by another 230,000 jobs before year end. A recent KPMG International survey of manufacturing executives confirms this projection. Roughly 41% of US manufacturing executives plan to hire in the coming year. However, the required skill sets have shifted to be more software and high tech-oriented. There is great opportunity for people willing to learn injection mold making and tool making.

Objectives

The paper describes the process of retrofitting a manual injection molding machine to be automated and remotely accessible, and assessing students' response to the technology. The system will serve multiple purposes. First, it can be used as part of a manufacturing processes course to teach students about injection molding and process control. Second, it can be used in an automation and robotics course as a case study of how sensors and controllers can be interfaced with a machine to make it automated and remotely accessible.

System Design

The proposed design aims to fully automate the original physical system to enable remote control capability. The physical system change includes:

- The piston position manual control will be replaced by a solenoid valve.
- The mold clamp will be replaced by a screw-rod that is driven by a stepper motor.
- Pressure control knob and meter are replaced by an electronic pressure regulator, which also has the analog output of the pressure reading.
- Temperature close loop control is automated by a set of relays and thermal couple.

After the modification, all the control signals and sensing inputs are connected electronically to an Arduino microcontroller, which in turn connects to a computer (webserver). The server serves as both control system as well as the host of the web-based graphic user interface (GUI). The proposed software architecture is a python flask library-based webserver that is hosted and accessible to anyone in the network. The webserver also accesses video streams from two cameras on the system to give real-time video feedback.

Hardware Overview

The structure of the physical system is summarized in Figure .

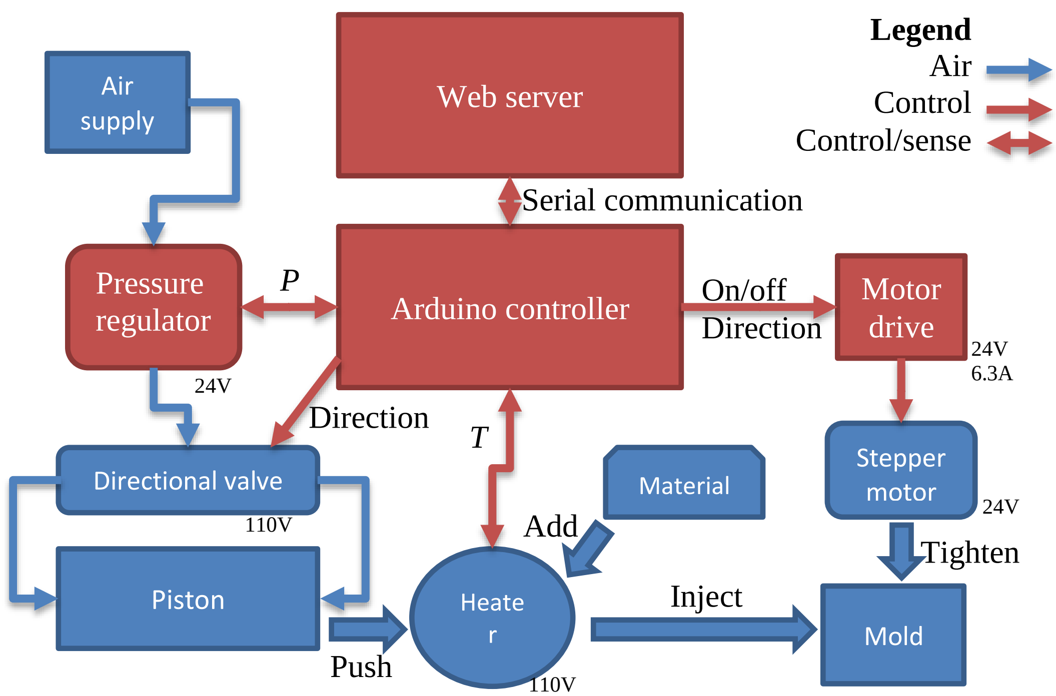

Figure 1. Remotely Accessible Injection Molding Machine System Architecture

The air supply is firstly connected to the pressure control valve, which sends pressure reading to as well as accepts settings from Arduino. The regulated compressed air is then sent to directional valve’s inlet, which is controlled by the Arduino again to decide if to extend or retract the piston. The heater is also controlled in the same fashion as the pressure regulator, except this time it is the temperature that is been regulated. The motorized clamp is driven by a stepper through a motor drive. The Arduino itself has two-way communication with the web server. The details of each of the components are detailed below.

Actuators

To enable remote control capacity, the following actuators are added to or substituted in the original physical system components in order to automate the process.

<u>Motorized mold clamp</u>
A heavy-duty stepper motor is added to replace the manual mold clamp. It is mounted directly to the original screw rod’s top, using shaft coupler, so the motor’s shaft can turn it, results in moving up and down. A slider fixture is installed to prevent the motor itself to rotate (Figure 2). The motor is controlled by Arduino controller through a high power (6.3A, 24V) driver. The driver is in the electrical box alongside the Arduino.

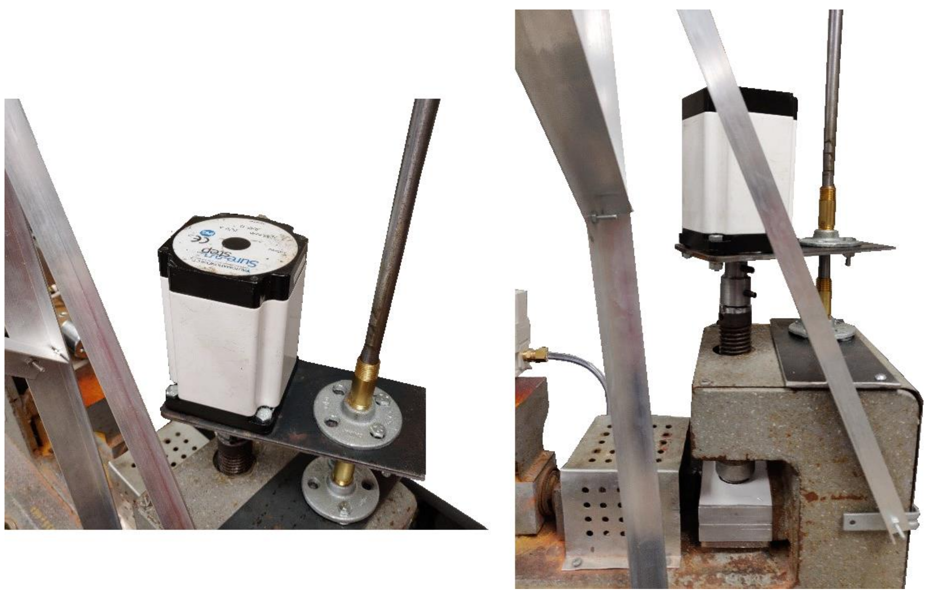

Figure 2. Stepper motor, threaded rod and fixture for mold clamp

<u>Solenoid directional valve</u>
To direct the compressed air to the piston for extending (for material injection) and retracting automatically, the old manual directional valve (Figure 3) is replaced with a solenoid valve (Figure 4).

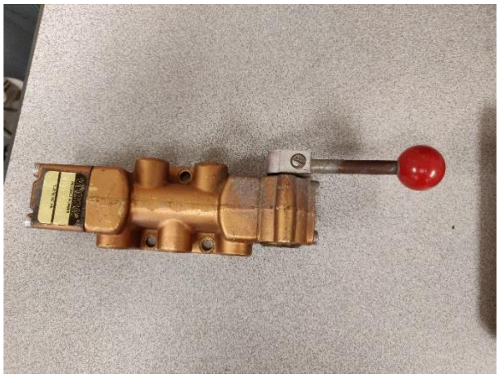 

Figure 3. Original manual directional valve. Figure 4. New solenoid directional valve.

The solenoid directional valve has three positions, outlet A on, all closed, and outlet B on. It has two 110V AC solenoids that are mounted to both end of the valve to move the spool inside of the valve to change the positions. When the left one is energized, outlet A is connected to the compressed air supply (and B to the exhaust hole), thus retracts the position. When the right one is energized, it extends the piston instead. When both are deenergized, both outlets are blocked, and the piston chamber can retain its pressure, so piston retains its current position.

<u>Electro-Pneumatic Regulator</u>

A proportional electro-pneumatic regulator from SMC is used to regulate the air pressure, replacing the original manual pressure valve (Figure 5). The valve is operating on 24V. It has four pins: +24V, GND, input signal and monitoring output. It controls the output pressure to the injection cylinder based on the PWM input signal from the Arduino. It can also report the current readings of the output pressure on its monitoring output pin, which also connects to the Arduino. The valve also features a small LED screen to show the current pressure.

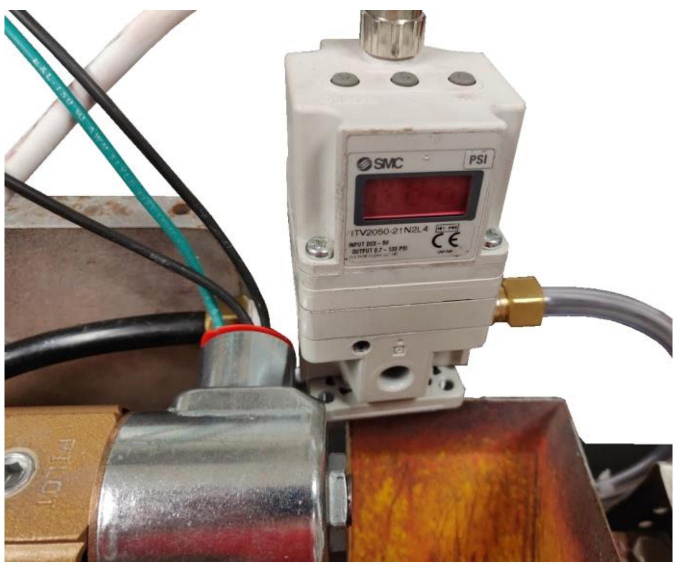

Figure 5. Electro-pneumatic regulator

Camera setup

Two cameras are added for real-time video feed of the system from different angles (front and top views, respectively). The top view camera is set up to monitor the material feeder and piston extension, and the current position of mold clamp (Figure 6). The front view camera is set up to look at the front panel and the overview of the whole system (Figure 7). It can show the indication light, gauges on front panel, and readings on pressure sensors. Example capture results of the cameras are shown in Figure 8.

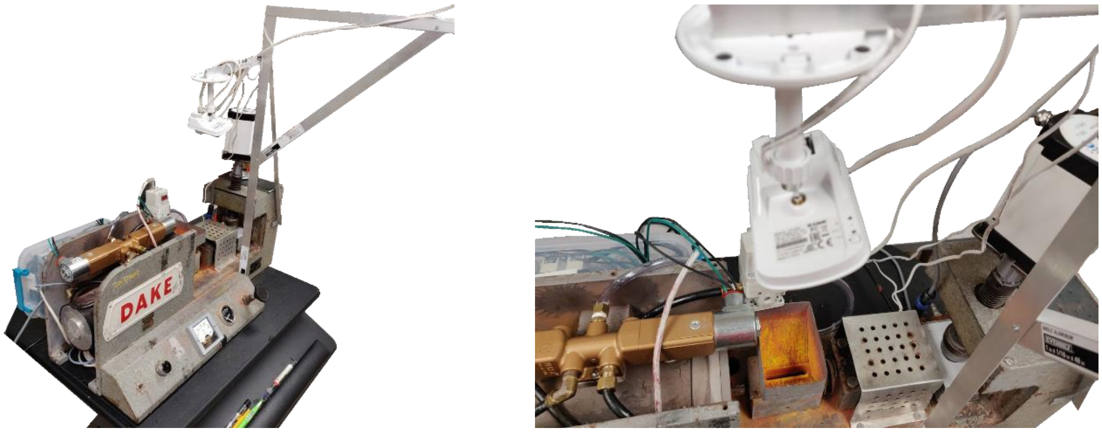

Figure 6. Top camera and its field of view

Figure 7. Front camera and its field of view

Figure 8. Camera image capture examples

Control system

An Arduino Mega microcontroller is adopted as the core of the physical control system (Figure 9). Arduino is an open-source electronics platform based on easy-to-use hardware and software that can be programmed in C. The language can be expanded through libraries [1].

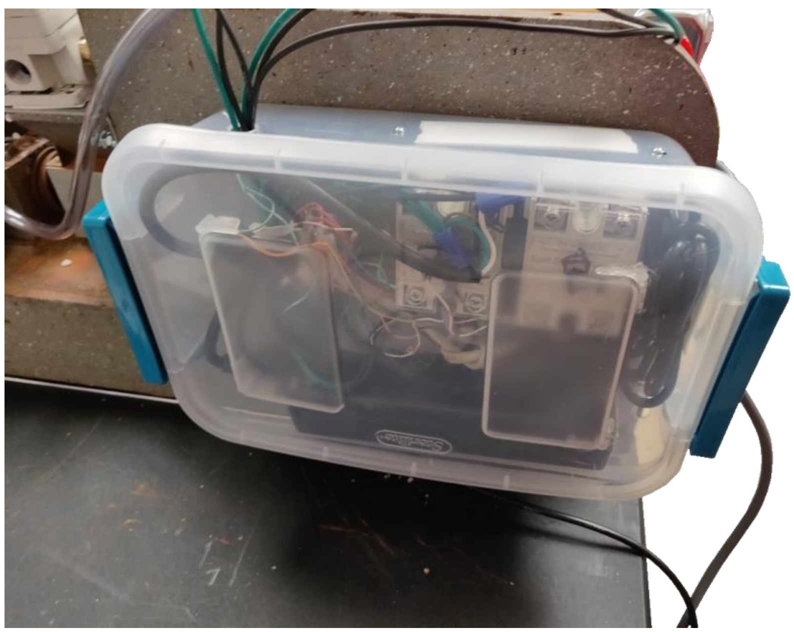

Figure 9. Control system box including Arduino, motor drive, power adapter and two relays

In the developed system, the Arduino controller is in charge of all the low-level controls, including receiving the input signals from two sensors, sending out signals to the actuators. The Arduino itself communicates with a web server through serial port (USB on computer side). A two-way serial communication between the two is used to bring the high-level control from the server to the Arduino, as well as to pass the sensory readings and system status to the server.

Software Design

The diagram in Figure 10 shows the interaction between user, server, and hardware. The web server can be described as two parts, backend and frontend (interface). It also has a small datafile used for storage. The Arduino is used to interact with the machine directly as a proxy of the web server. The camera system is a separate standalone system running on their own. Only their video/image streams will be incorporated into the final UI.

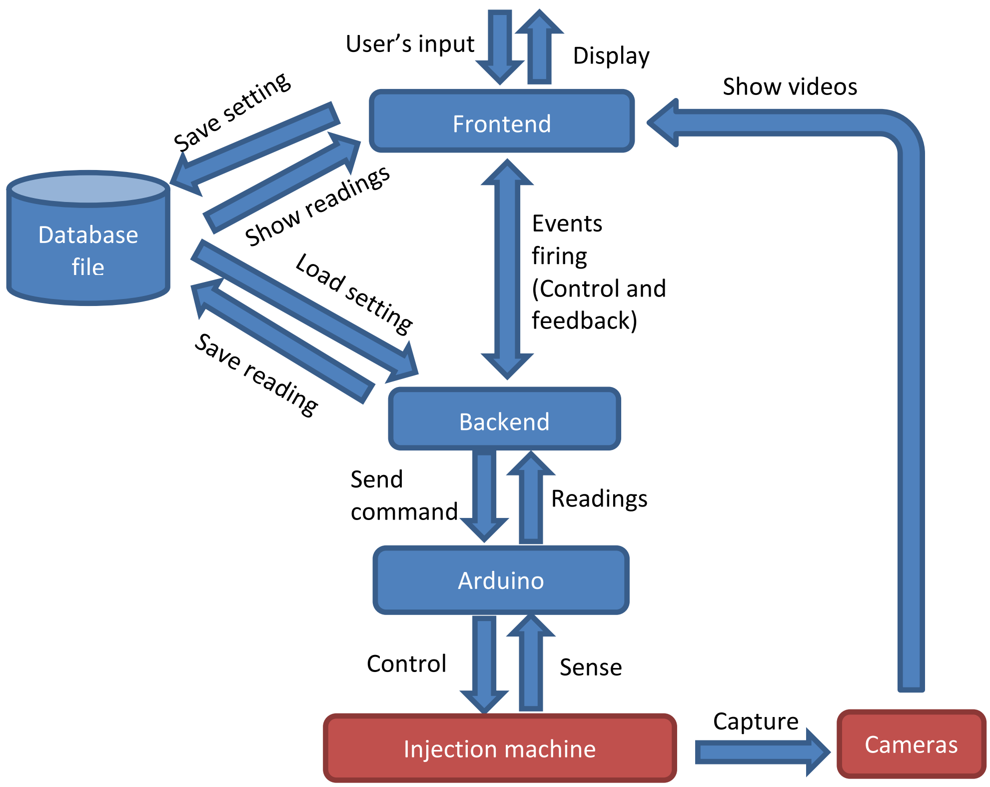

Figure 10. Software architecture

User interface

The user interface (Figure 11) of the application is a single-page app built using Jinja template engine and rendered by the Flask. The event handling on the front-end is handled by a Socket IO JavaScript module. A CSS grid design is adopted to have better flexibility on the layouts. It makes arranging and aligning elements much easier, as well as that it can fit into varying screen size.

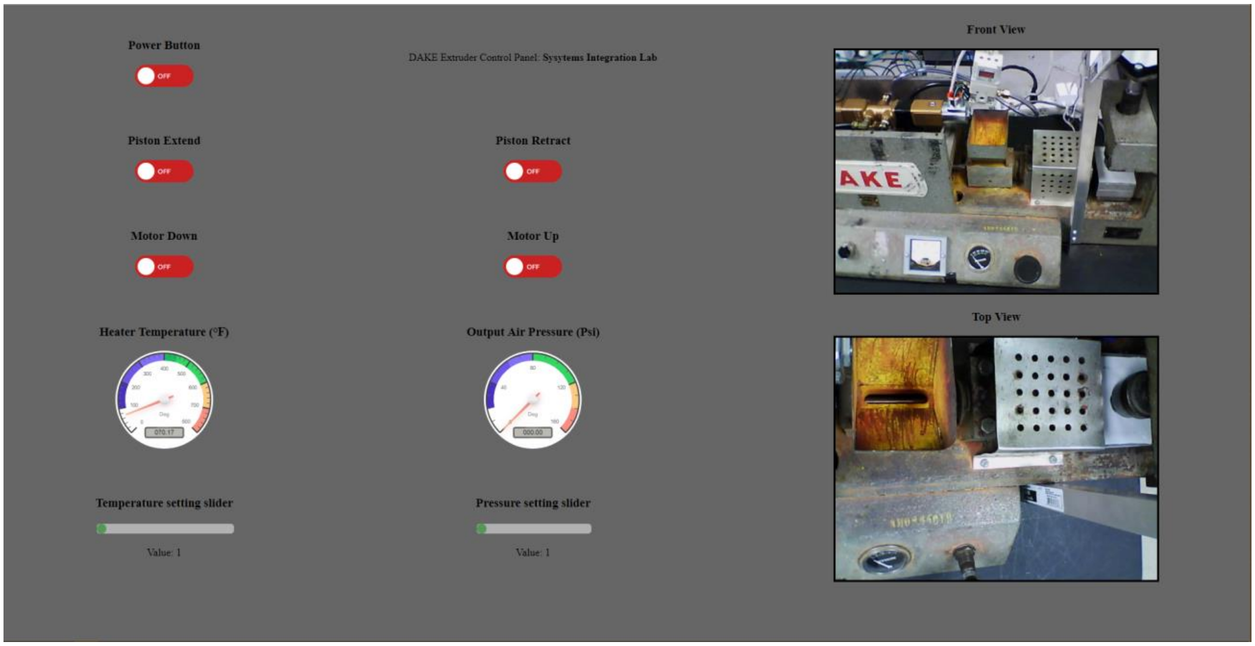

Figure 11. Graphical User Interface of the Remote-control System

The user interface features several control switches for power, piston, and motor, along with temperature and pressure monitoring displayed in an analog-like dial similar to the actual physical gauge. There are also sliders to control the temperature and pressure of the equipment remotely. The views from cameras are also inserted into the page. This layout was chosen to make the user interface as identical to the physical equipment as possible. The analog gauges give the exact feel of that on the machine. From top to bottom, on the left side:

- Power button
- Piston control buttons, extend and retract
- Mold clamp motor buttons, up and down
- Heater temperature gauge and air pressure gauge
- Heater temperature control slider and pressure setting slider.

On the right, there are two camera views for visual feedback on what is happening, which assist the user. Via this user interface, user can (1) turn on and off the system, (2) control the solenoid to move the postion forward and backword, (3) set up the temperature of the furnace and air pressure for piston, and (4) monitor the system operation via Webcam images.

Evaluation

The remote injection molding machine was evaluated by 51 undergraduate students. The goals were to determine students' opinions about various aspects of the remote injection molding machine, such as user-friendness, features, objective, emphasis on important information, use of multimedia, and relevance to their education.

All students provided ratings and comments on an opinion survey using a 7 point Likert scale (1=strongly disagree; 7=strongly agree). Figure 14 shows students' average ratings. Results suggests that students liked all aspects of the system, especially the interface design, which had an average of 6.5 on the 7 point scale.

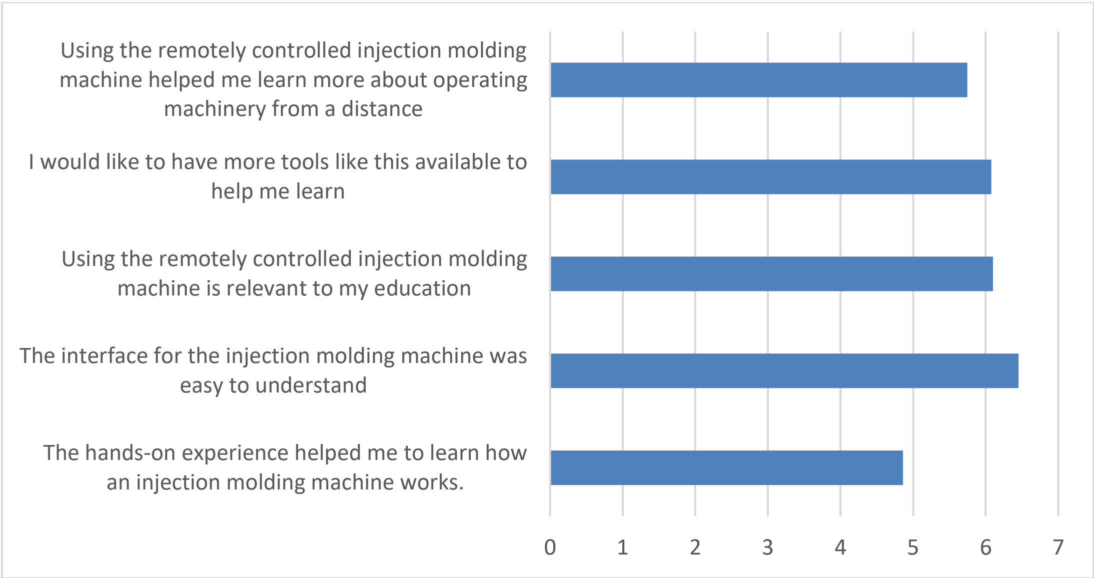

Figure 14. Results from opinion survey of undergraduate students about the remotely accessible injection molding machine.

Student Comments

In students' responses to the question "The most helpful thing about this project has been:" a common theme was that the hands-on, visual experience was helpful to learning. Below are some sample responses:

- The video feed to see what was actually happening
- Seeing the immediate changes
- Having the ability to run the machine gave me a better perspective on how machines can be used at a distance
- Pressure gauges/temp guages, cameras
- Seeing how a PLC would operate for a real life use
- Understanding the applications of PLCs/Value of PLC Systems
- Using it remotely allowed a look into operator secreen control
- Seeing the remote operation in use
- Being able to apply what is learned in class/lab to real world situations
- The interface for controlling the machine is intuitive
- Effects of air pressure and temperature
- Learning how to remotely operate a machine
- Operating the machine was the most helpful
- Being able to use cameras/The views w/ the camera

- Being able to operate the machine in real time helps with the understanding of automated systems
- The software hardware interface
- Getting hands-on experience with the HMI
- Convenience - do not have to be physically present
- Gave me an understanding of real world applications of what were learning
- Seeing material in real life
- Getting instant feedback through the camera
- Understanding how the system is monitored for different variables
- The distant view to see all components working together
- This gives us instant feedback
- Using the cameras to observe clamps

In students' responses to the question "This project could be improved by:" common themes were (1) more time and more examples to see how the machine work; (2) more detailed explanation about how the system was built and how it works; and (3) examples of how good parts are made. Sample comments are below:

- The interface was very buggy when the sliders were used
- We had more time to use the machine.
- More machines
- A larger variety of examples
- The process was explained a little more in depth
- If we could actually use it to create some parts and see in person how it was connected to the internet
- You could actually injection molding something and knew what the motor did
- Example of full press and results uere first implemented
- An object was created by the injection molder
- The motor was spun up more than 2 times so students could lower it more than twice
- An actual task was performed
- Better lighting

Conclusion and Future Directions

In this paper, we have described the process of converting a manually driven injection molding machine into an automated system. We also developed a software architecture that integrates sensors, actuators, and a controller to provide remote access capability. Pilot testing with undergraduate students suggests that tools like this are of great interest to students. The students provided constructive suggestions such as provide more labs and exercises that allow them to see how the machine works, and allow them to be able to play with the system. Future directions include expanding the system to include the loading of materials to the furnace, and automation of the process of unloading parts from the mold and continuing to make different kinds of parts.

Acknowledgements

This material was supported by the National Science Foundation's Advanced Technology Education Program (award no. 1304843). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

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