MRI-Compatible Olfactometer

BME 301

Team Members:
Steve Welch
Ryan Kimmel
Kaitlin Brendel
Joe Decker

Advisor:
Professor John G. Webster

Client:
Dr. Vivek Prabhakaran

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Abstract

In order to accurately deliver timed increments of odors to a subject during an fMR scan, an MR-compatible olfactometer is needed. This olfactometer will primarily be used for research purposes in the laboratory of Dr. Vivek Prabhakaran; however, it is a potentially marketable device for researchers who do not have the time or resources to build their own olfactometers. Three proposed designs to fulfill the requirements specified are outlined. All of these designs have similar components, but use different odor delivery mechanisms. Currently, the design which uses positive pressure and two-way solenoid valves is the best solution because of the accuracy of the odor delivery. Future work includes ordering the components that have been selected, constructing the prototype, and testing.

Problem Statement

Olfactometers are present in most olfactory research laboratories. This device allows the researcher to more accurately perform experiments that require an odor delivered to the subject. In our client, Dr. Prabhakaran's experiment, the odor must be delivered in a cycle: odor for 30s, followed by clean air for 30s. The duration of time the odor is delivered can be varied depending on the experiment. This odor delivery must occur during an fMR scan of the patient's brain in order to monitor brain activity during the experiment. Currently, the researchers in Dr. Prabhakaran's laboratory are using "smell sticks" to deliver the odors. The subject is instructed when to put the smell stick to their nose and when to take it away. This procedure poses major accuracy issues. One of the main requirements of the olfactometer is to deliver the odors at precise intervals. If the subject does not begin actively sniffing the smell stick at the correct time, the experiment may have considerable error. Also, a potential issue with the smell stick is that if the subject moves his or her head slightly (2mm), the fMR image will be ruined.

Motivation

The problems with the current method of using smell sticks provide an opportunity for design of an olfactometer device to deliver the odors directly to the subject. This device will allow the researcher to more accurately carry out their fMRI experiment. Some research topics which may have use for an MR-compatible olfactometer are Alzheimer's disease, obesity, and perfume.

Background Information

fMR Imaging

Blood oxygen level dependent (BOLD) functional magnetic resonance imaging (fMRI) is used to monitor brain activity. The fMRI measures the oxygen delivered to neurons by hemoglobin. Active neurons require more oxygen, which causes blood flow to increase in areas of increased neural activity. The MR machine detects oxyhemoglobin differently than deoxyhemoglobin. This difference in detection allows the fMR image to display the brain's neural activity.

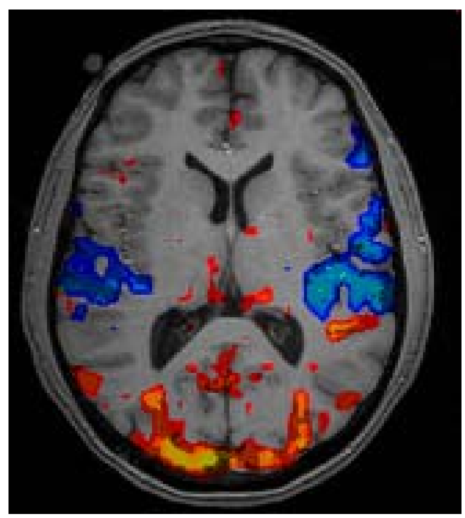

Figure 1. Activation Map of a simple fMRI experiment (http://www.fmrib.ox.ac.uk/education/fmri/introduction-to-fmri/what-does-fmri-measure)

The images produced by the fMRI machine during an experiment are called activation maps. These maps of the brain show where the brain activity is increased during a stimulus, such as an odor. Simple experiment alternating between a visual stimulus and dark every 30 s creates an activation map (Figure 1).

Olfaction Research

Olfaction is a relatively recent area of research, although there are some very important discoveries being made in this line of work. Alzheimer's disease could be diagnosed earlier by a loss of the sense of smell. Obesity studies have shown that the sense of smell is closely linked to the sense of taste, and olfaction researchers are discovering treatment methods for obesity based on that fact. In patients who are going through cancer treatments, the delivery of pleasant odors during treatment procedures has proven to relax the patient. The perfume industry also uses olfactory methods to determine if a scent is pleasant to people before marketing the perfume.

Experiment

The olfactometer will be used in an fMRI experiment to deliver odors in timed intervals. The interval times will vary from 20 s of odor cycling with 20 s of clean air (Figure 2).

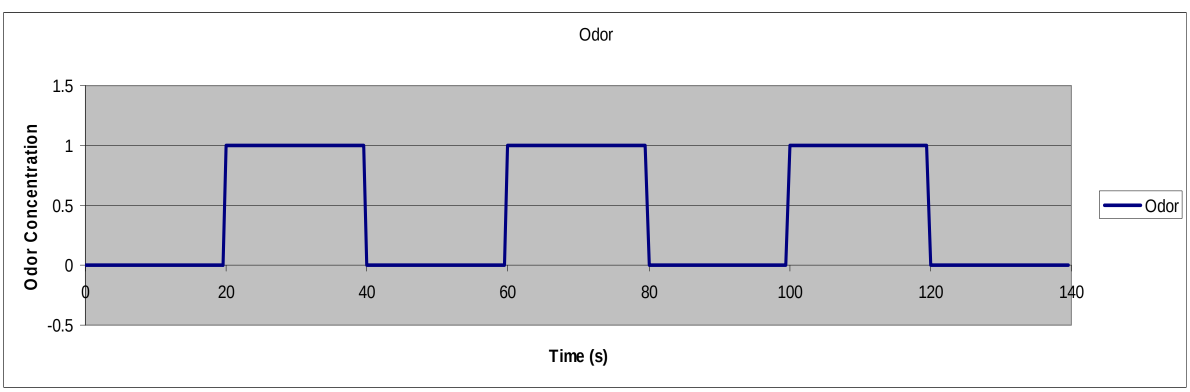

Figure 2. Example of odor delivery in the experiment versus time.

Literature Search

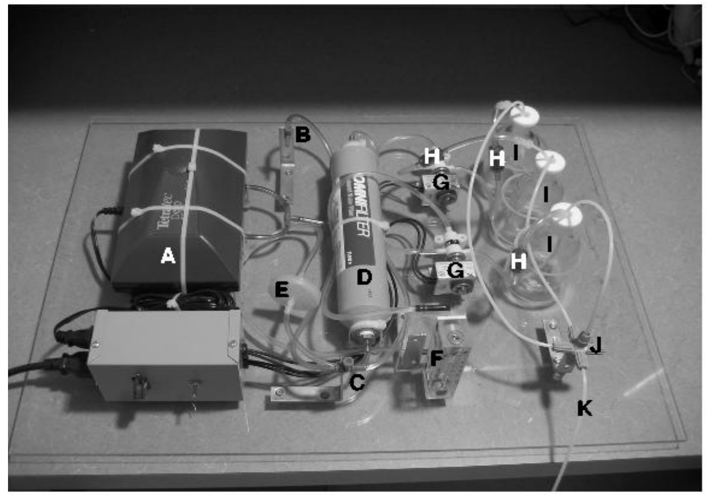

Figure 3. An olfactometer used at Harvard and McLean Hospital (http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1602106)

There have been many olfactometers constructed at different hospitals and universities for research purposes. Although many past researchers have designed and constructed olfactometers for their laboratory, no olfactometer was found in the literature search that is commercially available. Researchers at Harvard University and McLean Hospital constructed an olfactometer for their own fMRI studies (Figure 3).

The olfactometers that have been created for researchers at different hospitals and universities are all similar in theory, but differ in the features they have to measure the odor and air. Also, there are a limited number of olfactometers that have been developed to be MR compatible.

Design Specifications

Our client wants to use our olfactometer as the primary means of delivering odors to test subjects undergoing an fMRI scan. As such, the olfactometer must be compatible with the MRI environment. This means that any part of our design that is in the MRI suite must not have any ferromagnetic components; if the best design necessitates the presence of some sort of ferromagnetic material within the MRI suite, this material must be kept at a safe distance from the magnet, about 5 m. Any ferromagnetic components caught in the MRI's magnetic field will create an extremely dangerous environment for both the experimenter and the test subject, and will almost certainly cause a great amount of damage to the olfactometer itself.

In order to maintain a tolerable testing environment and obtain accurate results, our client would like to be able to control the temperature of the odors delivered to the test subject. The odors will be delivered at approximately 37.5˚ C, or body temperature. The reason for this is twofold. First, this temperature will prevent discomfort for the test subject. It is possible that odors delivered too hot or too cold will irritate the test subject, and inevitably leads to inaccurate results. Second, the client wants to keep odors delivered to the test subject at body temperature in order to prevent activation of the hot and cold receptors of the nose and face. The purpose of the client's study is to investigate which parts of the brain are involved in olfaction; this is accomplished via the fMRI scan. Olfaction is directly tied to the first cranial nerve, while the hot and cold sensors are directly tied to the fifth cranial nerve. If the fifth cranial nerve is stimulated too much, it will cause an fMRI reading due to the temperature of the odors, and not of their olfactory qualities.

Our client would like the olfactometer to have inputs for four different odors. These odors will be prepared as liquids and then delivered to the test subject as gasses. Our design must therefore be able to support four different liquid odors. These odors must be kept separate from each other to avoid contamination, and the container for them must either be disposable or washable if it is to be used more than once.

Our client would like to be able to control the olfactometer via the computer that controls the MRI machine. He would like the ability to program which odor is released at a certain time, and the duration that odor is delivered to the test subject. As such, a program needs to be created that can control the flow of air through the olfactometer and can dictate which odor is delivered at a given time. This program should readily interface with E-Prime, the program the client currently uses to control the fMRI. This insures that the olfactometer runs in conjunction with the data gathered from the fMRI, allowing for the most accurate results possible.

The olfactometer design must be compatible with our client's current experiment. Most notably, this means the design must be compatible with the active sniffing method of odor delivery. Active sniffing is a technique that has the test subject consciously smell the environment around them. This differs from other olfaction experiment techniques that deliver odors directly into the test subject's nose, eliminating any chance of missing the odor. In order to comply with the active sniffing technique, the odor should be delivered to and contained in an area surrounding the test subject's nose. This area should be sequestered from the outside environment, and should have conditions that can be dictated through the use of the olfactometer.

Common Design Components

There are certain components that are similar to every design as specified by the design requirements. Every design has a pump to drive the air through the system. This pump has connections to both the ambient air and the plumbing of the olfactometer.

The ambient air needs to be filtered before picking up an odor and being delivered to the test subject. The air is first passed through a charcoal filter. This filter removes any odors that were present in the ambient air, insuring that the only odor that reaches the test subject is the odor specified by the client. The second filter is a high efficiency particulate air filter (HEPA filter). This filter removes any charcoal dust from the charcoal filter, insuring a healthy test environment for the test subject and limiting contamination in the rest of the system.

All designs have five different leads: four leads run to odors and one lead through with clean air. These leads are controlled via solenoid valves, which interface with the computer program. Each line has identical tubing; this tubing must be Teflon coated after the odors are picked up in order to avoid having residual odor in the system after an odor is switched off via odor absorption in the tube. If the tubing were to absorb an odor, that odor would be present in all subsequent trials, leading to inaccurate results.

Air flow must be kept constant to the test subject in order to minimize tactile stimulation. Flow will be controlled using a needle valve which can range from being fully open to fully closed. A flow meter will be used in conjunction with this valve in order to monitor and successfully regulate the flow of odor.

The air is delivered to a mask which is to be worn by the test subject. This mask will be a basic anesthesia mask which will have one inlet for odorized air and one outlet for excess air. This mask will fit over the test subject's nose and mouth, and will be comfortable and accommodating to active sniffing.

Design Alternatives

Design Alternative 1: Five-Way Positive Pressure

Air flow is controlled by a single, five way solenoid valve which is controlled by the computer interface (Figure 4). The valve is only used to control the odors; when the client wants clean air delivered to the test subject, the valve is completely shut and clean air is delivered via a separate clean air line, which diverges from the main line before the five way valve. The pump, filters, flow control valve and mask are all as described in the common design components section.

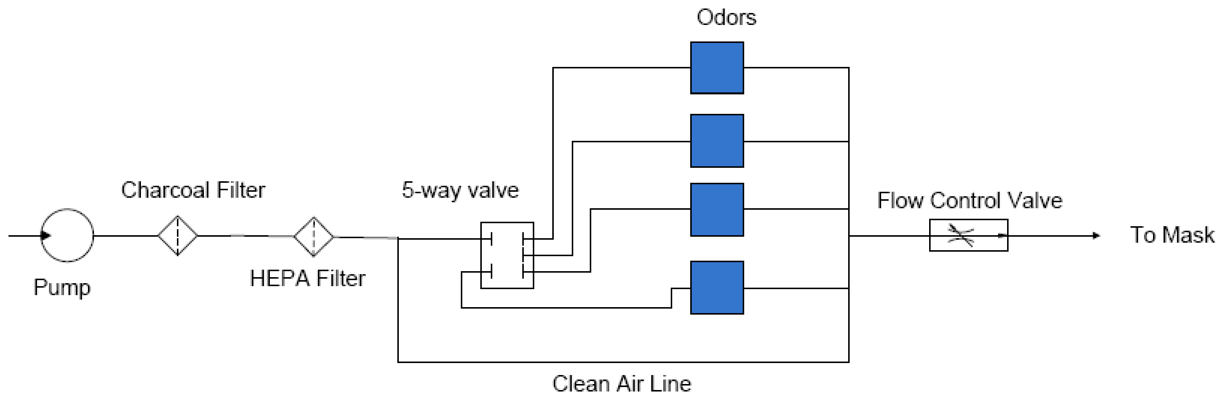

Figure 4. Five-way positive pressure system

Design Alternative 2: Two-Way Negative Pressure

This design incorporates four two-way solenoid valves (Figure 5). The air pump would pull air through the system as a vacuum, and it would be positioned after the mask. Additionally, the air flow would split to five lines. The solenoid valves would control four of the lines. The fifth line would constantly be open, and it would always be sending clean air through the system. Finally, the rate of flow would be controlled after the five lines meet and before the mask.

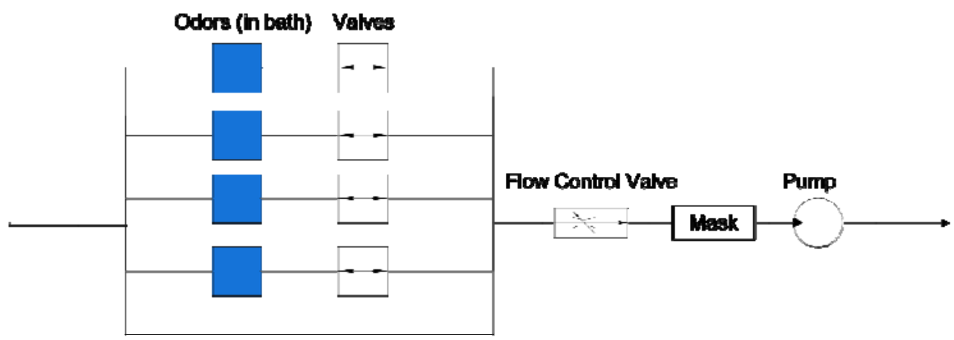

Figure 5. Two-way negative pressure system

Design Alternative 3: Two-Way Positive Pressure

This design also incorporates four two-way valves (Figure 6). The pump would push air out that would travel through the charcoal filter and then through the HEPA filter. Then the line would split into five directions. Four of the lines lead to the odor canisters and ultimately the solenoid valve. The fifth is the clean air line that would not be controlled by a valve. Therefore, clean air will always be directed to the mask. These five lines will then converge to the flow control valve. This component would consist of a needle valve to directly alter the rate and volume of flow and a flow meter to measure this amount. Finally, a line would be fed from the control room the MRI room that ends at the mask.

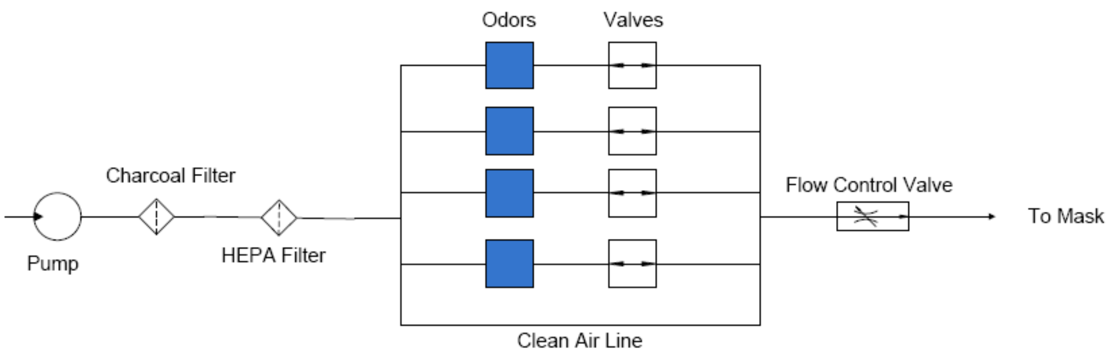

Figure 6. Schematic for the two-way positive pressure air flow system.

Design Matrix

Each of these designs would have the same amount of safety and ease of operation, since they all incorporate similar components and a nearly identical operating program (Table 1). The five-way positive pressure system would be the most cost efficient since the valve is only one part, but it is extremely difficult to find a five-way solenoid valve in the U.S. Furthermore, this system would be very accurate, but the researcher would not be able to mix any odors if he or she would desire. Finally, because this design has only one major component, this valve system is not durable. If something were to malfunction with this valve, the entire system would fail.

The two-way negative pressure system would be more expensive than the five-way valve system because it would require four valves and a more expensive vacuum pump (Table 1).

Since this system uses a vacuum, it would be very difficult to accurately control the amount of flow directed to the mask. Also, it would be medially durable, because the system could operate if one valve was to malfunction, but the vacuum pump may cause some damages to the connecting parts.

The two-way positive valve system is the best air flow design (Table 1). It is cost efficient, because the positive air pressure pump is very inexpensive. Pushing air through the system is the most accurate method, because the exact volume of the odor that reaches the mask can be controlled, and the air can be propelled over a greater distance. Also, the researcher can mix any odors for the experiment. The system can operate if one valve were to malfunction. Finally, this layout is very user friendly, because someone could easily learn how all of the parts function together to be able to fix any issues.

		AIR FLOW DESIGNS		
Design Consideration	Weight	**2-way negative**	**2-way positive**	**5-way positive**
Safety	15	**13**	**13**	**13**
Cost	10	**5**	**7**	**9**
Ease of Operation	15	**14**	**14**	**14**
Accuracy for experiment	20	**13**	**18**	**16**
Aesthetics	5	**3**	**4**	**3**
Durability	15	**10**	**12**	**8**
Precision	20	**18**	**18**	**18**
TOTAL	**100**	**76**	**86**	**81**

Table 1. Design matrix showing that the 2-way positive pressure system is the best airflow design.

Electronics

This section will cover the electronic components of the design. These components are necessary to power the solenoid valves and to give the user the ability to control the experiment. Control of the experiment includes odor selection for each cycle, the duration of each cycle, and the number of cycles.

Several components are required to accomplish these tasks. First, a program is needed that the user can directly interface with. Second, the program must be converted into electrical signals; this requires a bus interface. Third, since the bus interface has low power output, a power supply is needed to properly operate the solenoid valves. Fourth, this design requires a power relay system to switch from the low power bus interface supply to the high power source supply. Figure 7 (below) is a graphical representation of how these four components are assembled to operate the solenoid valves. Each component will be described in more detail.

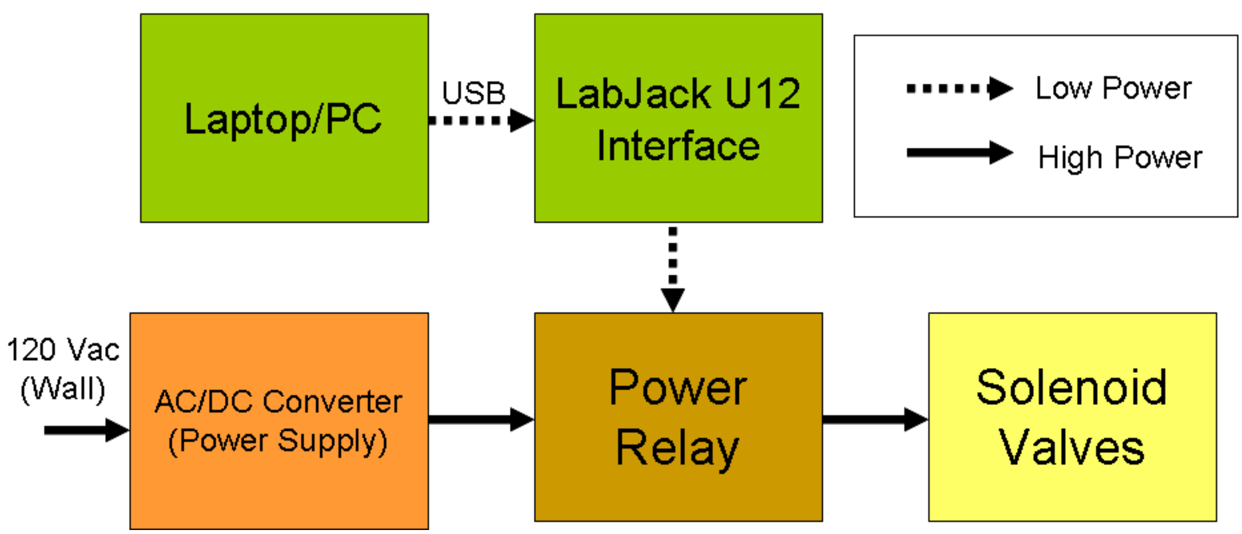

Figure 7. Electronic Layout of Design

Electronics: Program

The program is the most important component of the electronic layout (Figure 7). It defines the functionality of the system and directly interfaces with the user. The program was made specifically for the client's needs, and can be easily altered or rewritten in the future if desired. For this design, the program was written and implemented in LabVIEW.

Figure 8 shows the front panel display of the program; everything the researcher will be able to control is in this display.

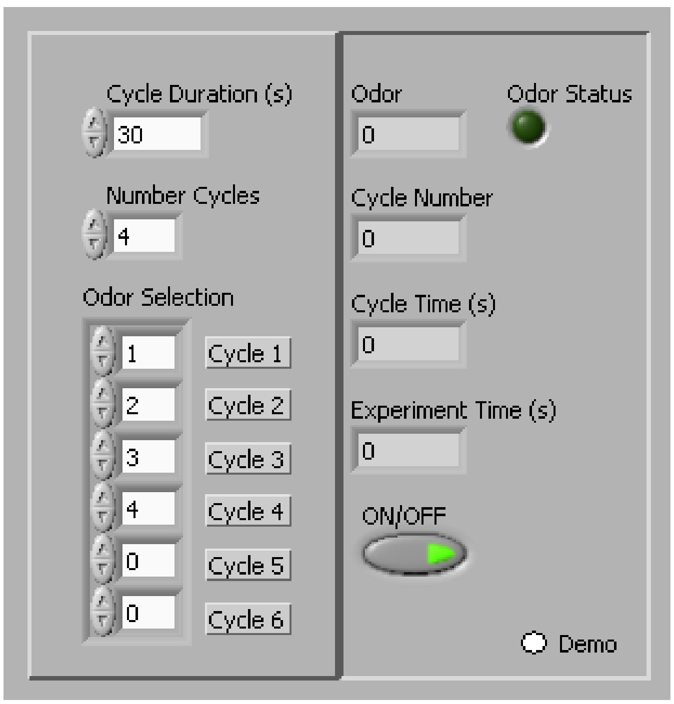

Figure 8: Front Panel Display

Starting from the top left, the user will be able to control the duration of each cycle. In this example, a cycle of 30 s was selected. This means that for each cycle, odor will be delivered for 30s, followed by clean air for 30 s. Next, the number of cycles can be chosen. This front panel allows for a maximum of six, but this maximum can be easily changed if necessary. In

Figure 8, four cycles were selected; this means the experiment will last a total of four minutes (30s odor + 30s clean air = 60 s/cycle). Finally, the specific odor can be selected for each cycle in the experiment. The design will have four odors available; each number (1-4) will correspond to a specific valve, tied to a specific odor. Also, releasing the ON/OFF button will terminate the experiment.

It is important that this program can be synchronized with E-Prime software for the experiment. To accomplish this, a start button was omitted from the front panel. Instead, the user simply needs to push the "Enter" key to start the experiment, even if the front panel is minimized on the desktop. This start key can be easily altered to better suit the client's needs. It may even be a combination of keys and mouse clicks; for example, the experiment can be programmed to start by first pushing the "S" key, then the right mouse button.

Aside from the user controls, there are also indicators on the front panel to keep the user informed during the experiment. The odor field shows the odor number for the current cycle; the odor status indicator will light up when the odor is being applied and dim when clean air is being applied. The other indicators include cycle number, cycle time, and experiment time. These are updated as the experiment progresses.

Electronics: Bus Interface

The program alone is not enough to operate the solenoid valves. A bus interface is required to convert the program's output into electrical signals. For this design, the LabJack U12 Interface was chosen (Figure 9). This interface plugs directly into USB, so any laptop or desktop computer with LabVIEW capability can use the design. Among the U12's many ports includes four digital I/O ports that will be utilized for each of the four solenoid valves (www.labjack.com). Unfortunately, USB allows for an output of only 5V with very low power, so these signals will need to be amplified.

Figure 9. LabJack U12 Interface (www.labjack.com).

Electronics: Power Source and Relay

The solenoid valves used for this design will require 12VDC with less than 5W power to operate. As previously mentioned, the LabVIEW interface only has roughly 5V available with very low power (less than 1W). An external power supply is therefore needed to turn the valves on. A 12V AC/DC converter that plugs into a standard wall outlet will be used for power (Figure 10). To switch from the low power LabJack signal to the high power supply signal, a power relay will be used (see Figure 7).

Figure 10. 12V AC/DC Power Converter.

Final Design Components

This design utilizes many different components. Specific models have been chosen for many of these components; the few that have not will be selected soon after acquiring the components that have been selected.

Final Design Components: Pump

The Elite 801 Air Pump by Hagen has been selected to serve as the pump for this design (Figure 11). This specific pump is a small diaphragm pump intended for aquarium use; however, it suits the needs of this design perfectly. It outputs about 21 kPa at 1500 cc/min and costs $7.99, making it a cheap and effective solution (www.hagen.com).

Figure 11. Elite 801 Air Pump by Hagen (www.hagen.com)

Final Design Components: Air Mask

Simple anesthesia masks will be used for the air mask system. They cover both the nose and the mouth, but they may need modification to allow for separate input and output lines (to allow for a constant flow of air across the nose). They are MR-compatible and easily replaceable. A drawback to this selection is that most of these are not Teflon-coated, which would leave odor residue in the mask. A single mask costs $3.99.

Final Design Components: Odor Canister

To set up the experiment, odors will be added to a container in liquid form. The container will be heated to 37.5 °C, where the liquid will evaporate and be carried out of the container. Erlenmeyer flasks with side arms serve this purpose very well (Figure 12); they have an input and output, and can be heated without damage.

Figure 12. Erlenmeyer Flask with Side Arm for Odor Canister

Final Design Components: Filters

Filters are needed to ensure the air being pumped into the system is pure and clean. For the charcoal filter, the OmniFilter R200 Refrigerator Icemaker Water Filter suits this purpose. This filter removes any residual odors in the air at a cost of $13.50 (filters.filtersfast.com). To remove any charcoal particles from the air, however, the Tiara Medical - Bacterial/Viral HEPA Filter for CPAP will be used. At $6.95, this is a cheap solution to clean air (www.montagemed.com). Both these filters have a long life span. If they wear out, they are easily replaceable and relatively inexpensive.

Future Work

The tubing and valve size cannot be determined until the pump orifice size is known. Once all the parts from the previous section are ordered and delivered, the tubing and valves will be ordered. Once all parts are acquired, the design can finally be constructed and tested.

Product Design Specifications: MRI-Compatible Olfactometer

Team Roles:
Team Leader: Steve Welch
Communications: Ryan Kimmel
BWIG: Kaitlin Brendel
BSAC: Joe Decker
Last Update: March 11, 2009

Function: The purpose of this design is to deliver timed amounts of olfaction stimulants to a test subject undergoing an fMRI scan.

Client Requirements:
- Must be user friendly
- Must have replaceable parts
- Must be automated
- Must have quick setup time
- Must be MRI compatible

Design Requirements:
- Constant temperature and humidity
- Have up to four odor canisters to 37.5° C.
- Control air pressure to 1 atm.
- Easily portable, must weigh less than 40 kg.
- Must fit within limited table space. Roughly 1 m x 1 m.
- Must have a computer interface.
- Must present odor for controllable amount of time
- Must have ability to control the flow rate
- Easy to set up
- USB connection
- Compatible with EPRIME
- Must be able to go to the no-odor condition in under one second
- Must not retain any residual odors
- Must be compatible with the "active sniffing" technique
- Must be able to determine when odor reaches subject

1. Physical and Operational Characteristics

a. Performance Requirements: The olfactometer must operate for a desired time sequence. For example, the odor could be sent for 30 s, and then clean air must be sent for 30 s. There will be four complete sets of odor sent to the mask and clean air sent to the mask.

b. Safety: The air pressure must not be strong enough to cause discomfort or dizziness to the patient. Therefore, the pump should not exceed 21 kPa.

c. Accuracy and Reliability: A high degree of repeatability is required. Flow rates must be constant and controllable. The temperature of the liquid odors must be kept at 37.5° C, and the humidity must be kept under 20%. Odor should be completely evacuated from the mask within 1s at the end of each cycle.

d. Life in Service: Parts should be made replaceable, increasing the service life indefinitely. The olfactometer will be used daily for at least 30 min. Parts will be replaced primarily following accidents.

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, mask, etc.). A ten-year life span would be desirable.

f. Operating Environment: The olfactometer will be used in an ordinary MRI environment. All of the components must be compatible so that they do not interfere with the magnet on the MRI scanner that operates with a magnetic field of 2 T and at a Larmor frequency of 42.57 MHz/T.

g. Ergonomics: The olfactometer should require as little human interaction as possible while still remaining reliable and user friendly. The users should be able to quickly control the desired flow rates and timing, then proceed with the experiment.

h. Size: The olfactometer must be small enough to fit on a 1 m x 1 m tabletop. It must be easily transportable between buildings.

i. Weight: The liquid controller must be light enough to be carried up and down stairs and between buildings by an average person. Therefore the weight should be less than 40 kg.

j. Materials: Materials must not interfere with the MRI machine. The tubes and mask should be made out of Teflon so they do not retain any odors. The canisters should be made of glass so they can be easily cleaned.

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

2. Product Characteristics

a. Quantity: One unit will be needed.

b. Production Cost:
Estimated budget: $500-$1000

ITEM	COST
(4) 2-way solenoid valves:	$300.00-$540.00

LabVIEW Interface	$109.00
Elite 801 Air Pump	$7.99
(1) Mask	$3.99
A/C Power Supply	$20.00
Relay Board	$100.00
Teflon Tubing	$50.00
Travel Case	$100.00
Flow Meter	$40.00
Warming Tray	$79.99
(6) Kimax Flasks	$131.42
OmniFilter R200	$13.50
Tiara Medical HEPA Filter	$6.95
	TOTAL
	$962.84-$1202.84

3. Miscellaneous

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

b. Customer: The olfactometer will be used by faculty members in the department of radiology and neurology on the UW-Madison campus. The customer prefers E-Prime for easy integration into already existing programs. An air pressure system will drive odors into the mask.

c. Competition: There are currently no devices on the market that meet all of the client's requirements.

References

Research

Lowen and Lukas. "A Low-Cost, MR-Compatible Olfactometer." Behav Res Methods, 2006 May; 38(2): 307–313

University of Oxford fMRI Centre Web Page. http://www.fmrib.ox.ac.uk/education/fmri/introduction-to-fmri/what-does-fmri-measure

Products

Elite 801 Air Pump by Hagen http://www.marinedepot.com/ps_viewitem.aspx?idproduct=HG10799&child=HG10801&utm_source=mdcsegooglebase&utm_medium=cse&utm_term=HG10801&utm_content=Elite801AirPump&utm_campaign=mdcse&site=google_base

Kimax* Filtering Flasks with Side Arm – 250 mL http://www.fishersci.com/wps/portal/SEARCHRESULTS?ru=http%3A%2F%2Fprodwcsserver%3A9060%2Fwebapp%2Fwcs%2Fstores%2Fservlet%2FSearch&searchPref=no&position=search&preferProd=unchecked&searchType=Rapid&catalogCode=HC_SC&keyWord=10-181D&catCode=ALL

OmniFilter R200 (Charcoal Filter) http://filter.filtersfast.com/search?w=omnifilter+R200&asug=&view=list

Bacterial/Viral HEPA Filter for CPAP or BiLevel – Tiara Medical http://www.montagemed.com/CPAP_products.php?sstr=HEPA+filter&dtype=keyword&submit.x=0&submit.y=0&submit=submit

LabJack U12-PH OEM Board-Only http://www.labjack.com/details.php?prodId=39&category=0

SMC Needle Valve http://www.usplastic.com/catalog/product.asp?catalog_name=usplastic&category_name=15615&product_id=15616

Broil King Warming Tray http://www.target.com/gp/search/179-6594524-5074236?field-keywords=warming%20tray&AFID=google&CPNG=Appliances&LNM=warming_tray&LID=4441699&ref=tgt_adv_XSGT0131