Automated Liquid Dispensing System

Sami Suteria

Undergraduate Computer Engineering

Texas Tech University

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Lab Partners

Carlos Alban
Rustin Harris

Abstract

This paper describes an automated liquid dispensing system. The system can dispense a prescribed and measured amount of liquid. The system has applications in manufacturing and food service where precise amounts of liquids are needed. The system also uses a three-axis arm to place and retrieve a container that the liquid is dispensed into. The system is controlled by a Texas Instruments MSP430 microcontroller and the user interface served by a Raspberry Pi computer. Liquid flow through the system is measured by flow meters and controlled by solenoid valves. Results and observations were measured and recorded with water as the liquid moving through the system.

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1. Introduction

The system is designed to automate liquid dispensing to create mixtures of the base liquids. The system consists of four primary parts – the dispensing system, the three-axis arm, a microcontroller, and a computer. The dispensing system was a wooden stand with liquid containers, tubing, inline pumps, flow meters, and solenoid valves. The three-axis was printed in PLA plastic and movement is controlled by servos [1][2]. The microcontroller the system uses is a Texas Instruments MSP430G2553 on a Launchpad development board [3]. The computer used was a Raspberry Pi running a version of Linux called Raspbian [4][5]. The computer was acting as a web server and the serving the user interface as web pages written in PHP [6].

The system is designed so a single user who is viewing the user interface on a tablet or phone web browser can operate it. The user would select a mixture from the list on the interface and then place a cup on the arm. The arm would move the cup under the dispensing system then the dispensing system. The dispensing system uses halls-effect flow meters to measure flow through the tubing and would open solenoid valves to dispense a liquid till the prescribed amount is dispensed. After all liquids are dispensed, the arm would move the cup back to the user then go to standby mode till another mixture is requested.

2. The Dispensing System

The dispensing system is a collection of independent systems for each liquid that are all attached to a wooden stand. Each liquid has a storage container, flow meter, pump, and solenoid valve. Brass and PVC plumbing connectors along with clear plastic tubing are used to connect everything and to direct the flow of liquid from the storage to the end area. The dispensing system is built so that 17 separate liquids could be dispensed although for testing only 3 were used. The flow of the liquid can be seen in Figure 1.

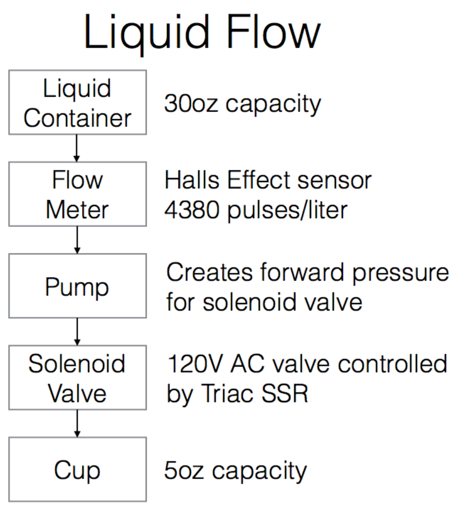

Figure 1 - Liquid Flow Diagram [7]

The flow meter is a magnetic fin and a Hall Effect sensor. When water flows through the flow meter, the fin spins and triggers the sensor. The flow meter's output pin outputs a signal that is a series of pulses. The frequency of the pulses determines the flow rate through the meter. The flow meters used in the system pulsed at a rate of 4380 pulses per liter [8]. An example of the pulses can be seen above in Figure 2.1. The flow meters are three pin sensors – Ground, Output, Vin. The output is series of pulses that pulse from ground to Vin. Since the output max voltage is the same as Vin, the 3.3V from the microcontroller was used to power it and no isolation was used between the output of the sensor and the input pin of microcontroller.

The pump is a DC motor that spins a fin to move water from the input valve to the output valve. The pumps operate at 12V DC and has to be electrically isolated from the microcontroller. An opto-isolator, the PS2501-4 [9], was used to isolate the pump. A 100 Ω resistor was used on the input (microcontroller side) and a 1kΩ resistor on the load (pump) side.

The solenoid valves are spring loaded solenoids that open to allow liquid to flow though when voltage is applied to them. The solenoid valves operate at 120V AC and to isolate them from the microcontroller a solid state relay was used to switch the solenoids on and off. The S102T02 was used since it has a small package size and easily available [10]. Similar to the opto-isolator, a 100Ω resistor was used on the input side of the SSR. No load resistor was used on the load side of the SSR as there was already one build into the solenoid valve. The valve ran at 120V AC and 50mA.

3. The Three-Axis Arm

The design for the three-axis arm is based on a design from the Universidad Carlos III de Madrid. The claw from the original design was removed and the base was modified to not have a hang over because of limitations of the 3D printer used to print out the arm. The arm uses three servo motors for movement. The servos used in this arm have a non-standard 4th pin which is attached to the internal potentiometer of the servo [11].

The purpose of the arm in the system is take cups from the user and place them under the dispensing system then to return the cup to the user after the mixture has been dispensed. The printed and assembled arm with the attached cup holder can be seen in Figure 2 below.

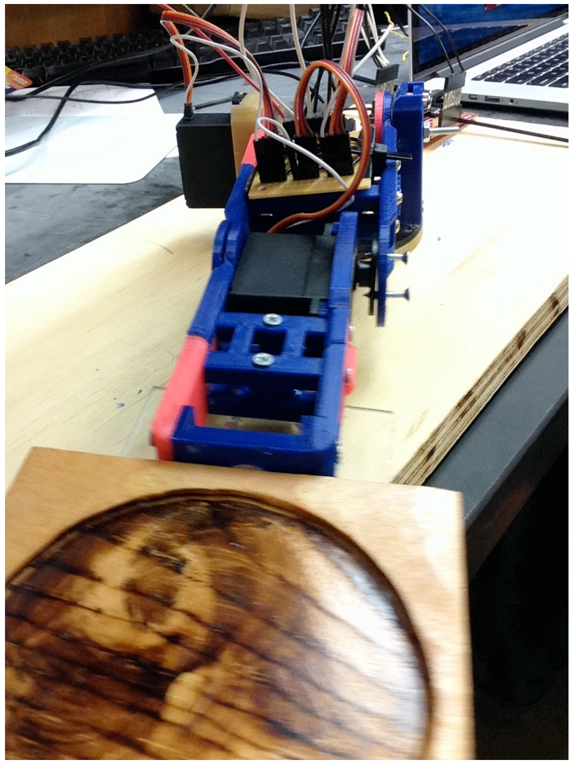

Figure 2 - Printed and Assembled Arm with Cup Holder [12]

The servos are controlled by a series of pulses where the width of the pulse corresponds to the angle the servo rotates to. All three servos used had 180 degrees of rotation on the axis of rotation. The servos were non-standard (as compared to other servos) because they were 4 pin devices. The pins were Ground, Signal, Vin, and Feedback. The servos could be ran between 4-6V DC and so 5V was chosen as the operating voltage because 5V regulators were easily obtained. Running at 5V, the feedback pin of the servos would have a voltage between 0.5V and 2.5V. Since the max voltage was under the 3.3V of the microcontroller, the feedback was not isolated before being connected to the microcontroller.

4. The Microcontroller

The microcontroller is a Texas Instruments MSP430G2553 on the Launchpad development board [3]. The microcontroller was programmed in C using IAR Embedded Workbench and with libraries from the open source project Energia [13]. The microcontroller has a built in 10-bit analog to digital converter [3]. The ADC was used for reading inputs from the feedback pin of the servos in the arm. The microcontroller was used for interfacing with the computer, the servos, the flow meters, the solenoid valves, and the pumps.

The microcontroller had five states, as seen in the figure below. The microcontroller is sent a command from the computer using the following syntax: "[X, Y, Z]" where X, Y, and Z are measurements for the amount of each liquid to be dispensed. The microcontroller is connected to the computer via the UART pins on each. When the microcontroller receives the character '[' the state would change from the "Wait" state to the "Parse" state. In the "Parse" state, the microcontroller would create and modify an array of integers based on the input from the computer. When the microcontroller receives a ']' character, it would transition to the "Place" state. During the "Place" state, the microcontroller send signals and read the feedback from the servos in a feedback loop till the arm was verified to be under the dispensing system. The microcontroller would then transition to the "Pour" state and iterate through the array for each drink opening the corresponding solenoid valve. The pins the flow meters were attached to were used as interrupts for this state and when the correct amount of liquid had flowed through the pipes, the microcontroller closed the solenoid valve and moved to the next item in the array. When the array was fully iterated through, the microcontroller would transition to the “Finish” state and use another feedback loop to move the arm back to its original position. After the arm is back in the default position, the microcontroller transitions to the “Wait” state and remains in that state until another command from the computer is received.

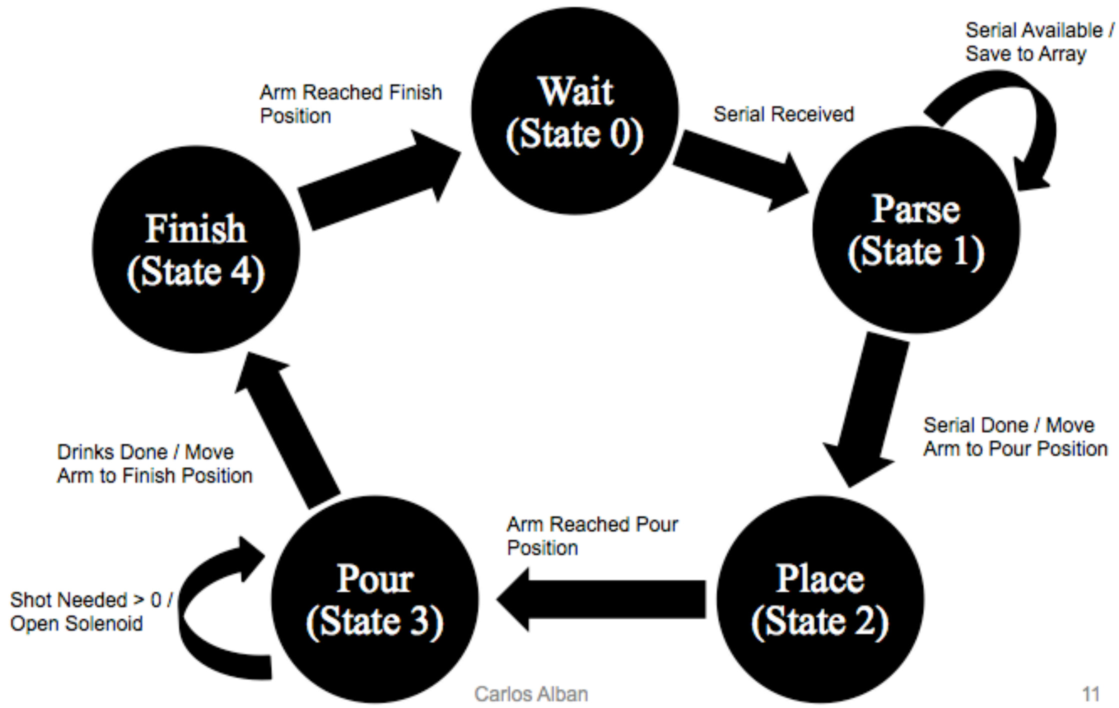

Figure 3 - State Diagram for Microcontroller [14]

5. The Computer

The computer used in this system is a Raspberry Pi Model B [4]. The Raspberry Pi is running a distribution of Linux called Raspbian [5]. The computer is running a web server called Apache to serve PHP pages to the user as the user interface. The PHP pages render the page using a combination of HTML5, CSS3, and Javascript to create a visually appealing interface. Using a combination of PHP and AJAX (asynchronous javascript and xml), the user does not have to reload the page or even leave the main page in order to make a selection in the user interface. When the user does make a selection, an AJAX request (from the rendered page) to the server, which runs a PHP function. This function sends a command to the microcontroller via the computer's UART pins [15]. The computer was attached to a wireless router and given a static IP address. The user interface could be accessed via a smartphone, tablet, or laptop that is connected wirelessly to this router. If multiple users were connected and each made a selection, a queue was produced in the microcontroller and the mixtures would be handled in a first come, first serve manner.

6. Measurements

During testing of the system, measurements were taking with different configuration of mixtures. Each test, as seen below, was ran 11 times and an average and standard deviation were calculated for each test. A larger standard deviation came when a larger mixture was made and we suspect this came from the solenoid valves leaking during continuous usage. The solenoid valves in the system behave ideally in a pressurized system and we suspect the pumps were not creating enough forward pressure for the valves.

Test Settings	Pump 1 Pulses 4 Estimated volume 15mL	Pump 3 Pulses 4 Estimated volume 15mL	Pump 1 & 3 Pulses 4 each Estimated volume 30mL	Pump 1 & 3 Pulses 12 & 8 Estimated volume 75mL
Test Case	Amount (mL)	Amount (mL)	Amount (mL)	Amount (mL)
1	15	20	30	80
2	13	15	30	60
3	15	13	27	70
4	15	15	28	70
5	15	15	29	76
6	15	15	26	70
7	15	16	32	95
8	15	15	25	89
9	15	15	35	90
10	15	15	28	65
11	15	15	36	65
Test Results	Average: 14.8182 % Error: 1.2121 Norm. Std Dev: 0.0402	Average: 15.3636 % Error: 2.4242 Norm. Std Dev: 0.1126	Average: 29.6364 % Error: 1.2121 Norm. Std Dev: 0.1167	Average: 75.4545 % Error: 0.6061 Norm. Std Dev: 0.1546

Figure 4 - Measurements [16]

7. System Power

The system requires three different power supplies. As seen in Figure 7.1, there are two DC power supplies and one AC power supply. The first power supply, a 5V source, powers a USB Hub which in turn powers the computer and the microcontroller. The second power supply, a 12V power supply, powers the pumps and the servos (through a regulator). Finally, there is a 120V AC power supply that is used for the solenoids. Special care must be taken when working with 120V AC especially around liquids. All connections were soldered then wrapped in electrical tape then wrapped in heat shrink. Any boards and wires with 120V AC running through them were attached to the wooden base and screwed in above the solenoid valves to prevent leaking water from falling on them. The regulators had heat sinks attached to them since an average of 1A were running through them continuously for the arm.

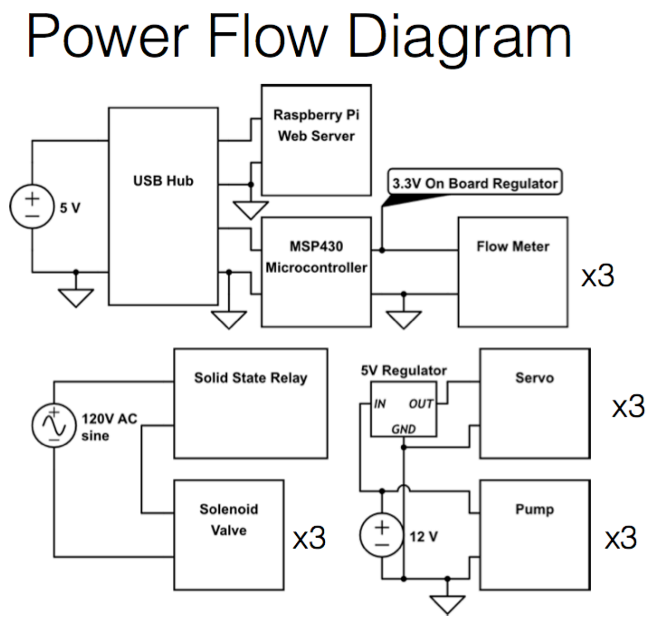

Figure 5 - Power Flow Diagram [7]

8. Conclusion

The system is not a practical solution for its intended application. A pressurized system with smaller solenoid valves would have removed the flaws in this system design but would have been more expensive. The trade offs in leaking and a slow moving arm verses a higher expense were not justifiable for this system. The software for the user interface and for measuring flow worked as intended and can be used with a similar system that is pressurized. The flow meters are very sensitive and give accurate readings for the amount of flow past them as long as they are used in a horizontal orientation.

References

1. Makerbot Replicator 2 3D Printer < http://downloads.makerbot.com/replicator2/MakerBot_Replicator2_features_list.pdf > May 13, 2014
2. Robotic arm with 6 DOF by ancastrog < http://www.thingiverse.com/thing:30163 > May 13, 2014
3. Texas Instruments MSP430x2xx Family User's Guide < http://www.ti.com/lit/ug/slau144j/slau144j.pdf > July 2013
4. Raspberry Pi Documentation < http://www.raspberrypi.org/documentation/ > May 13, 2014
5. Raspbian Documentation < http://www.raspbian.org/RaspbianDocumentation> May 13, 2014
6. Raspberry Pi Web Server < http://www.raspberrypi.org/learning/web-server-wordpress/ > May 13, 2014
7. Poster Slides – Created by Sami Suteria, May 3rd, 2014
8. HS01 High Precision Flow Meter White + Black < http://www.dx.com/p/hs01-high-precision-flow-meter-white-black-226937> May 13, 2014
9. PS2501-4 Photocoupler Datasheet < http://www.cel.com/pdf/datasheets/ps2501.pdf > May 13, 2014
10. S108T02 SSR Datasheet < http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Components/General%20IC/S108,208T02%20Series.pdf > May 13, 2014
11. Adafruit Analog Feedback Servo < http://www.adafruit.com/products/1404 > May 13, 2014
12. Project Photos by Carlos Alban May 3, 2014
13. Energia Reference < http://energia.nu/Reference_Index.html> May 13, 2014
14. Final Presentation by Carlos Alban, May 3, 2014
15. Raspberry Pi GPIO and PHP < http://www.instructables.com/id/Web-Control-of-Raspberry-Pi-GPIO/ > May 13, 2014
16. Measurements recorded by Rustin Harris, May 3, 2014

Appendix A – Budget

This appendix contains the budget for the system.

Equipment

Item	Cost	Source
Power Supply	$699.00	BKPrecision.com
3D Printer	$2,499.00	Makerbot.com
Oscilloscope	$1,999.00	Diligent
Soldering Station	$99.99	Wells
Multimeter	$45.99	Stockroom
Total	5342.98	

Components

Item	Cost	Source	Quantity	Purchased
MSP430 Launchpad	$9.99	TI.com	1	Yes
High Precision Flow Meter	$6.24	DX.com	3	Yes
Clear Tubing (10 feet)	$3.93	Home Depot	1	No
Solenoid Valve	$8.00	Aliexpress	3	No
16 Channel PWM Driver	$14.99	Adafruit	1	No
Wood (various sizes)	$50.00	Rustin	1	No
Plastic bottles	$2.00		3	No
Robot Arm	$50.00	Dr. Storrs	1	Yes
Raspberry Pi	$35.00	Amazon.com	1	Yes
Ball Valves	$1.35	Sograte Supply	5	Yes
Servos	$10.00	Stockroom	3	Yes
Various passive components	$50.00		1	
Total	$299.38			

Payroll

Name	Rate (per hour)	Hours (per week)
Carlos Alban	20	15
Rustin Harris	20	15
Sami Suteria	20	15
Total	9000	

Created by Sami Suteria

Appendix B – Gantt Chart

This appendix contains the Gantt chart for the system.

Group 9 - Gantt Chart - Spring 2014												
Week	1	2	3	4	5	6	7	8	9	10	11	12
	2/11/2014	2/18/2014	2/25/2014	3/4/2014	3/11/2014	3/18/2014	3/25/2014	4/1/2014	4/8/2014	4/15/2014	4/22/2014	4/29/2014
To Do												
1. Research Project/Discuss Options												
A. Research project options	90%	100%										100%
B. Research parts	75%	100%										100%
D. Aquire Parts		75%	100%									100%
2. Construction - Frame												
A.Visual Design		100%										100%
B.Obtain neccesary components		50%	100%									100%
C. Prototype			50%	100%								100%
D. Troubleshoot				50%	100%							100%
3. Flow Control												
A.Construct Schematic		100%										100%
B.Obtain neccesary components		50%	100%									100%
C. Prototype			50%	100%								100%
D. Troubleshooting				20%	40%	60%	80%	100%				100%
4. Retrieval												
A.Construct Schematic		100%										100%
B.Obtain neccesary components		50%	100%									100%
C. Prototype			50%	100%								100%
D. Troubleshoot Retrieval Device				50%	100%							100%
G. General Troubleshooting					20%	40%	60%	80%	100%			100%
5. Software												
A. Overall Design			100%									100%
B. Combinations								100%				100%
C. Graphical Interface								50%	100%			100%
E. Troubleshooting								50%	100%			

Created by Rustin Harris

Appendix C – Safety Concerns

This appendix contains safety concerns for this system.

The max voltage when running this system is 120V AC. This voltage in addition with liquids flowing through the system, a high level of care should be taken when working with the system. All electrical connections should be soldered well and wrapped in electrical tape and/or wrapped in heat shrink. All boards, wires, connections and power supplies should be elevated off the main surface and should not be under any of the tubing that liquid runs through. Leaks are unavoidable and safety should be a high priority when working with this system. Any exposed wires and connections should be isolated and secured before turning on power supplies.