Computer Control of Liquid Delivery for use with Microscopy

Mid-Semester Report
October 22, 2008

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Client: Dr. Ian Bird and Dr. Bikash Pattnaik
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Abstract

Our clients, Dr. Bird and Dr. Pattnaik, are currently researching the effects of calcium

concentration on various types of cells under various types of conditions. In order to conduct

these experiments in a timely and accurate manner, they would like an automated liquid delivery

system. This system must be compatible with the existing experimental setups; it must not kill

the cells that are being studied and it must not generate an electric field, which will skew the

experimental data. The clients would like the system to have a LabVIEW interface, and would

like the physical system to be portable.

In order to meet the client's requirements, our team came up with three design alternatives.

These three designs all had the same basic parts: the same LabVIEW interface, the same valves,

the same tubing, and so on. These were all either things dictated by the client or the most cost

and time effective way of solving the problem. The designs all differed in the way that the valves

were oriented in regards to the rest of the components of the system. One design had the valves

mounted directly onto a case that had all the other components inside. The second design had the

valves mounted onto a panel that was separate from the case with the components in it; this panel

could be mounted onto a ring stand when in use. The final design was identical to the second

design, except instead of having the panel permanently wired to the case, the wires would be

separable. After constructing a design matrix and discussing our ideas with our clients, we have

decided to go with the second design.

Future work for the project mostly entails fabricating the system itself. The LabVIEW program

still needs to be finished, and the power relay design finalized and then built. Upon completion of

the prototype, a round of testing will ensue and changes will be made to ensure that the system is

suitable for use with Dr. Bird and Dr. Pattnaik's experiments.

Current Design

Currently, our clients have a semi-automated system with all manual valves and a capacity for

eight reagents. The reagents are placed in syringes. These syringes are clamped to a board that is

fastened to a ring stand above the microscope stage where the actual experiment is preformed (see

Figure 1). Each syringe has a manual valve which leads to a length of 3/32 HPLC tubing. The

tubing for each syringe converges at an eight to one HPLC tubing junction, the outlet of which

leads to a three-way solenoid valve with an independent power supply. The three-way solenoid

valve has another inlet for a buffer solution and one

outlet that leads to the microscope stage. The current

design does not have provisions for automatically

controlling which reagent is in use at a given time or

automatically setting a buffer wash time.

Figure 1: Current experimental setup

Background

This project will be used on a number of experiments. These experiments are different in scope,

but similar in overall design. The main experiment that the liquid controller will be used on deals

with how intracellular calcium level affects vision and lung function in premature babies.

All cells respond to external stimuli, be it chemical, mechanical or electrical. The cell membrane

is generally the organelle that is responsible for responding to external stimuli. One of the major

cell signaling pathways is the manipulation of intracellular calcium levels. Our client is studying

the effect of calcium on lung and visual tissue by placing the tissues on a microscope stage while

infusing them continuously with calcium solution. Then, other solutions and stimulants are

applied to the cells in a controlled fashion. Once the new solution or stimulant has been added, the level of intracellular calcium is measured, along with the change in electrical response between the cells and the presence of other intracellular molecules in order to determine what effect calcium had on the cells.

Problem Statement

The client's current setup for doing experiments is both time consuming and error prone due to the manual nature of the design. The client would therefore like us to construct a device that will be able to deliver liquid reagents to a microscope stand for set amounts of time without constant human intervention. This device should utilize the overall delivery method as the current setup; that is, the reagents should be placed in syringes and then allowed to flow onto the microscope stage, with the difference being the automated control of the valves. The liquid delivery controller must not interfere with the experiment in any way: it cannot produce an electric field, kill the cells, or be too bulky to be used in a limited space. The client would also like the controller to be portable, as it is anticipated that multiple labs will have use for the device.

Design Requirements

Dr. Bird and Dr. Pattnaik want a fully automated system which they can easily program activation and deactivation times for each valve before the experiment. This program must be user-friendly, a system that people with limited computer skills can use. It must also be convenient. Part of this convenience stems from a savable format. With this feature, the user will be able to program on and off times for each valve, then save these times for a later instance. This will be a nice feature for the clients, since they will most likely wish to do the same experiment more than once.

Saving formats will allow them to quickly load their times they have pre-programmed, then proceed with the experiment immediately.

The design must also be chemically friendly. This means no foreign contaminants can enter the experiment in any way, leading to altered results and a frustrating situation for the clients. All components of the design coming in contact with the solutions cannot react with the reagents or corrode in any way. Salty solutions may be used, which can corrode components over time, so careful consideration of this when selecting appropriate materials must be taken.

These components cannot break during the experiments either, which would cause even more frustration for the clients. Reliability is extremely important for this reason. Breaking parts could also mean spilled solutions, which could mean more broken parts, and a very messy situation overall.

The last important factor in the design is transportability. Only one unit will be constructed this semester, and multiple labs could potentially use this product. This means the clients must be able to easily transport the product from lab to lab.

Overall Design

The overall design will incorporate the various requirements specified by the client as mentioned above. A program will be used to control the timings. This program will interface with specific hardware to output voltage signals to the eight valves, which will be mounted on a panel (See Figures 5, 6, and 7). These low voltages must first be boosted to meet the electrical needs of the valves (12 VDC, 500 mA). This will be accomplished via an external power source and a relay

board. All of this hardware will be stored in a portable case. The alternative designs will

explore the different physical configurations of this case and its attachment to the valve panel.

Design: LabVIEW and Power

The clients request the graphical programming language LabVIEW be used to control the valve

system. This allows for easy integration into already existing systems the clients may have or

wish to have in the future. LabVIEW also happens to be a good choice overall, since it possesses

a user-friendly front panel, it is easy to utilize, and it is effective for real-time output and

feedback.

The front panel will have a very convenient format. The user will be able to specify on and off

times for any valve in any given order using three labeled buttons (Figure 2). If more

programmed times are desired, the user can simply drag the box down, creating more boxes for

more valve timings. A stop button will allow quick cancellation if needed. An indicator of the

present experiment time will also be added, as well as an indication of which valve is currently

on.
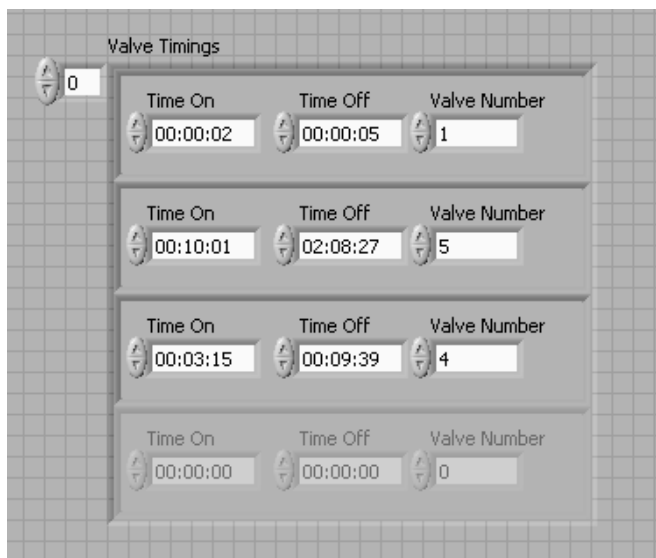
Figure 2: LabVIEW Front Panel. User-friendly interface allows easy programming of on/off times for any and all desired valves. A drag-down system lets the user specify an infinite amount of timings; each valve can be activated/deactivated more than once or not at all.

In case the clients wish to use the exact same or similar timings for another experiment, LabVIEW allows formats to be saved as a file for later use. This way, the client can load pre-programmed timings quickly and start the experiment without hassle.

If the clients also wish to submit their experiments for review, the program will print a log of times, indicating when each valve was activated and deactivated. This report will be exported as a text file, which can be opened using Microsoft Excel in a table format for further analysis or printing.

To interface this program with the valves themselves, extra hardware is required. A LabJack U12 interface will be used to output the signals from the program to the valves (Figure 3). This device plugs directly into USB, making it very convenient for a lab environment, since almost all laptops would be compatible. The U12 has 20 digital I/O ports, driving up to 25 mA of current each [1].

Figure 3: LabJack U12 interface [1]. Allows signals sent from program to activate each valve. Low voltage digital I/O signals from device must first be boosted to meet valve requirements.

This low voltage will have to be boosted up to the 12 volts required to operate each valve. In

order to accomplish this, a power relay board will be used. This component has yet to be finally

selected, but it is highly likely that an NI SC-2062 power relay board will be used (Figure 4).

This board has eight relays (which happens to be the right amount of valves) that can switch up to

6 A at 30 VDC [2]. An external power supply will be needed, plugged into a standard wall outlet.

An overall diagram of the design (Figure 6) illustrates this layout.
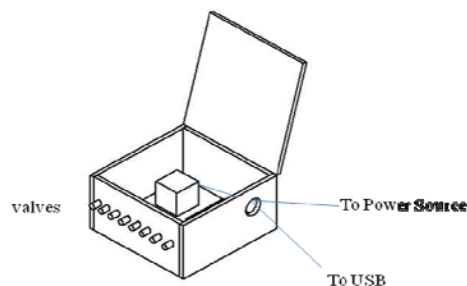

Figure 4: NI SC-2062 Power Relay Board [2]. Boosts the low voltage output from the LabJack U12 device to the 12 VDC necessary to drive each valve.

Valves and Panel

We will use two-way normally closed solenoid isolation valves as a transition point for liquid

traveling from syringes to the reservoir. The valves open when they receive 12 volts of direct

current (1.12 watts of power) [3]. The opening of the valve will allow substances to travel

directly into the reservoir. Each valve contains a Teflon coating, which prevents chemical

corrosion. These valves can be individually mounted to the valve panel using any two of the four

available mounting holes. Our client tests eight chemicals during an experiment, so we will

mount an array of eight valves to a panel.

Inseparable Panel

In the first alternative design, the valves are mounted directly to the component holding case (Figure 5). There would be no loose wiring, because the wiring would pass through the case panel and into the valve. This design allows for easy transportation between different labs, because all of the components (electrical, wires, and valves) are all locally contained within or on the case.

Figure 5: Inseparable Panel Design. Valves are mounted directly to the front panel of the case. Wiring to each valve is not seen at this angle, but passes through the front wall and attaches to each valve.

There are some disadvantages to this design. Each time the device is moved, the tubing would have to be reconnected. If a valve needs to be replaced, it would be difficult to remount and rewire new valves onto the side of the case. There is also a possibility for components being broken or damaged in this design. All the components are in a close vicinity of each other, which could lead to rubbing or breakage during transport. This attributes to a lack of durability for this design.

Semi-Separable Design

Another design alternative was to mount the valves on a panel separate from our case and attach the panel on a ring stand (Figure 6). In the semi-separable design we are incorporating the advantages of the non-separable, without the disadvantages of the all inclusive case. We decided it may be
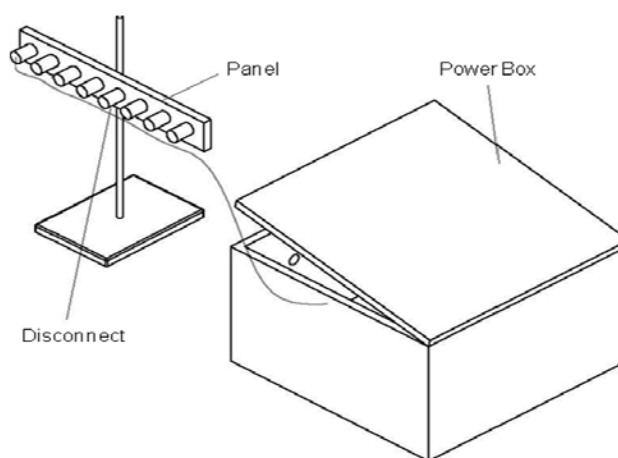
Figure 6: The semi-separable design incorporates the case as well as a separate valve panel.

better to move our valves on a separate panel. This allows our clients to use our system using

nothing but gravity as a feed for their experiments as the valves can be mounted higher than the

samples being examined. This design requires wiring from the case to our valve panel which is

mounted on the ring stand. The case for this design will contain the same components as the other

designs, but the valves will be on the separate panel, which will be removed from the stand and

attached to the case using Velcro in order to be transported.

This alternative allows our clients to move the case between themselves without the need to

reassemble the valve wires, while still allowing the flexibility of independent structures. In the

event of a valve malfunction, the semi-separable design allows our client with easy access and

replacement of valves. Another advantage of the semi-separable design is the increased durability

of the structure so the valves can be carried more safely than the inseparable design.

Separable Design

The separable design alternative is our effort at the most durable liquid delivery system (Figure 7). As transportation increases, so does the chance of components being broken, therefore, we added another ring stand and valve panel for the non-

separable design. In this design, each lab will have a ring stand and valve panel. Only the case will be transported. There will be disconnects for the power
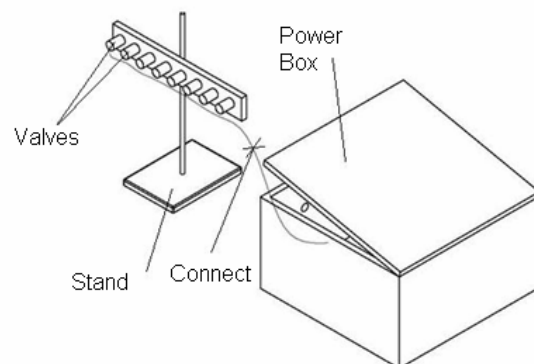
Figure 7:
The separable Design allows for
easy transportation between clients

supply near each valve and the client would then re-attach them once the case is transported.

With this design alternative there is one major benefit, which is the increased durability due to the limited need of transportation of our valves. However, this design also requires twice the amount of valves. At a cost of $60 each the 8 valve difference will cost an additional $480. Another drawback for this design alternative is the convenience for our clients as every time the case is moved the wires from each valve would need to be re-attached to their respective valves. If any wires were accidentally switched, the LabVIEW interface would signal voltage to the wrong valves. This would administer the wrong liquids and the experiment would be invalid.

Design Matrix

Our clients are looking for a high degree of importance of the reliability of the liquid delivery system that we choose to produce. Our group also believes that the user friendliness of our LabVIEW interface is of the utmost importance for our clients, since they have limited computer and programming knowledge. For these reasons we are selecting the categories of user friendliness and reliability to hold the most weight in our design matrix. All design alternatives will be using the same interface, so all three received the same score in user friendliness. In reliability, there are differences in all of our alternatives.

We are giving the separate structure the highest score followed by the semi-separable and inseparable structures due to the relative transportation of parts between clients. The more the components of our structure that are shifted around, transported between our clients, the more likely they will be damaged and need replacement. As discussed earlier, cost was also evaluated with the separate structure. This added a significant cost to the overall production of the design.

The convenience of each structure for our clients will also be important to their evaluation of the finished product. We gave the separate structure a deduction due to the need for the client to reconnect wires to their respective valves after transportation. The ease with which our clients will be able to swap out faulty equipment in our design is also included our design matrix. The non-separable design alternative scored the lowest in this category because of the limited access inside the case for detaching and reattaching the valves. The separate design would require re-splicing of the valve wires to be able to attach to the previous connector.

With the previously mentioned scoring methods and weighting taken into account, the semi-separable design alternative is the most beneficial for our clients. Table 1 illustrates the criterion used to make this decision.

Table 1: Design Matrix. Based on these criteria, the semi-separable case was chosen for the final design.

Design	User-Friendly (30)	Durability (30)	Replaceable (15)	Convenience (15)	Cost (10)	Total
Inseparable	30	20	10	15	10	85
Semi-Separable	30	25	15	15	10	95
Fully Separable	30	30	10	10	5	85

Projected Budget

We have established a basic budget based on our design and requests from our client. Each valve costs $60, and we need eight, so our valve expenditure will total to $480. Valves alone account for over 50% of our overall budget. We will also need to buy a power relay board and a LabVIEW interface, which will cost $50 and $130, respectively. We have also added an additional $100, which will cover various costs, such as case building materials, case components, tubing, wiring, and any additional purchases for unforeseen expenses. This brings our budget to a total of $750 (Table 2).

Table 2: Budget Summary. Our proposed budget for the Semi-Separable design.

Item	Unit Price	Quantity	Price
Valve	$60	8	$480
Power Relay	$50	1	$50
Power Supply	$20	1	$20
LabVIEW Interface	$130	1	$130
Misc. Materials	$100	1	$100
		Total	$780

Future Work

There is plenty of work that will be completed in the upcoming weeks, in order to present our client with a working prototype. Currently we have been writing a preliminary program that runs strictly on virtual input and output. Once we receive the LabVIEW interface, we will need to modify this program in order to apply real output voltages. Once we order and receive all of our materials, we can begin assembly. We will be wiring the valves to the LabVIEW interface, connecting tubing, assembling a case to hole components, and mounting the valves to an removable plate. Once we have a working prototype, we will test the device. We hope that everything will run correctly, but we will make modifications according to problems discovered during testing.

References

[1] LabJack U12 LabVIEW Interface Device. Obtained from www.labjack.com

[2] National Instruments SC-2062 Power Relay Board. Obtained from www.ni.com

[3] Two-way solenoid valves. Obtained from www.nresearch.com

Appendix

Product Design Specifications:
Liquid Controller

Team Roles:
Team Leader: Steve Welch
Communications: Joe Decker
BWIG: Dan Miller
BSAC: Justin Gearing

Last Update: October 21, 2008

Function: Currently, reagents are added manually when testing cell signal functioning under a microscope. This leads to problems regarding accuracy of timing and amount. To resolve this issue, an automatic system is desired. This system will use valves controlled by a computer interface to precisely deliver required reagents.

Client Requirements:

- Must be user friendly
- Must have replaceable parts
- Must be automated
- Must have quick setup time
- Must not interfere with the experiment

Design Requirements:

- Must be resistant to corrosion
- Cannot leak toxic material
- Plug into USB
- Can be externally powered via wall outlet
- Must fit within limited table space
- Must have a computer interface
- Must have ability to switch fluids because of time
- Must have ability to control the flow rate

1. **Physical and Operational Characteristics**
    a. **Performance Requirements:** The liquid controller must be able to run on a daily basis for sessions lasting over 30 minutes. The limiting factor here is the performance of the valves, which can only have current passing through them for short periods of time before overheating.

b. Safety: Product must be free from risk of electrical shock.

c. Accuracy and Reliability: A high degree of repeatability is required. The liquid controller must be capable of producing the same exact output each time that it is used in order to be able to repeat experiments. Time controls must be accurate to within one millisecond. Flow rates must be constant, controllable, and under 5 milliliters per minute.

d. Life in Service: Parts should be made replaceable, increasing the service life indefinitely. The liquid controller will be used daily for at least 30 minutes. Each component must be reliable for at least one year before replacement is needed.

e. Shelf Life: If properly cleaned, the liquid controller should last in storage as long as the shelf life of the commercially available parts used (the valves, pumps, etc.).

f. Operating Environment: The liquid controller will be used in an ordinary lab environment. Internally, several potentially corrosive materials will be used as reagents, including salts and organic solvents. The valves and tubing must be able to withstand this exposure. Additionally, the internal circuitry used in the hardware must be resistant to overheating. If this proves to be a problem, a fan must be used for cooling and ventilation.

g. Ergonomics: The liquid controller should require as little human interaction as possible while still remaining reliable and user friendly. The users should be able to quickly enter in the desired timings, then proceed with the experiment.

h. Size: The liquid controller minus the laptop should fit within the client's available desk space (approximately 1/3 square meter). It must be easily transportable, and should be no higher in height than 1/3 meter.

i. Weight: The liquid controller must be light enough to be carried up and down seven stories by an average person. This means a weight under 5 kg.

j. Materials: Materials must not corrode with repeated exposure to salt solutions. Materials must also not leak or be biologically incompatible.

k. Aesthetics, Appearance, and Finish: The liquid controller should be designed with functionality in mind, aesthetics is of secondary concern.

2. Product Characteristics
    a. Quantity: One unit will be needed.

b. Production Cost:

Estimated budget:

Item	Cost (est.) ($)	Qty	Total ($)
Two-way isolation NO Teflon valve	60.00	1	60.00
Two-way isolation NC Teflon valve	60.00	7	420.00
Power relay	50.00	1	50.00
LabJack U12 LabVIEW interface	130.00	1	130.00
External power supply	20.00	1	20.00
Miscellaneous*	100.00	-	100.00
Total (est.)	-	-	**780.00**

*Miscellaneous expenses include tubing, building supplies for stand, electrical wiring, and other necessities.

3. Miscellaneous

a. **Standards and Specifications:** No standards or specifications are required.

b. **Customer:** The liquid controller will be used by faculty members in the department of obstetrics and gynecology. The customer has limited programming knowledge. The customer prefers LabVIEW for easy integration into already existing programs. A gravity pressure system will drive the solutions (as opposed to using pressure delivered through a pump). The valves must separable from the case by at least five feet.

c. **Competition:** To the best of our knowledge, no device currently exists that meets all of the client's requirements.