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Research Article

Design of Control System for Desktop Injection Molding Using Raspberry Pi 3 B+

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A B S T R A C T

Injection molding is one of the techniques used to create plastic items. Plastic goods with good dimensional tolerances are frequently made using the efficient, accurate, and cost-effective injection molding process. The advantages of injection molding include quick product production, accurate process execution, cheap labor costs, automation of the process, and the ability to produce large quantities of items. There are many benefits to using a controller as a measuring device when injection molding. Making injection molding equipment easier to handle and observe is one of them. The process of regulating or controlling one or more quantities (variables) so that they are at a specific objective is known as a control system. In this study, a compact, mobile, automatic plastic injection machine that can create small plastic objects was developed. This was to overcome several issues that still exist in the present application of injection molding control. The design process is developed using the Python programming language, and the control system is a microcontroller of the Raspberry Pi type that has a complete architecture, including Wi-Fi and Bluetooth modules, as well as a lot of memory. A NEMA 23 stepper motor with a torque of 2.2 Nm and a TB6600 motor driver are used in the drive system to control the voltage and rotation of the motor. A band heater-type heating element with a maximum working temperature of 350°C at 220 volts is used in the heating system. A desktop program running on a 7-inch TFT display will show the process of controlling and monitoring the device.

1. INTRODUCTION

Polymer-based goods are manufactured in large quantities because they are inexpensive, simple to shape into a variety of goods, and have a high economic value. Injection molding is one of the production processes used to create items made of polymers [1].

Injection molding is the technique of creating an item or product out of plastic material that has a specific shape and size and is then heated up and put under pressure using mold-like tools [2].

Plastic goods with good dimensional tolerances are frequently made using the efficient, accurate, and productive injection molding method, which is also very inexpensive. Many people choose injection molding because it has a number of benefits. Making features like difficult-to-form forms, rapid production rates, minimal material utilization (useless material), automatic control, and low labour requirements are a few of them [3].

The basic idea behind injection molding is that the plastic material is placed into a container (hopper), transported by a revolving screw into the screw (barrel), and then melted in the barrel by a heater

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(heater) with a temperature-controlled flame. Once it has melted, the plastic will be ready to be injected into the mold. The mold will close under a particular amount of pressure prior to the injection process, and the plastic liquid will be injected into the mold or molds. After this, a holding procedure takes place to perfect the product and withstand back pressure. Following that, a charging and cooling procedure takes place, which is beneficial for filling material and cooling the plastic product in the mold. After the mold is opened, the ejector will remove the cooled plastic product [4].

The advantages of injection molding include quick product production, precise operations, cheap labour costs, the ability to automate processes, and the ability to produce items in large quantities [5].

The design of Injection Molding, which employs the HDX 328 PLC TECH2 control, uses three DC motors, two of which serve as screw drives and one of which presses the plastic pressing lever into the mold. Goodship Middleton's research supported the control system. The heater is a band heater type. The injection volume is 30 cm, the maximum injection pressure is 45 bars, and the highest temperature produced by this injection molding is 400°C. The device's capacity for plastic material is 100 kg per process, and it is autonomous and quick to cool. The negatives include high maintenance costs, prolonged cycle durations for movement, and high electrical power requirements [6].

J. Avery's subsequent research involves the design of an injection molding machine that uses a Raspberry Pi 4 microcontroller module, six different types of band heaters, PID heater control, five different types of stepper motors for propulsion, two motors for screw driving, three motors for pushing a pressure lever, and two power supplies to divide the electric current input. As a result, the injection machine's pressure can reach a maximum of 100 kg/cm2 and can be controlled for temperature. The quick cooling in the mold and the user-friendly interface are the tool's strengths, while its sluggish cycle time, bulky size, and high electrical power requirements are its shortcomings [7].

According to the studies mentioned above, the control system design is still quite large, consumes a lot of electricity, and is generally quite expensive. As a result, a desktop injection molding design that is compact, portable, automatic, simple to operate, and affordable was developed.

2. METHODOLOGY

To design a desktop injection molding control system is the aim of this research. Python programming on a Raspberry Pi microcontroller is used in this study. A desktop application will manage and keep an eye on the design. The flowchart in Figure 1 shows the steps of the procedure that were used.

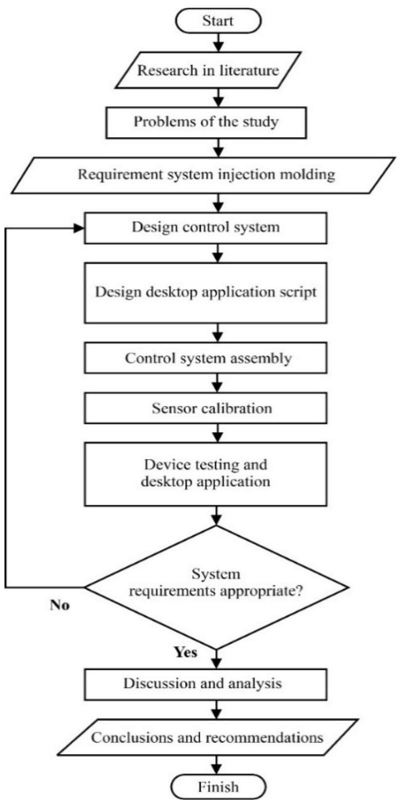

Figure 1. Research of Flowchart

2.1. Design Control System

The system is made up of a number of closely related components that work together to accomplish specific objectives [8].

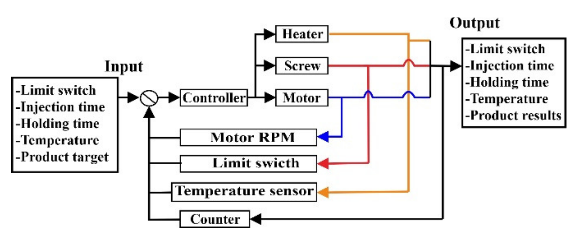

Figure 2. Schematic Block Control System

The system has a number of inputs (limit switch, injection time, holding time, temperature, and product target) [9].

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The microcontroller in this system will operate the attached motor, screw, and heater, with the motor speed being controlled by a motor driver and the heater temperature being detected by a temperature sensor. The microcontroller module processes the value read by the sensor and generates a number of outputs, including a limit switch, injection time, holding time, temperature, and amount of product produced.

2.2. Electrical Schematic Injection Molding

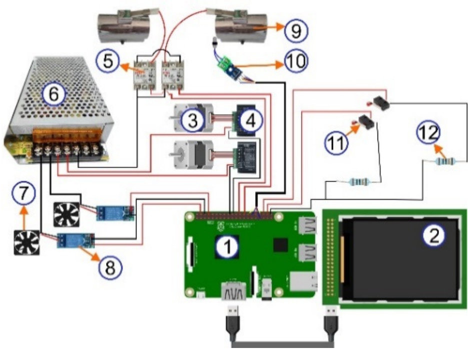


Figure 3**.** Wiring Schematic

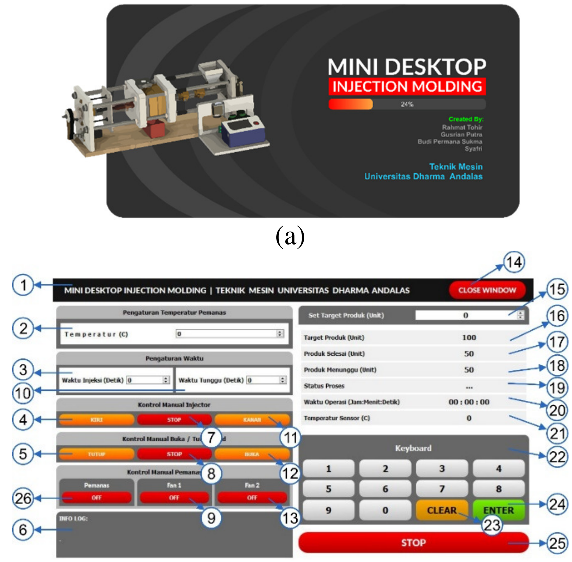
Using Figure 3, the following details and elements are used:

1. Raspberry Pi 3 B+
2. TFT display 7 Inch
3. Motor stepper nema 23
4. Driver motor TB6600
5. Solid state relay
6. Power supply 24V 30A
7. Fan Delta 12V 0.10A
8. Relay 1 channel Tongling 5 VDC
9. Band Heater 220V
10. Temperature sensor MAX 6675
11. Limit switch 3 pin
12. Resistor

3. RESULT AND DISCUSSION

3.1. Design Desktop Applications

Based on Figure 4, the name of the injection molding tool is indicated by the tool name label (1). The injector is controlled manually by the motor stop button 1, the motor left button 1(4), the right motor button 1, and the components of the set temperature spin box (2), injection time spin box (3), and holding time spin box 2. Manual controls for opening or closing the mold are included in the motor mold close button 2 (5), motor open mold button 2 (12), and motor stop button 2 (8). The heater, fan 1, and fan 2 can be manually turned on using the heating button components (26), fan button 1 (9), and fan button 2 (13). The process status when the tool is to be utilized is represented by the info log component (number 6). A button to close or quit desktop programs is part of the close button component (14).



(a)

(b)

Figure 4**.** (a) Splash Screen and (b) Home

Information:

1. Tool name
2. Spinbox set temperature
3. Spinbox injection time
4. Button left motor 1
5. Button close mold motor 2
6. Process state
7. Button stop motor 1
8. Button stop motor 2
9. Button fan 1
10. Spinbox holding time
11. Button right motor 1
12. Button open mold motor 2
13. Button fan 2
14. Button close
15. Set product target
16. Product target
17. Product finish
18. Product waiting
19. Process state
20. Time operation
21. Temperature sensor
22. Button keyboard
23. Button clear
24. Button enter
25. Button start
26. Button heating

The product target set spin box component (15) has a parameter where you can enter the value you want to produce for the product target set. Control metrics for observing the production of products include product target label elements (16), finished products (17), and waiting products (18). The process status component (19) serves as a label to indicate whether the device is "stopping" or "running" at the moment.

The operational time component (20) is used to calculate how long the tool will take to process information while it is "running". Determine the current temperature from the sensor using the sensor temperature label component (21), a component. The keyboard component (22) is used for value input in desktop application requirements. If a value does not suit your needs, you can eliminate it by pressing the clear button component (23). When a value has been "inputted," the enter button component (24) is the button component that executes the "Save" command. The start button component (25) is the button for initiating and terminating automatic processes.

3.2. Results of the MAX6675 Type K Thermocouple Sensor Calibration

The infrared thermos gun, a measurement device that uses the same principles as a temperature sensor, is used to calibrate the MAX6675 type K thermocouple sensor. In order to determine whether the sensor is correctly calibrated, it is necessary to compare the values that the sensor and measuring instrument read.

Table 1. Results Sensor Calibration MAX6675

Temperature Set (°C)	Average ($\bar{X}$) Thermogun Infrared (°C)	Average ($\bar{X}$) Sensor (°C)	Margin Error	% Error
50	50.74	50.4	0.3	0.67
100	100.9	100.4	0.5	0.49
150	150.5	150.4	0.1	0.06
200	200.9	200.6	0.3	0.14
250	251.4	251.0	0.4	0.15
300	302.3	302.0	0.3	0.09
		Average ($\bar{X}$)	0.32	0.26

Six calibrations are performed, after which the sensor reads the data based on the parameters of the heated coil. The heating tube is not filled with plastic pellets throughout this barrel calibration operation. Table 1 displays the calibration data results.

Based on the calibration data results presented in Table 1, the first experiment was conducted by setting the heaters temperature value to 50 °C. Once this temperature was reached, the sensor average reading was 50.4 °C, and at the same time, the average temperature value was 50.4 °C. The infrared thermometer recorded a temperature of 50.74°C. The margin of error in the calibration experiment at 50°C was 0.34, with a percent error of 0.67%. Whereas the overall calibration process average margin of error is 0.32, with an average percent inaccuracy of 0.26%. On the sensor and the infrared thermometer, it is evident that the temperature values are not significantly different. This is due to the sensor comparatively high level of precision and accuracy.

In Figure 5 below, the outcomes of this sensor calibration are displayed.

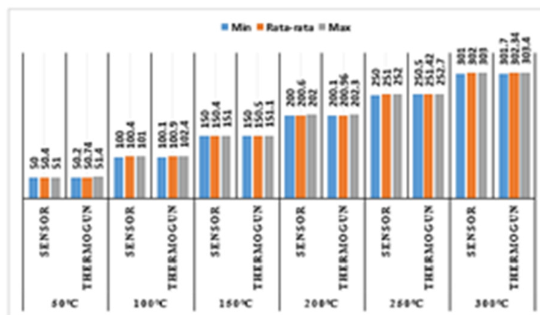


Figure 5. Graph results of the calibration of a type K thermocouple sensor MAX6675

Three different sorts of colours are displayed on the graph in Figure 5, which is a sensor calibration. The sensor and infrared thermometers minimum value is shown by the colour blue, while the average temperature is shown by the colour orange, and the maximum temperature is shown by the colour grey.

Comparisons between the minimum value, maximum value, and average value for five tests in each measurement temperature range are shown in the three different types of colour graphs above. The smallest value that can be read by the sensor in the calibration measurement range of 50°C is 50°C, while the minimum value that can be read by the infrared thermometer is 50.2°C. After six tests, the average temperature measured by the sensor is 50.4 °C, and the average temperature read by the infrared thermometer is 50.74°C using the same range of calibration measurements. Whereas the sensor maximum reading is 51°C, Themo gun Infrared maximum reading is 51.4°C. The calibration measurement range also extends to 300°C.

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The graph also shows that there is not a huge difference between the minimum, maximum, and average numbers the sensor reads. This demonstrates that the sensors' rather high level of precision was determined from the results of the six tests.

Figure 6 below depicts a linear regression graph that illustrates how the values received by the sensor and the values read by the standard measuring device relate to one another.

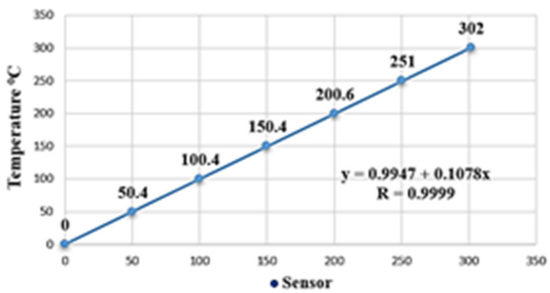


Figure 6. Graph sensor linear regression

Based on Graph 6 and Table 2, the constant value (intercept) for the regression is equal to 0.9947, and the constant value (slope) is equal to 0.1078. Therefore, the linear regression equation is Y = 0.9947 + 0.1078x, where the correlation coefficient value is 0.9995. This indicates that the measuring device and the sensor have a very strong association because the correlation coefficient value is in the range of 0.8–1.00. So, it can be said that the sensor has a very high degree of accuracy and has been correctly calibrated.

Table 2. Statistic Regression Sensor Calibration

Statistic Regression	
Coefficient correlation	0.999995809
Coefficient determination	0.999991619
Standard error Experiment	0.3443420226

3.3. *Functional Testing Desktop Applications*

To make sure that each test object behaves as expected in each test scenario, desktop application functional testing examines each test object using a variety of test cases. Figure 7 displays the outcomes of this desktop application's functional testing.

Based on Figure 7, it is possible to see the outcomes of the tool's functional testing procedure both during and after testing. The outcomes of the functional testing can be seen in Table 3 to understand the methodology.

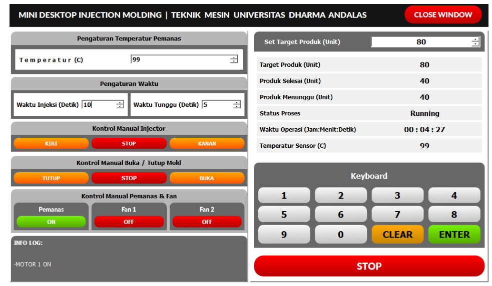
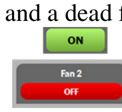
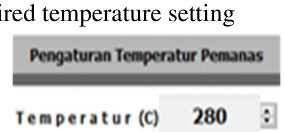
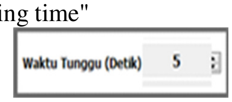
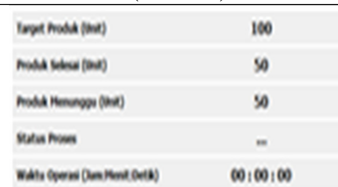


Figure 7. Desktop Application

Table 3. Results Testing Functional Desktop Application

Object	Scenario
Button Start	The system will show the automatic process state as "Running" if you click the start button  **(Success)**
Button Stop	The system will show the status "Stop" for the automatic halt procedure if you press the stop button  **(Success)**
Button Close	The system will terminate the desktop application if the close button is clicked  **(Success)**
Button Heating	The system will show the status "On" for the heater being on and the status "Off" for the heater being off if you touch the heater button   **(Success)**
Button Fan 1	If you push the Fan 1 button, the system will show an "On" status for the fan that is on and an "Off" status for the fan that is off  **(Success)**
Button Fan 2	When you push the Fan 2 button, the system will show the status of a live fan as "on" and a dead fan as "off"  **(Success)**

Object	Scenario
Button Enter	If you press the Enter key, the system will execute the "Save" command to enter the entered value  (**Success**)
Button Clear	The "Delete" command will be carried out by the system if you press the clear button  (**Success**)
Button Keyboard	The system will carry out the "Input" value command if you press the keyboard key  (**Success**)
Button Left Motor 1	Motor 1 will move to the left if the left button on the motor is pressed  (**Success**)
Button Right Motor 1	Motor 1 will move to the right (CW) if you press the right button on the motor  (**Success**)
Button Stop Motor 1	Motor 1 will "stop" if the stop button is pressed  (**Success**)
Button Close Motor 2	The motor 2 will close the mold "CCW" if you press the motor 2 close button  (**Success**)
Button Open Motor 2	If pressing the open motor 2 button, the mold "(CW)" will be opened by motor 2  (**Success**)
Button Stop Motor 2	The motor will "stop" if you press motor stop button 2  (**Success**)
Spinbox Temperature	The system will display the "set temperature" value if you enter the desired temperature setting  (**Success**)
Spinbox Injection Time	The system will display the "set temperature" value if you enter the desired temperature setting  (**Success**)
Spinbox Holding Time	If you enter the waiting time value, the system will display the value "Waiting time"  (**Success**)
Spin box Set Product Target	The system will display the value "Product target set" if you provide the product target set value.  (**Success**)
Monitoring - Product target - Product finish - Product waiting - Process state - Time operation	 (**Success**)

3.4. Functional Testing Tool

The tools functional testing seeks to test every test object using numerous test scenarios to make sure that they all work as expected for the scenario. Figure 8 depicts the desktop injection molding device.

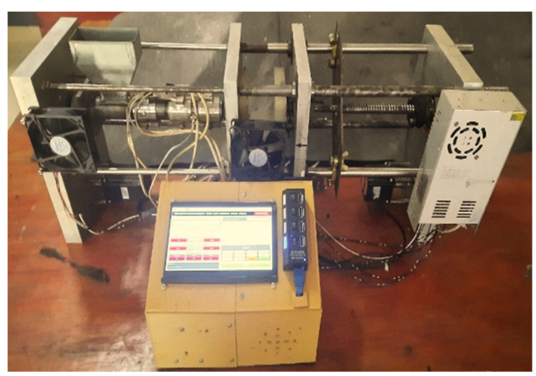


Figure 8. Tool Injection Molding

Figure 8 shows that the desktop injection molding tool performs in accordance with the design. Table 4 shows the process and the outcomes of the functional testing.

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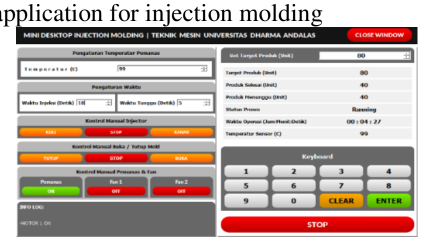
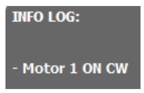
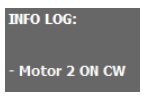
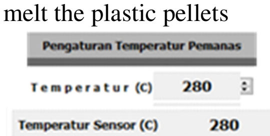
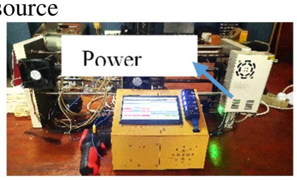
Table 4. Results Functional Testing Tool

<table>
<tr><th>Object</th><th>Scenario</th></tr>
<tr><td>Display</td><td>The touchscreen can be used to access the display, which will show the desktop application for injection molding

(Success)</td></tr>
<tr><td>Motor 1</td><td>Motor 1 will rotate at a speed of 200 rpm to drive the extruder screw, which is moving to the right

(Success)</td></tr>
<tr><td>Motor 2</td><td>Motor 2 will rotate at a speed of 200 rpm to open and close the mold, which moves to the right and left

(Success)</td></tr>
<tr><td>Heating</td><td>According to the desired temperature, the heater will heat the barrel (heating tube). Between 200°C and 300°C, the heater will begin to melt the plastic pellets

(Success)</td></tr>
<tr><td>Fan</td><td>Step 4 of the procedure, the cooling process phase, will dictate how the fan rotates

(Success)</td></tr>
<tr><td>Limit Switch</td><td>The motor will stop when the limit switch is depressed. At process steps 2 and 4, the limit switch is pressed

(Success)</td></tr>
<tr><td>Power Supply</td><td>In order to turn on the motor and fan, use a current input divider. The motor and fan can be started with the help of the 24 V, 30 A power source

(Success)</td></tr>
</table>

4. CONCLUSIONS AND RECOMMENDATIONS

Conclusions from the study that has been done can be reached based on the descriptions and explanations that have been offered. The following are some possible conclusions.

The authors of this work were successful in constructing a desktop program to operate and monitor injection molding tools that are based on microcontrollers. The injection molding tool is in compliance with the functional design based on tool functional results and desktop application functionality, as there are no test scenarios that fail during functional testing.

Based on the calibration of the thermocouple sensor, the correlation coefficient is R = 0.9995, the average margin of error is 0.32, and the average percent error is 0.26%. This demonstrates that the sensor has a very high level of accuracy and has been correctly calibrated.

A microprocessor of the Raspberry Pi type was used to control the design process. This microcontroller has a complete architecture, including Wi-Fi and Bluetooth modules, as well as a large memory capacity. A NEMA 23 stepper motor with a torque of 2.2 Nm and a TB6600 motor driver are used in the drive system to control the voltage and rotation of the motor. A band heater type heating element with a maximum working temperature of 350°C at 220 volts is used in the heating system. A desktop program running on a 7-inch TFT display will show the process of controlling and monitoring the device.

The ideas for this injection molding tool can still be improved, specifically how to make the heater operate better so that it heats up more quickly. Moreover, in order to boost production rate, the motor speed must also be increased.

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