UW-MADISON COLLEGE OF ENGINEERING
DEPARTMENT OF BIOMEDICAL ENGINEERING

Intervention Device for Handwashing Compliance

Claire Flanagan – Team Leader
Robyn Hrobsky – BSAC
Adam Rieves – BWIG
Bradford Rogers – Communicator

Client: Dr. Carla J. Alvarado
Advisor: Dr. Brenda Ogle

12/12/2007

Hospital acquired infections are responsible for approximately 99,000 deaths per year. Thus, hand hygiene of the clinician is paramount to patient safety. To increase hand washing compliance and reduce the possibility of cross-patient infection, a device was created to interface with electronic medical records entry systems and deliver a dose of disinfectant to both the user's hands and keyboard. A custom designed pump atomizes an ethanol-based disinfectant onto the user's hands and keyboard upon a pre-determined command signal. In order to evaluate the effectiveness of the system several tests were performed. A microbial culture test verified that the delivery system was effective for sufficient disinfection. Also, a keyboard durability test confirmed that a keyboard does not lose its functionality even after a 48 hour exposure to concentrated ethanol. Finally, a questionnaire was given to 29 nurses at UW-Hospital. The surveys indicated that 76% of nurses would support the implementation of this design. In the future further testing will be done on the formulation of the disinfectant, as well as more efficient ways to effect atomization.

CONTENTS

BACKGROUND

Hand Hygiene in Healthcare

Hand hygiene is an integral part of the daily procedure of a health care worker. It is the most essential component in preventing further spread of sickness and disease. One study found that the average hand washing compliance in a teaching hospital was only 48 percent (Bischoff, 2000). Therefore, to increase compliance, a movement to decrease contamination must be effected, a standard for which has been established by Spaulding (1972). The Spaulding Definition for Decontamination consists of three levels - high, intermediate, and low. The first procedure kills vegetative microorganisms, inactivates viruses, and eliminates some bacterial spores. The intermediate level, the one being used for this project, kills vegetative microorganisms, all fungi, and inactivates most viruses. As a basis for comparison, the lowest level kills most, but not all, vegetative bacteria. In the clinical setting, the patient can be exposed to many types of bacteria and microorganisms. The health care worker can also transmit bacteria through his or her own saliva, blood, or just from rubbing his or her eyes. Finally, the patient can become infected with his own flora if proper precautions are not taken. This type of infection is common in urinary catheterizations, for example.

Computer Based Patient Data Entry

When HIPAA was enacted in 1996, it mandated that, in the near future, all hospitals will be required to utilize the electronic medical record (EMR) (Connecting For Health, 2004). Hospitals and clinics enter data and patient information on machines called Computers on Wheels, or more commonly COWs. These come in a variety of different models, but generally all have the same components. There

Figure 1

Figure 1. This figure shows a typical COW used in a clinical setting. The design is streamlined for mobility.

http://www.interiormall.com/images/cat/furn/COW20-CoverDW1_b.jpg

is a monitor, a CPU, and a keyboard that are incorporated into a stand that can be easily moved from one room to another. **Figure 1** shows a COW commonly used in clinical settings. The newer models emphasize its compact shape, easy maneuverability, and safe and ergonomic design for improved workflow and accuracy. These are generally lightweight and can be used by anyone familiar with a

desktop computer. Some models, as the one shown in Figure 1, have very little space around the keyboard and monitor and very few objects can be added before the workspace becomes cluttered. Other COWs use a laptop computer in place of a desktop computer and have even less space around the keyboard area. Typical COWs run on standard 120 V power and are plugged in every time they are wheeled to another room. Many also come equipped with a battery, but it serves as a secondary power source. However, with advances in technology come new challenges. The mobility offered by COWs also poses the risk of unintentionally transporting and consequently transmitting infectious agents from one patient room to another. These infectious agents pose a significant risk to an immunocompromised patient; however, a healthcare worker is chronically exposed to these pathogens and also risks becoming infected if proper hygiene techniques are not observed.

Current Enforcement of Hand Hygiene

To manage hospital infections, standards have been set to enforce handwashing compliance. According to the Association for Professionals in Infection Control and Epidemiology (APIC) regulations, it is mandatory for health professionals' hands to be clean at all times when working with patients (Larson, 1988). If a person's hands are not visibly soiled, an alcohol-based hand rub may be used for decontamination. In order to achieve disinfection of the hands, about 3 mL of a waterless, alcohol-based antiseptic should be rubbed into the hands for 30 seconds, followed by a repeat application for the same time duration. When a health care professional transfers from working on a patient to working on a computer, the complying professional, is required to wash his or her hands before and after touching the computer keyboard. This should be routinely done throughout any normal procedure whenever data is entered into a computer; however, this provision significantly slows down a worker's progress in the presence of current technology.

There are many types of disinfectants used by hospitals and medical staff for various procedures. Hydrogen peroxide is commonly used in clinical settings and is FDA-approved for antimicrobial purposes. It has an unpleasant odor and can cause irritation to the eyes and skin. Triclosan® is a potent antibacterial and antifungal agent that is used in Microban® materials (Schweitzer, 2001). However, some bacteria have developed a resistance to it (Brenwald, 2003), and when combined with chlorine, it can form chloroform (Rule, 2005), which is carcinogenic. Glutaraldehyde is excellent at quickly killing bacteria, fungi, viruses and spores and is commonly used to sterilize medical and dental equipment. It is also colorless and non-corrosive. However, it has a peak exposure limit of 0.05 ppm in most countries, so it has some toxic effects (Takigawa, 2006), and causes severe eye, nose, and respiratory irritation. Ultraviolet lamps are used in laboratories and in medical facilities to sterilize equipment. Its wavelengths, however, are known to cause some kinds of cancers.

Ethanol as a Superior Disinfectant

However, alcohols are the most effective and rapid means of disinfection, and alcohol-based gels have become the preferred method of many health care workers due to its efficient and extensive disinfection. Alcohol solutions containing 60-95% alcohol are most effective, since they have been proven to kill 99.99% of germs when used correctly (What Everyone Should Know, 2007). Specifically, alcohol eliminates contamination by denaturing proteins in the membrane of cells, and the lower percentages within this range are actually the most effective because water facilitates this denaturation process (CDC, 2002).

As previously stated, the final design needs to achieve an intermediate level of disinfection. With this in mind, alcohols have excellent *in situ* germicidal activity against gram-positive and gram-negative vegetative bacteria, including antibiotic–resistant pathogens such as Methicillin-resistant

Staphylococcus Aureus (MRSA) and various fungi (CDC, 2002). Furthermore, 60-70% alcohol terminates enveloped viruses such as Hepatitis B and C. In addition, alcohols are rapidly germicidal when applied to the skin, but they have no appreciable persistent activity (CDC, 2002).

These considerations are important in achieving handwashing compliance, but there is a need for tools to be implemented in the clinical setting to better enforce handwashing. Such tools must embrace the advent of EMR while also reducing the amount of time to disinfect, which will ultimately lead to decreased hospital-transmitted infections.

PROBLEM STATEMENT

Hand hygiene is an integral part of a health care professional's job, and the single most important infection control procedure in preventing contamination. This design project is focused on achieving an increase in compliance with hand decontamination when moving from computer keyboard to the patient. The device should expedite the process of hand decontamination while keeping the health care professional and patient safe. It should also be affordable and able to assimilate in to any clinical setting.

DESIGN CONSTRAINTS

Client Based Requirements

The implementation of a device to aid in improving health care hand washing compliance must meet several criteria. Most importantly, it must disinfect the user's hands and maintain the cleanliness of the keyboard and the device itself while keeping the health care professional and the patient safe. The design should not interfere with the health care professional's work and should not allow any discomfort for the user or the patient. It must be safe for prolonged use, meaning that it should also conform to any CDC or APIC regulations, and it should consistently disinfect the user and itself. It should be easily maintained and cleaned while remaining user-friendly. The chemicals incorporated into the device may degrade over time so proper storage devices and shelf life should be considered in the final design. Finally, the product should not impede the user's typing process or ability to easily access the keyboard. Furthermore, the design must fit seamlessly into the clinical environment, preferably being easily incorporated into the COW and taking up relatively little space. It is expected to be used 20-30 times per clinician, per day, and up to about 10 minute intervals each time. It should be reliable and accurate so it can withstand the mobility requirements. Also, the device should be small because of the COWs' minimalist designs. Any additional bulk will take away from the functionality of the COW design, so the device must optimize the COWs mobility without compromising the device's ability to disinfect the keyboard and user's hands. Finally, the entire device should be cost-effective for it to be accepted by a wide market.

Design Based Requirements

In the beginning of the semester we realized that there were several approaches to accomplish the disinfecting tasks. However, it was quickly determined that atomizing a spray would be the superior method to reach these ends. This led to the addition of requirements for the device. Mainly, atomizing a spray requires a significant amount of pressure (>30psi). Also, the device will need to deliver the spray in a manner which does not affect the user's ability to perform his or her task. As such, an adequate dose of disinfectant must not take more than five seconds to deliver.

COMPETING PRODUCTS

Currently, there are no products that both disinfect itself and the user's hands while using a COW. However, all disinfecting agents, including hand sanitizers such as Purell®, could be considered competition as well as some types of keyboards. Within the keyboard market, there are some products that prevent bacteria buildup on their surfaces, which makes cleaning relatively easy. One such product is called InduKey (**Figure 2**). It is an ergonomic, cordless keyboard and mouse, which features an antimicrobial surface that is ideal for medical or hygiene-sensitive environments. It also has a special Dura-coating (http://www.indukey.com/content/featured_prod.html) that provides mechanical and chemical resistance. This makes it able to withstand spills in a clinical setting. However, it requires an

Figure 2

Figure 2: Indukey keyboard with antimicrobial surface.

http://www.indukey.com/content/featured_prod.html

entirely new keyboard instead of being retrofitted onto an existing one. It only helps prevent bacteria buildup instead of totally disinfecting itself, and it does nothing to disinfect the user's hands.

Another product that is similar is the Unotron® (http://www.unotron.com/) washable keyboard. These are wireless keyboards that are designed to be able to be cleaned under running water or be immersed in an antimicrobial agent to reduce the spread of germs. This neither disinfects itself or the user's hands, but it allows it to be easily cleaned, which can not only save time in a clinical setting but also help reduce bacteria buildup on the keyboard itself.

Microban® keyboards, which use Triclosan® to maintain an antibacterial surface, could also be considered competition. These are common products that can be bought at many different stores that sell generic computer equipment. They only resist bacteria, however, instead of promising a completely disinfected keyboard. These also need to be separately-purchased and do nothing to disinfect the user's hands.

Another product, known as the hand washing signaling device (handwashinghelp.com, 2007), emits a beep telling the user when enough soap has been dispensed. Then, a series of beeps informs the user that it is safe to rinse his or her hands and finish. This product works well to influence the user to use good hand washing technique. However, our intended product is much different than this as this does not use alcohol-based hand rubs or is intended for use with a computer.

FINAL DESIGN

The decision to atomize a disinfectant presented a unique set of challenges which ultimately resulted in the creation of a customized pump to effect the spray. At mid-semester the search began for a pump which would meet all of the pressure and flow requirements of this application; however, an interesting trade-off emerged while looking for a pump. Many pumps that were able to support the pressure required did not have output volumes that match those needed for this application. High pressure pumps were typically too large and designed for industrial applications instead of small, metered dispensing. The trade-off emerges when moving to smaller pumps built for microapplications. These pumps can support the output needed but could not support the pressure required to atomize a spray. After an extensive search, no pump was found that was able to support both the pressure and flow requirements for this application within our budget. Therefore, a customized pump was created.

Figure 3

Figure 3. A side view of the final design showing the nozzle in the upper right, the reservoir on the bottom right, and the linear actuator and syringe on the left.

The resulting design is a modified diaphragm pump. Diaphragm pumps involve a set of one-way valves which draw fluid into a chamber under negative pressure, and force it out under positive pressure. The final design consists of several different components including a reservoir, one-way valves, a modified syringe, a linear actuator, and the spray nozzle. A picture of the entire set-up is shown in **Figure 3**.

Linear Actuator

The linear actuator in this design moves the syringe plunger and creates the dynamic pressure within the chamber. The variables that determine the pressure/flow within the system are the force of the plunger, the speed at which it moves, the diameter of the syringe, the volume of fluid dispensed, as

well as the total volume of tubing. Since there are so many variables which affect the pressure/flow, several simulations were run in Maple in order to determine the best configuration for this application. It was determined that a linear actuator would work for this application with a syringe of diameter .85 in if it could support 150 lbs of force, and move at 0.4 in/s. The actuator purchased possessed these features, and was implemented into this design. Since there will be 150 lbs of force on the actuator, and one end of the actuator must be stationary, it will be secured on one end by a pin-connection to a board. A free body diagram is shown in **Figure 4**.

Figure 4

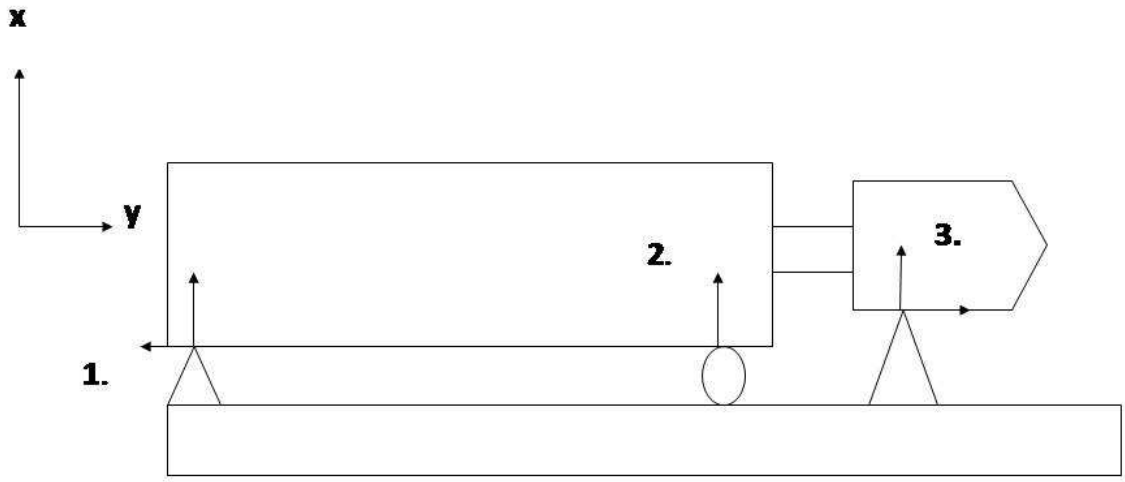

Figure 4. **1) The base of the actuator acts as a pin connection, with reaction forces in the x and y directions.**
2) The top of the actuator acts as a roller connection, with a reaction force only in the x direction. Remember, the actuator is mounted in a vertical position.
3) The syringe is mounted by two nails, which act as a pin connection, having forces in the x and y directions.

Pump Assembly

The pump was assembled using the linear actuator, a one-way valve oriented from the reservoir into the chamber, a one-way valve oriented from the chamber to the spray-nozzle, the modified syringe

Figure 5

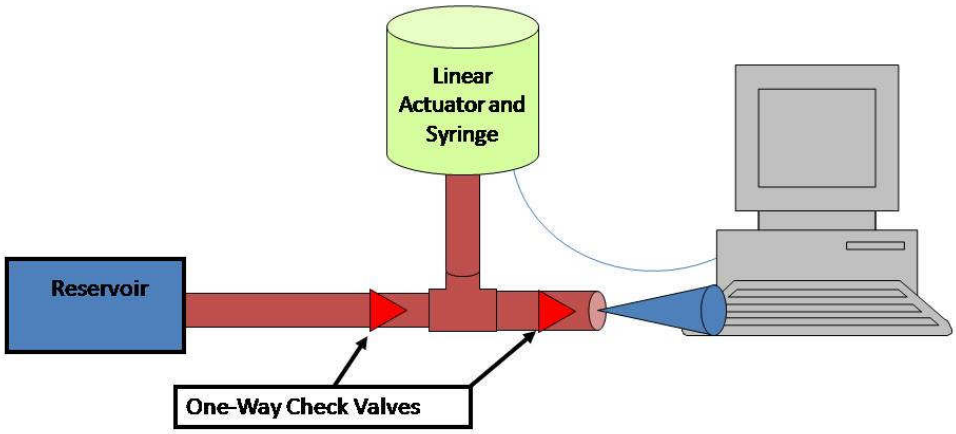

Figure 5. The configuration of the one-way valves which allows for chamber filling under negative pressure and dispensing under positive pressure

and plunger, as well as connective tubing. A schematic of the pump is shown in **Figure 5**. When the syringe plunger is drawn back, the one-way valve from the spray nozzle closes, and creates negative relative pressure within the syringe barrel. This draws fluid through the one-way valve from the reservoir into the syringe chamber. As the syringe plunger is pushed forward, the one-way valve from the reservoir closes, and the disinfectant is forced out of the spray nozzle under high pressure.

The syringe plunger in this design is connected to the linear actuator via a pin connection. However when the plunger is within the syringe barrel the connection acts as a collar; thus the syringe plunger only has two degrees of freedom, twisting within the barrel, as well as moving up and down the barrel. Also modified for the syringe plunger was the reinforcement of the gasket. Under the relatively high pressure that the syringe is subjected to, another gasket was attached to the first (**Figure 6**) to prevent leaking. Adding another gasket in this

Figure 6

Figure 6. The actuator-syringe junction. Note the double-gasket to aid in sealing the chamber under high pressure.

configuration allowed for a tighter seal for one main reason. The more distal gasket is flexible on the face which is exposed to the most pressure because it is not supported by plastic as the proximal gasket is. Under pressure the second gasket deforms outward, reinforcing the seal.

Circuit and Command

The linear actuator used in this application runs on 12 VDC. When +12 VDC is applied to the leads, the actuator moves forward, but when -12 VDC is applied the actuator moves backwards. In order to interface the device with the computer, a custom designed circuit was built to turn the switch on and off. A schematic of the circuit is shown in **Figure 7**.

Figure 7

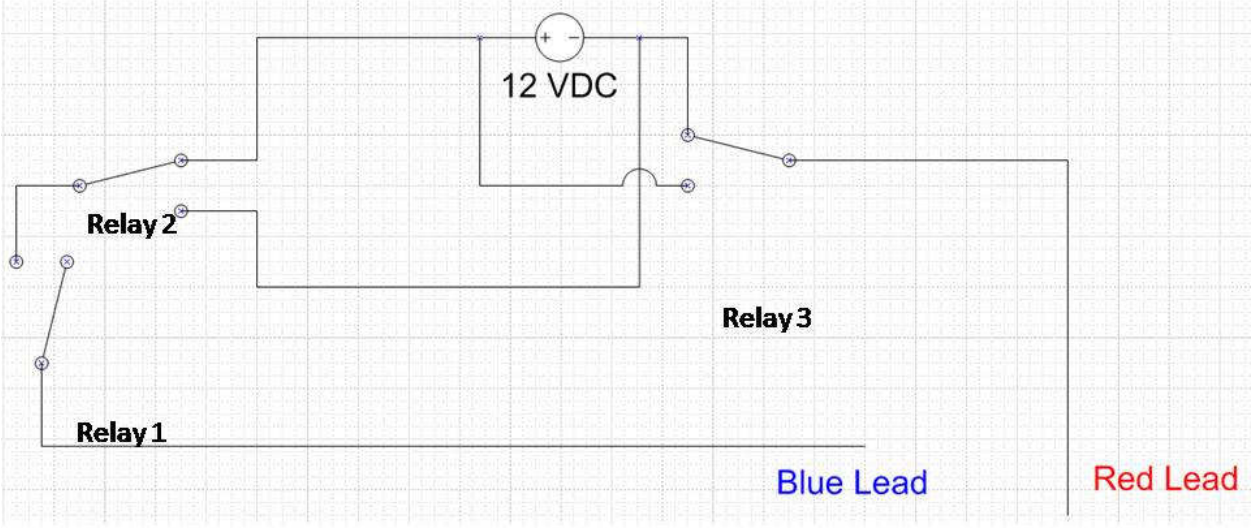

Figure 7. The circuit design. Each of the three relays is independently controlled by the computer. The red and blue leads connect to the linear actuator.

The command signal from the computer is a digital 5 VDC signal and each output corresponds to one of the three relays. Relay one controls the on/off status of the actuator, and relays two and three control the forward/back operation. When relay one is on, the relay is activated. If relays two and three are off, the actuator will move forward. If relays two and three are on, the actuator will move backward. **Figure 8** shows the circuit in each of three states – off, forward, and back. The longer the circuit is turned on in the forward configuration, the more volume will be dispensed. In this application, it has been determined that 10 mL of disinfectant would be an adequate amount to cover both the keyboard as well as the user's hands. In order to deliver 10 mL and refill the chamber, the circuit must move forward for 1500 ms and move backward for 1600 ms. The reason for the difference in time between forward and backward is a physical shifting of the barrel when the plunger is pulled back. However, the next generation prototype the chamber will be completely immobile relative to the actuator; thus eliminating the need for sophisticated circuit timing.

A customized LabVIEW VI controls the state of the actuator. When the user types CTRL+ALT+ENTER, the prototype is set to automatically dispense 10 mL of fluid. This command sequence is designed to simulate a log-on procedure; however, it can be customized to any combination of keys desired. After the user triggers the command, there is a five second timeout before the user can stimulate another signal from the computer. This will prevent overuse or unintended use of the system.

Figure 8

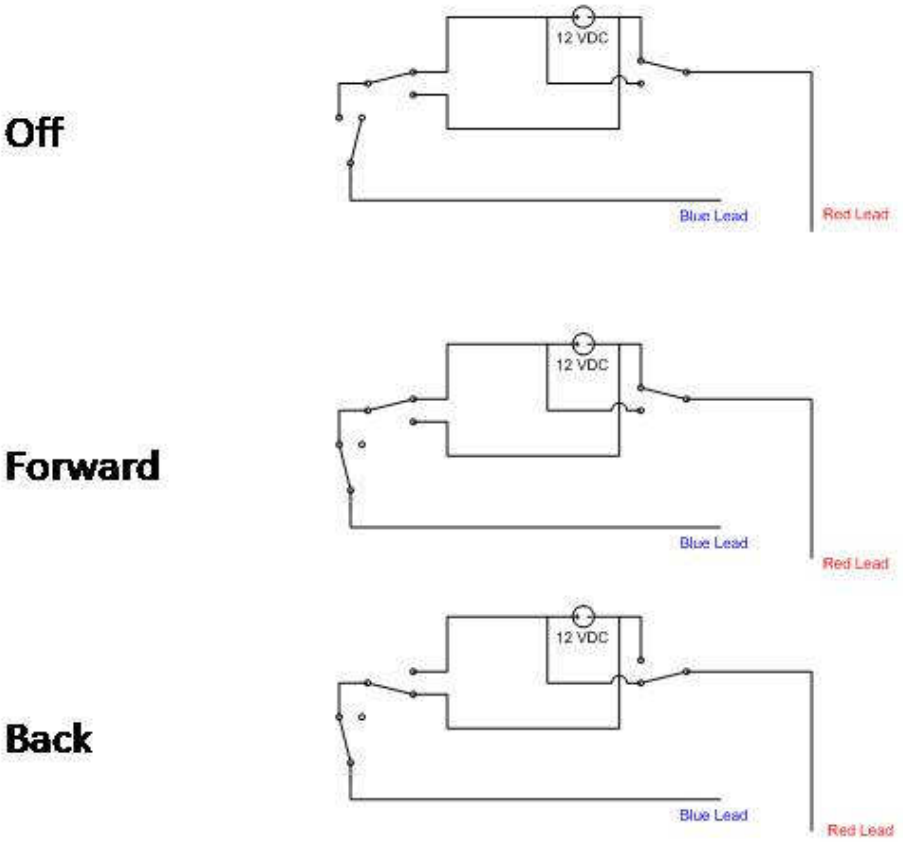

Figure 8. The circuit in each of the possible configurations and their effect on the linear actuator.

Final Assembly and Mounting

All of the components in this system were assembled onto a mobile computer cart. The reservoir was mounted on the base of the cart, and the tubing leading to the actuator was secured by zip ties. The actuator-syringe apparatus was secured vertically to the cart using bolts. The reason that the apparatus was mounted vertically was so that any air-bubbles in the system will be forced out the nozzle, and will not be permitted to accumulate within the chamber. This configuration allows for proper dosing of the disinfectant over multiple uses. Finally, tubing connects the chamber to the nozzle, which is secured in a static position by a brass collar. **Figure 9** is a picture of the mounted spray nozzle. A detailed part list with dimensions can be found in the expenses section on page 19.

Figure 9

Figure 9. The spray nozzle connected to the work station that atomizes the ethanol solution.

Determination of Ethanol as a Superior Disinfectant

Various alcohols, such as isopropanol, ethanol, and n-propanol are all examples of disinfectants. However, each one has unique viral coverage with ethanol acting as the most effective antimicrobial agent for a clinical setting. The concentration of ethanol is equally important to its activity. Concentrations below 65% do not adequately kill microbial growth, yet concentrations above 95% are ineffective because they do not contain enough water to permit protein denaturation. Therefore, we determined that a 70% w/w solution of ethanol would offer the most clinical benefit.

Highly concentrated ethanol can cause damage to a person's skin, so many hand sanitizers and hand soaps have added emollients to the solution to help moisturize the skin. A study using alcohol-based hand rubs, antibacterial agents, and other soaps found that the alcohol hand sanitizers with emollients caused substantially less irritation and dryness than the soaps and antibacterial agents without emollients (Klimes, 2006). Emollients and moisturizers, synonymous terms, are used to prevent dryness and scaling of the skin. There are two categories of emollients of interest to this application, which include occlusives and humectants. Occlusives provide a layer of oil on the skin to slow water loss, while humectants are substances that increase the skin's water-holding capacity (NZDS, 2006).

Humectants are a better choice for our application because they do not leave as much residue as occlusives. A common humectant that is used in many hand sanitizers and cosmetic products is glycerin, also known as glycerol. It is used to improve the smoothness of the skin and provide lubrication and is especially beneficial for those with sensitive skin (NZDS, 2006). However, it should not be atomized because it may irritate mucous membranes found in the eyes, nose, and respiratory tracts. In addition, polyethylene glycol (PEG) is a type of emollient that is used in many types of hand moisturizing solutions. It is usually mixed with other emollients, such as glycerin, because it does not work well by itself. Finally, vitamin E is an emollient used in skin care products. It is a highly effective antioxidant that protects the skin cells against free radical damage (Vitamin E, 2007).

Ultimately, our solution contained 70% ethanol, vitamin E, PEG and water. The ethanol was added based on weight so ultimately, an 86.6% v/v solution was used with diH_2O comprising the remainder of the solution. Also, 2% v/v of a water-soluble vitamin E oil were added and 3% v/v of 8KDa PEG were added.

SAFETY CONSIDERATIONS

Given the environment in which this device will be used, several people will routinely depend on reliable, safe performance from our technology. Ultimately there are two main safety considerations for this design – the reliable performance of the device as well as the effectiveness of its use. Many concerns that can be posed about the safety and efficacy of this device have been addressed in its development; however, we aim to be as comprehensive as possible in this analysis.

The primary safety concern for this device is that it poses no additional risks to its users than before its implementation. Ethanol is a relatively energy dense material, and if a 10 mL metered dose of pure ethanol completely combusted, 232.07 kJ of energy would be released. However, for this to occur, an ignition source would need to be present at the time of use. Because the one-way valve from the nozzle is located at the nozzle, any ignition would not be able to propagate beyond the one-way valve. In the future development of the prototype, studies will have to be performed using the final formulation in order to evaluate its flammability. These may include how near or far from the spray an ignition source must be in order to initiate combustion, how the formulation may be varied to minimize the risk of fire while still remaining effective for disinfection, as well as how the spray may be directed to minimize human injury in case of fire while still maintaining full coverage, among others. While considering ignition sources, it is important that the circuit controlling the device is properly wired and grounded so that it does not become a fire hazard. Also important to the safety of this device is what may happen in the event of electric failure. The device is designed such that if the circuit malfunctions or loses power the actuator will not move. In this case, the device does not take any action and the COW is unaffected by the presence of the device but cannot benefit from it until power returns. The device would not be considered a necessary medical device, and thus a back-up power source is unnecessary. Finally, the device does operate under relatively high pressure and forces. Thus it was important to purchase equipment rated for the pressures we were dealing with, as well as to properly brace the actuator to the COW so that it does not move.

Equally vital to this project as safe dispensing of the disinfectant is the assurance that it is actually adequately performing the disinfecting task. Therefore it will be necessary to test the shelf life of the final formulation and to determine that the solution is homogeneous over time, as well as to assure users that the solution does not degrade over time. It is also imperative that the device adequately covers the entire keyboard as well as the user's hands. Future refinements of the design may include moving the spray nozzle or possibly adding another nozzle to ensure full coverage. The formulation of the disinfectant is also important to the safety of its user. A certain percentage of the population is sensitive to alcohol, and skin irritation may result from exposure to it. As a result, any

hospital that employs someone with this condition would have a method to minimize that employee's exposure to this device or to substitute the original formulation with an alcohol-free one. However, further testing would have to be done to determine the extent to which those with alcohol sensitivity would need to be isolated from the system. Finally, it is possible that those who are resistant to having their hands be disinfected while using a computer may find ways to circumvent the system and avoid disinfecting their hands. These users may be persuaded to accept the system by implementing training programs and assuring them that they will be improving patient safety by using the device. However, there may still be people who refuse to utilize this system. Although some users may ultimately choose to avoid the disinfectant spray the keyboard will still be disinfected, thus accomplishing half of the device's original task.

DEVICE TESTING

In order to effectively translate our technology into a clinical setting, several tests were conducted to evaluate the mechanical performance of the device, its epidemiological efficacy, and the usability of it in a hospital environment. The results of these tests can be paired with the background research of our design and the nuances of the design development process to yield a product that is better suited to achieve its design goals and for mass production.

Microbial Testing

One of the most important criteria in achieving the design constraints for our technology was that the device must be able to adequately disinfect both the surface of the keyboard and the user's hands. To objectively evaluate this, we took an epidemiological perspective and performed several microbial cultures in an effort to determine whether our delivery system could effectively accomplish intermediate-level disinfection on the required surfaces. As previously described, intermediate-level disinfection kills vegetative microorganisms, all fungi, and inactivates most viruses, so we aimed to identify the pathogens that grew on agar plates both before and after disinfection of subjects' hands and of a keyboard sample.

To evaluate the efficacy of keyboard disinfection, a previously discarded keyboard was used. Initially, one mL of diH_2O was applied to the keyboard's spacebar using a pipette, vigorously mixed around, and drawn up. This solution was then transferred to the left-hand side of an LB agar plate, where microbial growth would be monitored for the subsequent 48 hours. After the spacebar was allowed to dry for ten minutes, the device was triggered to deliver 10 mL of 70% v/v alcohol to the keyboard. Once again, one mL of water was applied to the spacebar, mixed around, and drawn up before plating it on the right-hand side of the agar dish.

The testing procedure for the hands was based on the "glove juice test," (Leyden, 1989) which is commonly used to evaluate the efficacy of different hand disinfectants. First, each of four subjects donned nitrile Neuthera® gloves and wore them for a ten minute interval. After this period, one mL of diH_2O was added to the interior of the glove in the palm region, and then the palm was palpated momentarily before the solution was drawn up. The purpose of this procedure was to extract the sweat produced while wearing the gloves and, with it, a representative sampling of the microbes, both innocuous and pathogenic, that were present on each subject's hands. Furthermore, the palm region was chosen because it is more likely to produce sweat than other areas of the hands, it can readily pool the one mL of liquid, and it is also the most concealed region of the had from the spray of disinfectant, so if the test produced favorable results for this region, it is likely that the device is effective. However, one drawback of this technique is that we could not guarantee that all of the microbes were collected from the hands using this technique, the results were relative to before and after disinfection rather than quantitative for each.

Next, LB agar plates were inoculated with the subjects' hand sweat solutions and set aside. On the left side of each plate was a culture from the subject's left hand, while the right side contained a culture from the right hand. Before obtaining cultures of the hands after using the device, each subject allowed their hands to dry for ten minutes to ensure similar testing conditions between each experiment. After this period, each subject placed their hands on the home row of a test keyboard and an atomized spray of 10 mL of disinfectant was delivered to the keyboard region to simulate the conditions of our device in a clinical environment. The subjects immediately applied gloves a second time, and after wearing them for ten minutes, one mL of diH_2O was added, mixed, and drawn up as in the first portion of the study. New agar plates were inoculated with samples from the left and right hands post disinfection.

Finally, two control plates were prepared to better evaluate the extent of growth on the plates. One of the controls contained a sample of the disinfectant solution without coming into contact with the skin, while the other plate served as a positive control. A combination of saliva and beneath-the-fingernails grit was plated under the assumption that these would have high microbial activity. All of the plates were incubated right-side-up for 24 hours and then flipped upside down for another 24 hours, so that the microbial colonies would grow only where they were streaked onto the plate and would not spread across the plate if condensation formed on the surface of the agar. An example of the cultures after 48 hours can be seen in **Figure 10**.

Figure 10

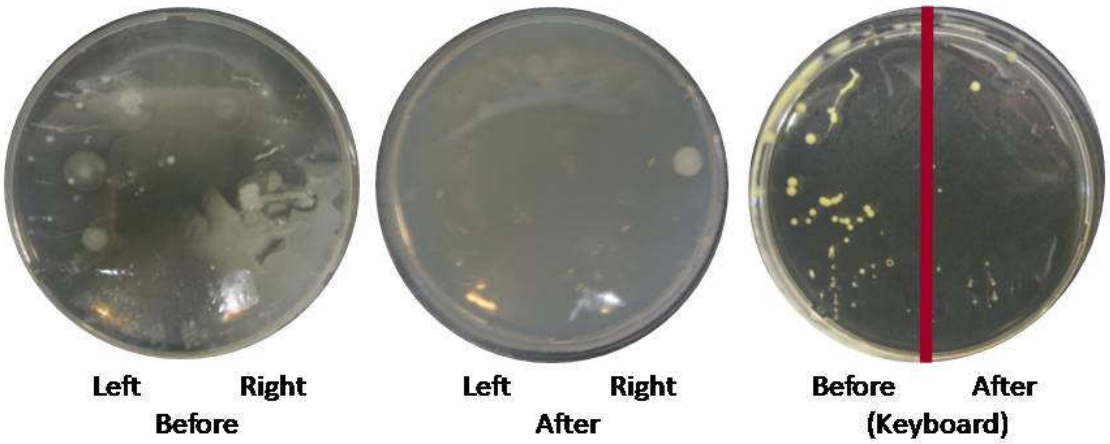

Figure 10. The results of the microbial culture indicate that disinfection using our device significantly reduces colony formation. This figure shows an example of one of the subjects' hands as well as the keyboard.

To analyze the cultures, a qualitative approach was taken. First, a list of commonly-transmitted pathogens was created from a comprehensive review of the transmission of infectious agents in a healthcare setting, published by the CDC (2007). These microbes, shown in the table above (**Table 1**), were then used as a basis for comparison in determining those found on the plates.

Table 1. Common microbes found in clinical setting.

Adenovirus	*Haemophilus influenza*	*Ringworm*
Campylobacter species gastronteritis	*Hepatitis*	*Rotavirus*
C. difficile	*Human metapneumovirus*	*Rubella*
Chlamydia pneumoniae	*Listeria monocytogenes*	*Salmonella*
Conjunctivitis (bacterial and viral)	*MRSA*	*Shigella*
Cryptosporidium	*Neisseria meningitidis (meningococcal)*	*Staphylococcus aureus*
E. coli	*Noroviruses*	*Streptococcus*
Fungi	*Parvovirus B19*	*Vibrio cholerae*
Gram-negative enteric bacteria	*Rhinovirus*	*Yersinia enterocolitica*

The microbes were predicted using colony morphology characteristics; seven pathogens were reasonably identified in the pre-disinfection culture, based on the CDC study and a microbiology website (http://www.microbelibrary.org/asmonly/details.asp?id=2566&Lang=). On these include the following:

Potential Pathogens Identified in Study:

- E coli
- Candida
- Klebsiella pneumonia
- Proteus mirabilis
- Pseudomonas aeroginosa
- Staphylococcus aureus
- Yeast

As shown, there were several pathogens that were purportedly present in the initial cultures, which would pose a risk of infecting either the patient or clinician. Although yeast is, for example, fairly harmless, the others have consistently received attention for causing urinary tract infections, pneumonia, ear infections, and dermatitis, and pseudomonas aeruginosa is known as the most frequent colonizer of medical devices (Medical Devices, 2003). Therefore, it is even more notable that most of the colonies were completely eradicated in all samples tested, and, in fact, in the example shown above, microbial growth was significantly reduced. Just one colony grew on the plate after the subject's hands were disinfected. The keyboard shows similar results. These findings are promising for the implementation of our design, since it shows that the device is able to thoroughly and efficiently disinfect both surfaces.

Ideally, these results would be enhanced by isolating each colony and establishing new cultures for each of them and then carrying out some common biochemical assays to verify the pathogens that were identified. Furthermore, it would be helpful to carry out the entire procedure in such a way that we could evaluate all of the microbes on the keyboard and subjects' hands in order to reach a more quantifiable conclusion. This would most likely be accomplished by carrying out a more rigorous glove juice test, which would involve adding a significant volume of culture medium to the gloves and inoculating several agar plates with the entire volume of the medium. From this data, we could conceivably estimate the number of CFUs (colony forming units), which would represent the total number of microbes on each of the evaluated surfaces.

Keyboard Durability

To evaluate the long-term effects of ethanol exposure on the keyboard, a large volume of 70% w/w ethanol was prepared, and a functional keyboard was submerged in the solution so that the ethanol could penetrate the keyboard's surface at all times. After 48 hours, the keyboard was removed, and allowed to dry. After drying, the surface of the keyboard was determined to be somewhat affected, since it exhibited some minor corrosion and drying effects, and the keys were slightly more difficult to type on. However, when the keyboard was plugged into a computer, it was fully operational, which signifies that long-term exposure may not have much of an effect on the performance of the keyboard. Furthermore, in the final application of our device, the keyboard would never be completely submerged in a liquid and would always have time to dry in between deliveries of the disinfectant. This variation would most likely reduce the drying effects, although an inexpensive plastic cover could be purchased to cover the keys as a precaution.

Task Analysis and Usability Survey

A human factors approach was used to evaluate the overall need and market for the hand washing compliance technology. The goal of this study was to improve product usability through user-centered statistical analysis and design. To this end, a survey was distributed to a random sampling of thirty health care workers in the cafeteria of the UW Hospital in Madison, Wisconsin. The questions and the average response to each question are stated below (**Table 2**).

Table 2. Shown below is a list of the questions asked by the survey and the average answers determined from the 30 participants interviewed.

Question	Average Response
1. How often do you need to wash your hands per patient visit, on average?	**4**
2. How many patients do you see in a shift?	**15**
3. How long do you spend writing on a chart each time you enter information, on average?	**15 minutes**
4. How comfortable would you be to have your hands disinfected by a fine mist of spray while using a keyboard? *Rate 1-5, with 1 being the least comfortable.*	**3.78**

The first two questions were intended to give a better estimate of the need for the device, based on current hand washing compliance and the extent of patient interaction during an average shift at the hospital. As shown, the average number of hand washing interventions per visit was four, which would most likely take form as one hand wash (or gel application) upon entry to the patient's room, one instance of patient data entry (which would require a hand wash before entering the information as well as one upon returning to the patient) and one wash prior to leaving the room. However, this average value was subject to significant deviation, which we attributed to substantial variation in the job requirements of those surveyed. These demographics specifically relate to the random sampling of the health care workers and the fact that the selection was restricted to a hospital cafeteria during lunchtime hours. However, we were able to receive responses from several divisions throughout the

hospital but were not able to gain a comprehensive understanding of any of those divisions. Of the areas represented, the circulatory nurses in the cardiac catheterization lab and the traveling nurse surveyed had the most reported washes, with approximately ten interventions per patient. By contrast, the health care worker from Inpatient/Outpatient OR had the least reported washes, with just one intervention per patient. A complete list of the positions represented is included in the table on the right (**Table 3**). The second question in the survey also yielded significant variation and most likely traces back to the divisions represented. For example, a phlebotomist estimated 300-400 patients per shift, while an ICU staff nurse reported 2-6 patients per shift. Nevertheless, the combined information gained from the first two questions of the survey gives a general idea of the overall usage of the device per person, per shift. UW Health is a large organization, and it employs over 7,000 people, many of

Table 3. Departments represented by survey respondents

Anesthesiology	Oncology
Cardiac Cath Lab	Patient Escort
Critical Care SOS	Phlebotomy
ENU Services	Psychiatric
ICU	Radiology
Inpatient/Outpatient OR	Travelling Nurses
Med/Surgery SOS	Urology

which have contact with patients throughout the day (University of Wisconsin Hospitals and Clinics Authority, 2007). Each health care worker who works with patients on a regular basis could conceivably reach about 60 uses per day, based on our survey. Thus, there is an inherent need for our technology, especially with the transition to the electronic medical record.

The third question was directed toward understanding more about when and how frequently the atomization of the disinfectant could be initiated. We initially determined that shorter durations would indicate that the spray must occur immediately upon login to the computer system, while longer durations would allow more flexibility in the timing of the spray. As determined from the survey, the average time spent charting currently is approximately 15 minutes, so there is room for flexibility as to when the spray is initiated. However, this statistic is based on handwritten charts, so a more realistic value would have to take into consideration the time required to log into the system and to bring up the patient's chart as well as the increased/decreased time it would take to type rather than to write notes. Regardless, the 15 minute average is ample time to consider the incorporation of an automatic, atomized spray for the keyboard and hands, and even the shortest reported value of 1.25 minutes would be adequate for optimal performance of our design, which only takes three seconds to deliver the spray.

The last question was designed to serve as a basic usability assessment for our device. With minimal information about the specifications of the design or the duration of the spray, the question was developed as conservatively as possible. We feel that most users would anticipate a lengthier, more space-invasive spray than the one we have developed so we wanted to gauge how the functional

need for our device compared to the comfort needs of the user, although this assumption could be confirmed or refuted in a more comprehensive usability study in the future, possibly by using a heuristics analysis. As shown in the table above, the average ranking was a 3.78, but a more detailed breakdown of the responses is shown in **Figure 11**. Approximately 78% of those surveyed found the device to be at least somewhat beneficial, and those who were skeptical about the design typically told

Figure 11

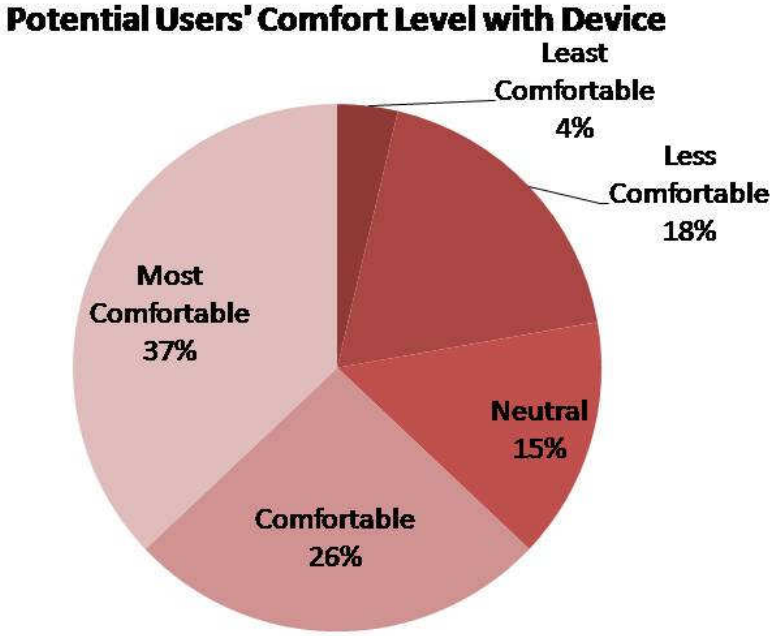

Figure 11. The results of the usability survey show that a majority of respondents found the concept of our technology would be beneficial.

us that they thought it would take some getting used to and that the spray might interfere with the task at hand. A future study that would allow participants to evaluate our technology firsthand, if approved by the IRB, could help us gain a more accurate understanding of the user acceptance of our technology. Furthermore, it may also be beneficial to carry out the three-question task analysis for more subjects within each department of the hospital to determine who would gain the most benefit from this device. Since the design is human factors-oriented, studies like these will be instrumental in the translation of our product into the clinical setting.

EXPENSES

Our expenses for the semester - including parts for the prototype, ethanol and emollients for the solution, and parts for testing as well as other miscellaneous items - came to a total of $530.51. Our first purchase was a fogging nozzle for $30.93, which atomized the solution and directed the spray over the keyboard and the user's hands. This was included in all of our designs throughout the semester and was one of the main features in our final design. Next, once we finalized our design, we bought a linear actuator, a power adapter, a rocker switch, and a mounting bracket so we could attach it to a desktop

work station. These parts, which were all used in building the prototype, came to a total of $268.99. Once we had these parts, we had to purchase parts for the circuit and procure valves and tubes to make the final prototype. These parts came to a total of $83.36. We purchased a pressure gauge for $9.98, which we hoped would help measure the pressure flowing through the system. This theory did not work out, however, because we were unable to completely attach the gauge to our system. We also needed to buy supplies for the final formulation. A liter of ethanol was $65.10, and the vitamin E was $12.32. We bought two different types of vitamin E. One was a liquid formula that we believed would easily dissolve in our ethanol solution. The other one was in gel capsules form and contained other emollients that we considered such as glycerin. We tested both formulas and ultimately went with the liquid form. We also bought a waterless disinfectant for $1.87, which we used to prove that multiple types of disinfectants would be able to atomize. Finally, we bought a PC cart for $39.96, which we used to show how our final prototype might be used on an actual COW in a clinical setting. Below is table which summarizes all of our expenses for the semester (**Table 4**).

Table 4. This table includes a complete list of our purchases this semester.

Date	Item	Product No.	Supplier	Price
9/28/2007	Fogging Nozzle	4759T22	McMaster	$30.93
11/16/2007	12vdc 10 Amp Power Adaptor (~12VDC)	PA-12V-10A	Firgelli Automations	$85.00
	6" Stroke Tubular Actuator 150 lbs force	FA-05-12-6"	Firgelli Automations	$129.99
	Mounting Bracket for all Tubular Actuators (x2)	MB2	Firgelli Automations	$36.00
	Manual "Sustaining" Rocker Switch (weather proof)	MAN-RS	Firgelli Automations	$18.00
11/28/2007	Brass Spring-loaded Piston Check Valve, 1/4" Npt, Female X 1/4" Npt Male, Buna-n Seat 1	7768K22	McMaster	$8.09
	Brass Spring-loaded Piston Check Valve, 1/4" Npt, Male X 1/4" Npt Female, Buna-n Seat 1	7768K26	McMaster	$8.09
11/28/2007	ICB88 PC Board	2760149	RadioShack	$1.99
	DPDT10A 120 V (AC) Relay	2750217	RadioShack	$8.49
	Project Box to house circuit	2701903	RadioShack	$3.00
11/28/2007	PC Cart (Workstation)		WalMart	$39.96
	Vitamin E Gel Capsules (Water-soluble)		WalMart	$8.94
	Vitamin E Oil		WalMart	$3.38
	Waterless Disinfectant		WalMart	$1.87
11/23/2007	Electrical Wire		Home Depot	$8.88
	Pressure Test Gauge		Home Depot	$9.98
	Reducer Bushing		Home Depot	$4.39
	Barb 1/8" x 1/4" 3@$2.77		Home Depot	$8.31
	3/4" x 1/2" Hose Adapter		Home Depot	$3.22
	1/2" Pipe Reducing Coupling		Home Depot	$0.25
	1/4" BR Nipple 2@$1.66		Home Depot	$3.32
	1 4/3 LtG WHP		Home Depot	$7.97
	1/4" BR Pipe Tee-2@$5.09		Home Depot	$10.18
	25' Poly		Home Depot	$2.49
12/1/2007	5VDC/1A SPDT Micro Relay	275-240	RadioShack	$4.69
	Ethanol-1L	676829	Sigma Aldrich	$65.10
	Project Poster		UW-Madison CIMC	$18.00
			Total Cost	$530.51

FUTURE WORK

Although we have made great strides in the development of a product that accurately and efficiently accomplishes its design goals, there remain several components to perfect in all areas of the design before the technology is ready to be implemented into a clinical setting. More specifically, there are several modifications to the design itself that would be beneficial to its performance as well as several additional tests that would both expand upon our current results and explore the performance of other features of our design. Ultimately, the product will have to be subjected to a much more rigorous usability study than the one that has been completed thus far before it is ready to be released on the market.

To optimize the features of our prototype, we would like to focus on a selection of specific tasks. First, the syringe barrel used as the chamber for the pump is not designed to support the pressures generated by the actuator. This problem can be overcome by fabricating a custom chamber by boring out a block of PVC. This modification would be advantageous because it would eliminate the need for several pin supports around the chamber and would better absorb the forces exerted by the linear actuator. Also, the connection to the syringe barrel currently involves a plastic barbed connection, a length of plastic tubing, and a brass tee connection, which leads to both the reservoir and the one-way valve; however, with the PVC chamber modification, the tee connection could be milled into the block to reduce the number of parts that would be required. Another component of our prototype that will require modification is the mounting of the linear actuator. It would be preferable to eliminate the need for the actuator to be screwed into the workstation and to design the device so that it can stand on its own, with the option to support it with ties or screws. This would most likely involve some sort of casing for the actuator, chamber, and circuit components, which would also be a favorable way to reduce the number of cords associated with the device. Also, the circuit controlling the actuator can be significantly refined. Ultimately, a USB interface with the computer will make implementation of the design very simple. The next generation prototype will most likely contain a USB microcontroller, and in the final design the circuit will be placed on a printed circuit board. It may also be possible to incorporate timing into the device itself, simplifying the software utilized. This will result in even less strain on the computer's memory. Also, a more appropriate method to direct the spray only onto areas that we desire, a shield may be implemented into future generations of the design.

In addition to the future tests previously mentioned in the testing section, more tests of the prototype will be necessary. A study to more accurately determine the pressure and flow within the system will also be performed. This was not done this semester due to a lack of an appropriate testing apparatus, but can easily be performed given the correct equipment. The usability survey must be expanded, and will involve more subjects actually using the device. Also, the sample size will increase for each department represented in the survey. Additional microbial testing of the effectiveness of the spray on each region of the keyboard will determine whether or not the nozzle orientation and number is appropriate. Finally, we are aware that the formula may change with the involvement of a corporate client. Also, associated testing would be necessary with the new formulation.

CONCLUSION

The need for our device is rooted in the overall hygiene required in a clinical setting for both the patient and the clinician. However, because of the use of COWs, cross-patient contamination can occur if proper hand hygiene techniques are not practiced. Therefore we have designed an intervention device to increase the hand washing compliance among healthcare workers. This device disinfects the clinician's hands and keyboard in a safe and reliable manner. The device utilizes a spray nozzle, which atomizes a 70% ethanol solution onto the user's hands and the keyboard upon a customizable command

signal. The spray is effected by a modified diaphragm pump, uniquely designed for this application using a linear actuator. In order to ensure that the device adequately disinfects, microbial cultures were taken from subjects' hands and for a keyboard. The results of this test showed that the ethanol did significantly decrease the number of microbes on both surfaces. Also, tests were performed that evaluated the usability of the device and the effect on keyboard durability. Finally, research and a preliminary test were conducted to assess the constitution of the optimal formulation of disinfectant. Additional testing and improvements need to be made to prepare the device for further development by a manufacturer.

APPENDIX

$$\frac{Volume}{Drop}\left(\frac{m^3}{drop}\right) = \frac{4}{3} * \pi * \left(\frac{Droplet\ Diameter\ (m)}{2}\right)^3$$

$$Total\ Number\ of\ Drops = \frac{10^{-5}\ (m^3)}{Volume/Drop}$$

$$\frac{SurfaceArea}{Drop}\left(\frac{m^2}{drop}\right) = 4 * \pi * \left(\frac{Droplet\ Diameter\ (m)}{2}\right)^2$$

$$Total\ Surface\ Area\ (in^2) = Total\ Number\ of\ Drops * Surface\frac{Area(m^2)}{Drop} * 1550\left(\frac{in^2}{m^2}\right)$$

$$Total\ Evaporation\ (g/use) = Evaporation\ Rate\ \left(\frac{g}{\min * \text{in}^2}\right) * Total\ Surface\ Area\ (in^2) * \frac{1\ min}{60\ s} * \frac{3s}{use}$$

	Low	High
Volume/Drop (m^3)	3.82E-16	1.80E-13
Total Number of Drops	2.62E+10	55681030
Surface Area/Drop	2.54E-10	1.54E-08
Total Surface Area (m^2)	10333.33	1328.571
Total Evaporation (g/use)	**2.066667**	**0.265714**

REFERENCES

Banrud, H., and Moan, J. “Use of short wave ultraviolet radiation for disinfection in operating rooms.” Tidsskr Nor Laegenforen. 2000; 120 (953).

Bischoff, W.E. et al. “Handwashing compliance by health care workers: The impact of introducing an accessible, alcohol-based hand antiseptic.” Arch Intern Med. 2000 April; 10 (160): 1017-1021.

Boyce, J., and Didier, P. “Guidelines for Hand Hygiene in Health-Care Settings.” 2002. 25 Oct. 2002 <http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5116a1.htm>.

Brenwald NP and Fraise AP. “Triclosan resistance in methicillin-resistant Staphylococcus aureus (MRSA).” J Hosp Infect. 2003 Oct; 55(2): 141-4.

Cesarano FL, Piergeorge AR. “The Spaghetti Syndrome. A new clinical entity.” Crit Care Med. 1979 Apr;7(4):182-3.

Connecting for Health. “Achieving Electronic Connectivity in Healthcare: A Preliminary Roadmap from the Nation’s Public and Private-Sector Healthcare Leaders” 2004. Retrieved October 20, 2007 from <www.connectingforhealth.org/resources/cfh_aech_roadmap_072004.pdf>.

Ebelhack , Amy. “Peristaltic Pumps — Matching the Tubing to the Fluid: Considering Peristaltic Pump Tubing Performance Parameters.” Chemical Processing. 2001 July. Retrieved from <http://www.coleparmer.com/techinfo/techinfo.asp?htmlfile=PPTube_match.htm&ID=576>.

“Emollients and Moisturizers.” New Zealand Dermatological Society, Inc.” 26 Dec. 2006. < http://dermnetnz.org/treatments/emollients.html>.

Guggenbichler, J.P., Boswald, M., Lugauer, S., & Krall, T. “A new technology of microdispersed silver in polyurethane induces antimicrobial activity in central venous catheters.” Infection. 1999; 27: S16-23.

Handwashinghelp.com. 2007. <http://www.handwashinghelp.com>.

Klimes, Rudolf. "Hand Hygiene for Health Care Workers." Learnwell.org. 23 Dec. 2006. LearnWell Resources. 7 Nov. 2007 <http://www.learnwell.org/handhygiene.htm>.

Lahlou,M. “Ultraviolet Disinfection. TechBrief: A National Drinking Water Clearinghouse Fact Sheet.” 2000; 1-4.

Larson, E. "APIC guideline for handwashing and hand antisepsis in health care settings." American Journal of Infection Control. 1988 December. 16: 253-266

Leyden JJ, McGinley KJ, Kates SG, and Myung KB. Subungual bacteria of the hand: contribution to the glove juice test; efficacy of antimicrobial detergents. Infect Control Hosp Epidemiol. 1989 Oct;10(10):451-4.

Medical Devices & Surgical Technology Week. (*2003)*Adhesion of *Pseudomonas aeruginosa* strains to PVC devices tested.

Ophardt,H. U.S. Patent No. 20060213924. Washington, D.C. U.S. Patent Application. 2006.

Parab-Prop , R. S. (no date). Retrieved October 18, 2007 from <http://www.processpumpscorporation.com>.

Rule, Krista L; Ebbett, Virginia R. and Vikesland, Peter J. "Formation of Chloroform and Chlorinated Organics by Free-Chlorine-Mediated Oxidation of Triclosan." Environ. Sci. Technol. 2005; 39 (9): 3176 - 3185.

Schweizer, Herbert P. "Triclosan: a widely used biocide and its link to antibiotics." FEMS Microbiology Letters. 2001. 202 (1): 1–7.

Serven, Edward J. Jr. and Rhodes, R. R. "Pump Theory." Industrial and Engineering Chemistry. 1960 July; 52 (7): 557-560.

Siegel JD, Rhinehart E, Jackson M, Chiarello L, and the Healthcare Infection Control Practices Advisory Committee, 2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings, June 2007 http://www.cdc.gov/ncidod/dhqp/pdf/isolation2007.pdf

Silvestry, R., Sicairos-Ruelas, E.E., Gerba, C.P., & Bright, K.R. (2007). Silver as a disinfectant. Reviews of Environmental Contamination and Toxicology, 191, 23-45.

Spaulding, EH. "Chemical disinfection and antisepsis in the hospital." J. Hosp Research. 1972. 9: 5-31.

Takigawa, Tomoko and Endo, Yoko. "Effects of Glutaraldehyde Exposure on Human Health." Journal of Occupational Health. 2006; 48 (2): 75-87.

University of Wisconsin Hospitals and Clinics Authority. Working at UW Hospital and Clinics. (2007). Accessed at: <http://www.uwhealth.org/page.asp?contentid=11152>.

"Vitamin E." Office of Dietary Supplements. 7 Nov. 2007. <http://dietary-supplements.info.nih.gov/factsheets/vitamine.asp>.

"What Everyone Should Know About Hand Hygiene Products." 2007. Retrieved October 23, 2007 from <http://www.pfizerch.com/Purell/content/know_the_facts.html>.