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Award Number: W81XWH-04-1-0419

TITLE: An Integrated Civilian Medical Response to Mass Casualty Incidents

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REPORT DATE: May 2005

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release;
Distribution Unlimited

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 2005	Annual (6 Apr 04 - 5 Apr 05)

4. TITLE AND SUBTITLE
An Integrated Civilian Medical Response to Mass Casualty Incidents

5. FUNDING NUMBERS
W81XWH-04-1-0419

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 Words)

Abstract is attached.

14. SUBJECT TERMS
Bioterrorism, Civilian, Emergency, Preparedness, Technology, Predictive Algorithm, Dispersion, Modeling, Command and Control

15. NUMBER OF PAGES
44

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

ABSTRACT

Proposal Title: *(120 Characters Maximum)* An Integrated Civilian Medical Response to Mass Casualty Incidents
Keywords: *(6-8 words)* Bioterrorism, Civilian, Emergency, Preparedness, Technology, Predictive Algorithm, Dispersion Modeling, Command and Control

Abstract: (Type within outline: approximately 200 words)

US military and civilian populations have much to accomplish in the effort to enhance preparedness for potential mass casualty incidents. In this effort, CIMERC has partnered with many regional, national, government, and non-government organizations. The proposed projects will benefit from the established, comprehensive network, and the proven success of the respective institutions in integrating diverse interests and expertise into a large scale biodefense initiative.
Command and Control Operational Capabilities will be developed to address mitigation and remediation issues inherently critical to mass casualty incident preparedness and response. This work will integrate a wireless network with a set of essential communication tools intended for incident commanders.

Biodefense Assessment, Implementation, and Evaluation will be enhanced by means of algorithm development for predictive systems that can automatically identify developing scenarios and alert relevant personnel at critical moments.

Readiness and Response Training will be enhanced to further prepare the nation's emergency response workforce. The Forum answers the need for a Web-based educational system that interfaces with existing training modalities and facilitates learning and assessment throughout response communities. The Forum permits the development of highly specific education and training programs for a widely diverse group with a differing knowledge base, while correcting weaknesses through training remediation.

CIMERC is well positioned to manage the development of the proposed work. Use of rural-urban test beds provides CIMERC with the unique opportunity to incorporate distinct response elements inherent in each locale. CIMERC will also be able to leverage resources and accomplish project objectives through its extensive network of research professionals.

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COMMAND AND CONTROL OPERATIONAL CAPABILITIES

Command and Control Imaging

Introduction:

Extensive interviews with first response teams and site commanders reveal that verbal communication between parties in dynamic environments like battlespaces or disaster areas are often misinterpreted. The purpose of this research was in designing a system that acquires, processes and distributes visual data to eliminate ambiguities and improve situational awareness. Components for acquiring and distributing image data were successfully developed in previous phases. Integrating visual data processing is the subject of this research phase. The research scope concentrated on: (1) developing a virtual whiteboard; and (2) creating pervasive services for image acquisition and distribution. Demonstrators were constructed and field-tested.

Research Accomplishments

Background: In previous phases, a system that acquires raw visual data, like live video and snapshots, and distributes processed images to wired and wireless hardware, like fax machines and handheld PDAs, was successfully prototyped. For example, pictures displaying ingress and egress routes can be wirelessly retrieved from our server and viewed remotely on handheld devices. Such pictures eliminated the need to verbally communicate, thus reducing misinterpretation. The prototype is based on ubiquitous and rugged wireless local area network and Internet technologies. Key components include: (1) both wired and wirelessly networked video cameras that acquire different perspectives of an environment; (2) a web server to distribute the imagery generated; (3) wireless handheld devices like Pocket PCs and Palm Pilots for downloading and viewing imagery; (4) imagery creation software that processes raw video; (5) mechanisms that fly cameras in the air and control robots that transport cameras into denied areas; (6) software that allows a virtual walk-thru of urban scenes based on aerial photos; (7) algorithms that process an aerial image to identify streets and overlaying global positioning system (GPS) coordinates; (8) programs that aligns different photos into a mosaic – a larger photo that combines all views to provide a greater field-of-view; and (9) image enhancement algorithms that compensate for poor lighting or noise. The net effect is an infrastructure that can acquire visual data and distribute imagery.

Gap in the Knowledge Base: To the best of our knowledge, systems that enable non-verbal communication using imagery have not been widely developed. To be effective, an automated system must minimize the time required to transform raw visual data into distributable imagery. For example, it takes time for experts to view raw aerial photos and circle the locations of targets or threats. Such time and expertise requirements have motivated information technology research like data mining to automate the process of obtaining useful information. Open-ended problems like image understanding and decision theory form challenging gaps that prevent vertical advances in such automation. We take a more pragmatic approach; we seek to design tools that augment rather than replace personnel. Viewed in this matter, the gap becomes a lack of tools for generating useful imagery.

Technical Objectives: The long-term goal is Command and Control (C2) augmentation. Towards this goal and filling the gap a virtual whiteboarding system was created. Here, a whiteboard scanner that uses infrared receivers to track and record the location of the marker's stylus was employed. Screen captures of whatever is written or drawn on a whiteboard is then combined with database images to rapidly generate useful imagery. Also persistent services were created from ad-hoc sensor nodes. Here, matchbox-sized wireless devices were used to acquire sensor data and perform localization.

1. Virtual Whiteboards Figure 1 is an artist conception of the virtual whiteboarding system. The circled numbers in the figure indicate the step-by-step process in transforming raw visual data into distributable imagery. (1) Raw video and snapshots of the scene captured by cameras at the scene are transmitted to the C2 center; (2) These images are projected on a whiteboard; (3) C2 personnel write on the whiteboard, thus virtually marking up the projected image; (4) The mark ups are scanned into a graphic, fused with the originally projected image via image processing software, and distributed

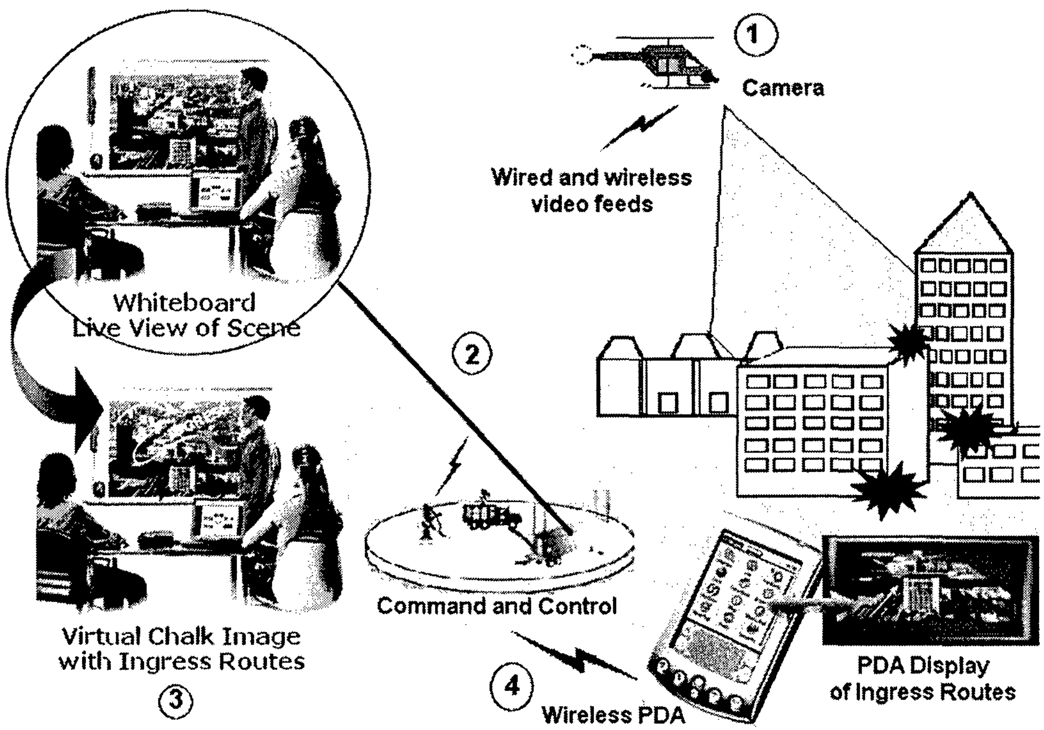


Figure 1: Artist's conception of the virtual whiteboarding system. Circled numbers depict the sequence of steps starting from acquisition of raw video to the distribution of visual information on handheld PDAs.

to wired and wireless devices like fax machines, PocketPCs and cell phones. The result is a tool for C2 personnel to generate imagery by indirectly marking up a photo. The net effect is akin to the visuals that sports newscasters produce when commenting on plays; lines, crosses and circles mark up the video replay to explain what the team did.

Newscasters use lightpens that activate phosphorous areas in cathode ray tube monitors. Two key limitations are: first, there is no way to erase mistakes and second, lightpens cannot generate color. As such, mark ups must be kept simple which can limit the impact and usefulness of the resulting imagery in C2 applications.

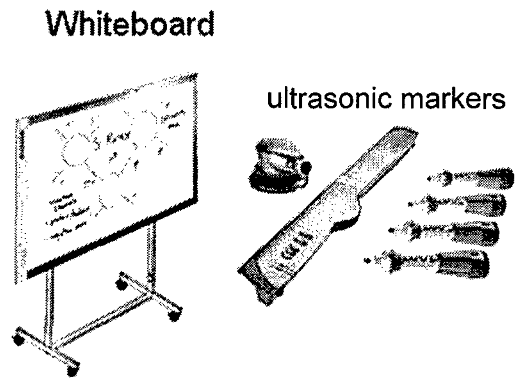


Figure 2 A graphic image depicting whiteboard content is achieved with ultrasonic position sensors

Mimeo is a commercially available whiteboard that uses an ultrasonic sensor to capture a marker's position on the whiteboard (see Figure 2). A 2-foot long capture bar is an ultrasonic tracking array that mounts on the edge of the whiteboard and connects to a PC via a serial or USB interface cable. Ultrasonic transmitters embedded in the marker sleeves provide a signal for the capture bar to triangulate the pen's position on the board as the user writes. The real-time position of the pen is recorded and results in a graphic image of whatever was transcribed on the whiteboard.

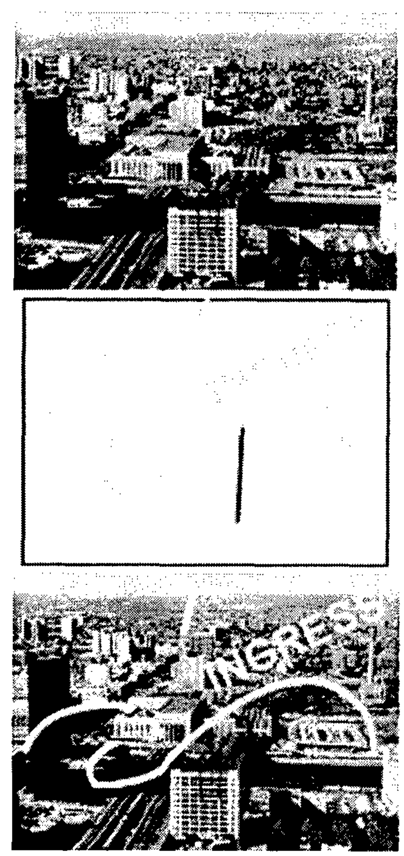
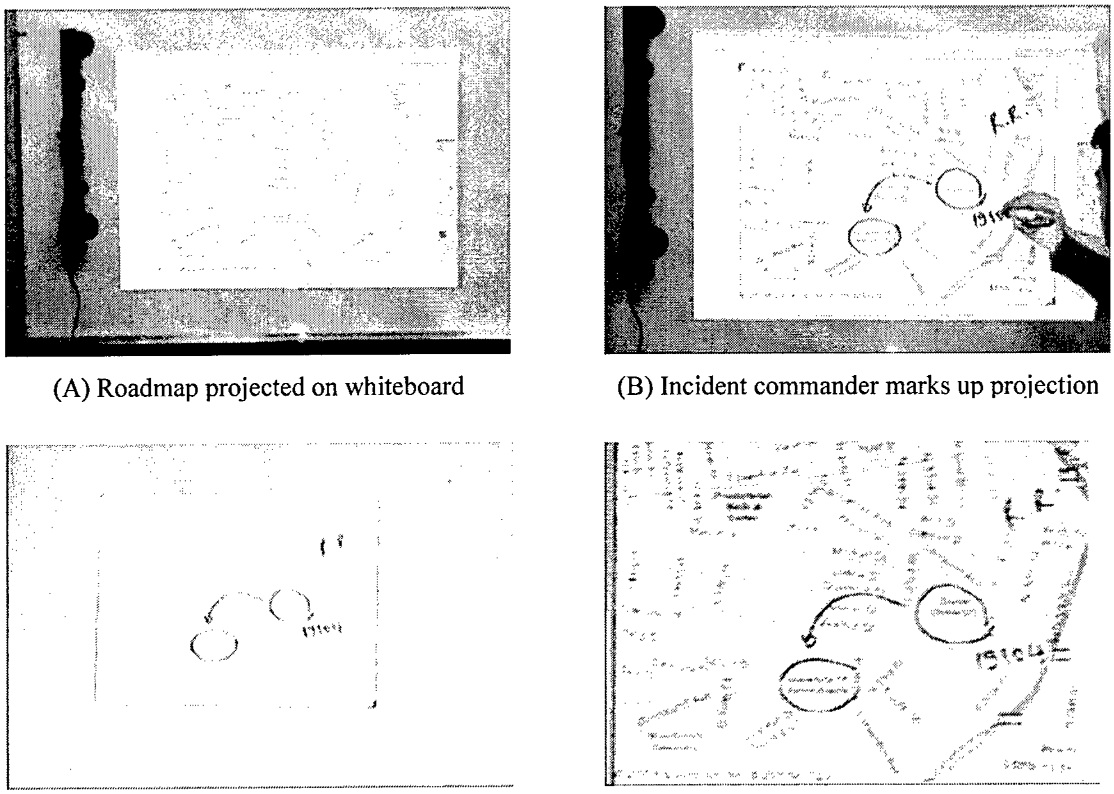


Figure 3 Original image (top) and whiteboard mark ups (middle) are fused in an image-processing step to create the imagery (bottom)

Building upon such hardware, a C2 imagery generation tool may be constructed as illustrated in Figure 3. Here, the image of the scene is projected on the white board (top). C2 then writes on top of the projected image using the ultrasonic markers. This results in a graphic image consisting of whatever was written on the whiteboard (middle). Image processing then fuses the two images which overlays the graphic image on the originally projected image (bottom). The net effect is a rapid means to generate image-based information that can then be distributed to end-users like first responders, site commanders and decision makers.

Implementation: Figure 4 depicts the field-test results of a prototype whiteboarding system. As shown in Figure 4A, a roadmap of West Philadelphia is projected onto a whiteboard. Users like an incident commander, marks up the projected image (Figure 4B), circling areas of interest, outlining transportation routes, and annotating resources. These mark ups are then captured and digitized into a graphic file (Figure 4C) and then merged with the original roadmap. The resulting image (Figure 4D) is imagery that can be distributed to end-users like first responders.



(A) Roadmap projected on whiteboard

(B) Incident commander marks up projection

(C) Markups are captured to a graphic file

(D) Final imagery merges map and markups

Figure 4: Results of field-testing whiteboard prototype

2. Pervasive Services

Ad-hoc sensor networks that wirelessly transfer information or perform distributed computing can be engineered using cell phones or radio frequency equipment.

2.5G Java-enabled cellular phones, like Nokia's 3650, are ubiquitous devices that host Sun's J2ME (Java 2 Micro Edition). Such phones provide a means to deliver services and dynamic content, like images, to mobile users. By pressing phone keys, the mobile user can interact with such services in real-time. As such, a distributed client-server network can be constructed whereby mobile phones can capture photos of a scene and upload them to a C2 server. C2 can also distribute imagery, which can be retrieved and viewed on such phones.

Cell phone hardware and service costs are impractical when designing low-cost dispensable systems. As such, amateur or standard (e.g. 433 or 900 MHz) frequency equipment becomes attractive alternatives, respectively shown in Figures 5 and 6.

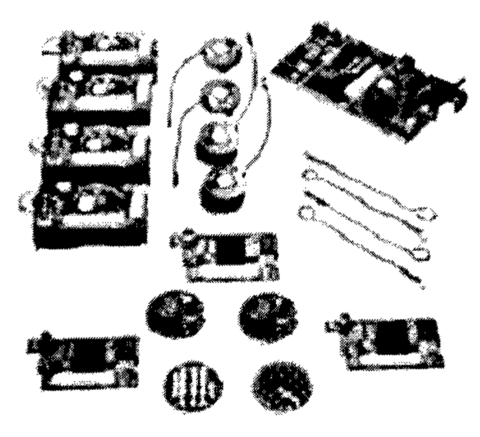


Figure 5: 433 or 900 MHz wireless ad-hoc sensor motes – Courtesy Crossbow Technologies.

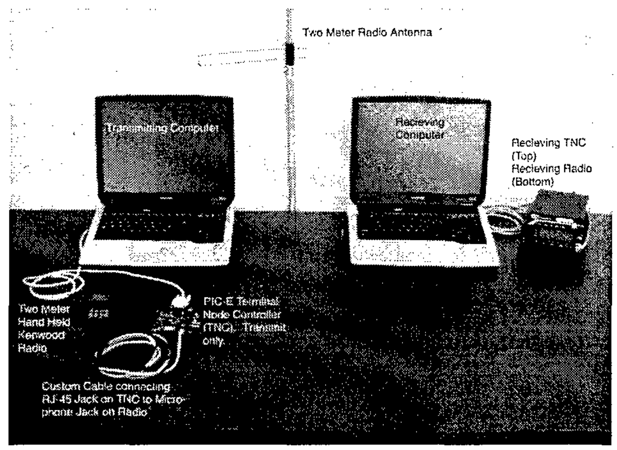


Figure 6: Amateur (ham) radio equipment that can interface to computers to transmit video and GPS coordinates

Implementation: Figure 7 depicts a search-and-rescue field-test using an aerial robot (6-foot Helium filled blimp) equipped with an on-board camera. Casualties (mannequins) are scattered in an emulated disaster area consisting of overturned furniture and debris.

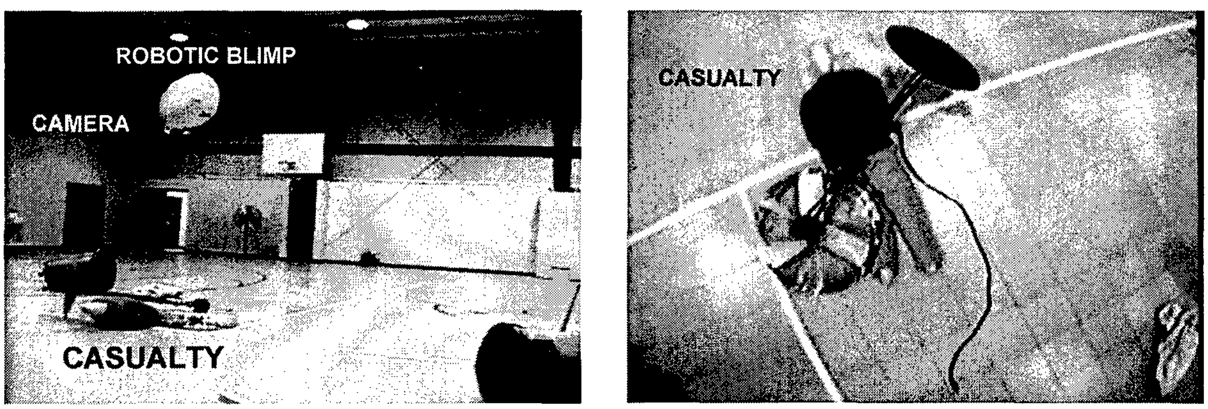


Figure 7: Emulated Disaster Area (left). Casualties scattered in the debris, are identified from video (right) acquired by aerial robot's on-board camera

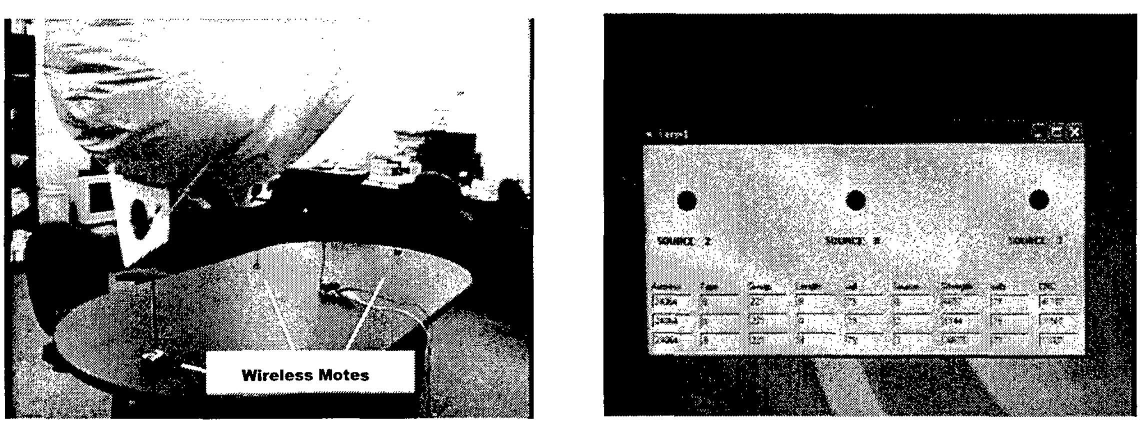


Figure 8: Motes (shown on table in Left image) would be airdropped next to casualties. The resulting ad-hoc sensor (displayed on laptop in Right image) would assist in localizing victims.

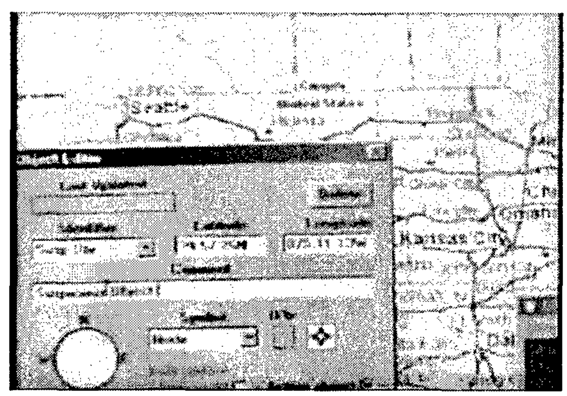
Crossbow wireless sensor motes (Figure 8) on the blimp enables localization. When a casualty is identified, the blimp airdrops a radio identification tag that would allow first responders to quickly locate the victim when first responders begin extracting casualties.

Persistent Services: Blue-Force Tracking with GPS: Amateur radio frequencies (ham) can also be used for persistent services. For decades, ham radio operators have assisted emergency responders by providing additional bandwidth for relaying communications. In addition to transmitting voice and GPS coordinates, video can also be exchanged. Consequently experiments in blue-force tracking, where an incident commander may wish to track the location of first responders were conducted and illustrated in Figure 9.

(A) Incident Commander with ham receiver

(B) First responder with GPS transmitter

(C) First responder finds suspicious item



(D) Screen image displaying responder's location

Figure 9: Persistent services with blue force tracking. Ham radio equipment used to transmit GPS coordinates of first responder to command-and-control headquarters

Bulleted List of Key Research Accomplishments

- Designed and prototyped a virtual whiteboard hardware and software system
- Constructed and field-tested aerial robot platforms (20-inch rotor helicopters and 6-foot blimp) equipped with on-board wireless cameras
- Wireless acquisition and distribution of image data (stills and videos)

- Designed and prototyped persistent services using 433 MHz wireless motes
- Demonstrated the deployment of ad-hoc sensor networks for casualty localization
- Demonstrated persistent services for blue force tracking using amateur radio frequency equipment to exchange GPS data

Manuscripts based on work supported by this award;

1. A Competition to Identify Key Challenges for Unmanned Aerial Robots in Near-Earth Environments, *2005 IEEE International Conference on Advanced Robotics*, Seattle WA (accepted for publication)

2. Robotic Rotorcraft and Perch-and-Stare: Sensing Landing Zones and Handling Obscurants, *2005 IEEE International Conference on Advanced Robotics*, Seattle WA (accepted for publication)

3. Designing an Aerial Robot for Hover-and-Stare Surveillance, *2005 IEEE International Conference on Advanced Robotics*, Seattle WA (accepted for publication)

Non-thermal Plasma Sterilization

Introduction

Recent increasing threats of bioterrorism have raised awareness of the dangers of airborne microorganisms in indoor environments. In the event of a biological terrorist attack, large quantities of dangerous pathogenic bioaerosol could be released into the ventilation system of a large building endangering the lives of thousands of civilians. The current air cleaning technology employed in most large commercial buildings is high efficiency particulate air (HEPA) filters. HEPA filters are effective at trapping particles down to 0.5 microns in size; however, studies have shown that they are not as effective at capturing airborne viruses, which are among the smallest (20-300 nm) known microorganisms [1]. HEPA filters also have a limited lifetime and create large pressure losses within heating, ventilation, and air conditioning (HVAC) systems giving rise to higher energy costs. In this study, non-thermal atmospheric pressure plasma is employed as an improved method for the sterilization of air from biological contaminates. Non-thermal plasma has been proven to inactivate many different types of microorganisms, such as viruses and bacteria, on surfaces of materials, but there have been few scientific studies of *air sterilization* using non-thermal plasma. The purpose of this project is to examine the sterilization effect of two types of non-thermal plasma - dielectric barrier discharge (DBD) and magnetically-rotated gliding arc [2] on air contaminated with high concentrations of aerosolized Influenza A virus and a unicellular bacterium known as Synechococcus Elongatus, or Cyanobacteria. Experiments were performed in a wide range of conditions from high flow rates that would be commonly found in a standard HVAC system, to very low air flow rates. Within the scope of the project, the two non-thermal plasma devices were designed and manufactured as well as a bioaerosol containment facility, known as the Pathogen Detection and Remediation Facility (PDRF), which was designed to provide a sterile sealed air flow environment for these experiments. Two modified liquid impingers were developed for use as the primary air sampling equipment to capture airborne microorganisms at specified time intervals. The development of the air sampling equipment was challenging and required many calibration experiments to be performed to provide an understanding of the efficiency of these devices at isolating the microorganisms from sampled air. As a result, there were delays in performing air sterilization experiments with the plasma devices. However, an additional understanding of the plasma sterilization effect was gained through the development of a physiochemical model that is capable of predicting the rate of inactivation of various types of airborne microorganisms. The following section of the report describes research accomplishments associated with each task outlined in the approved statement of work.

Project Activities and Experiments

Activity 1: Design and manufacture the DBD-electric discharge unit

Although Dielectric Barrier Discharge (DBD) and magnetically-rotated Gliding Arc are quite different in terms of current-voltage characteristics and operational power levels, both devices can provide a high concentration of active chemical species, which are a

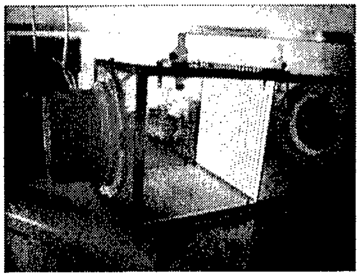


Figure 1. Dielectric Barrier Discharge for air sterilization

necessary component of the sterilization process. There are two main sterilization effects that bioaerosols are subjected to as they are passed through each plasma device: the direct interaction with the lethal environment of the discharge itself and the downstream interaction with active chemical species, such as ozone (O_3) and hydroxyl (OH), produced by the discharge. DBD is a low temperature discharge that is very efficient for the production of ozone, which is a strong oxidizer and proven microbial disinfectant [3-6]. Figure 1 shows a photo of the DBD device which consists of a thin plane of wires with equally spaced air gaps of 1.5 mm. The high voltage electrodes are coated with a quartz capillary dielectric that has an approximate wall thickness of 0.5 mm and the device requires 14 kV for breakdown while consuming less than 200 watts of power. The DBD device has two air sample ports located on either side of the discharge area so that bioaerosol can be sampled immediately before and after it enters the plasma discharge. This sampling configuration will allow the de-coupling of the sterilization effects from the discharge itself and the downstream interactions with the active chemical species (ozone, hydroxyl) generated by the plasma.

Activities 2 & 3: Design and manufacture the experimental test facility, Assemble and test the plasma sterilization facility

The plasma sterilization facility, as defined in the approved statement of work, has been named the Pathogen Detection and Remediation Facility (PDRF) and includes a plug flow reactor that provides a sealed air flow environment, bioaerosol generation equipment, and the air sampling system that includes the modified liquid impingers. Figure 2 shows a scheme of the Pathogen Detection and Remediation Facility. The PDRF is capable of simulating a wide range of air conditions with regard to temperature and humidity that could be found in various indoor environments. The system also has an overall volume of 250 liters, and can operate at air flow rates up to 25 liters per second. The PDRF houses the interchangeable non-thermal plasma devices, DBD and Magnetic Gliding Arc, which are connected to the system with four inch (10 cm) diameter flexible piping. At a flow rate of 25 L/s, the residence time, that is, the time for one droplet to make one revolution

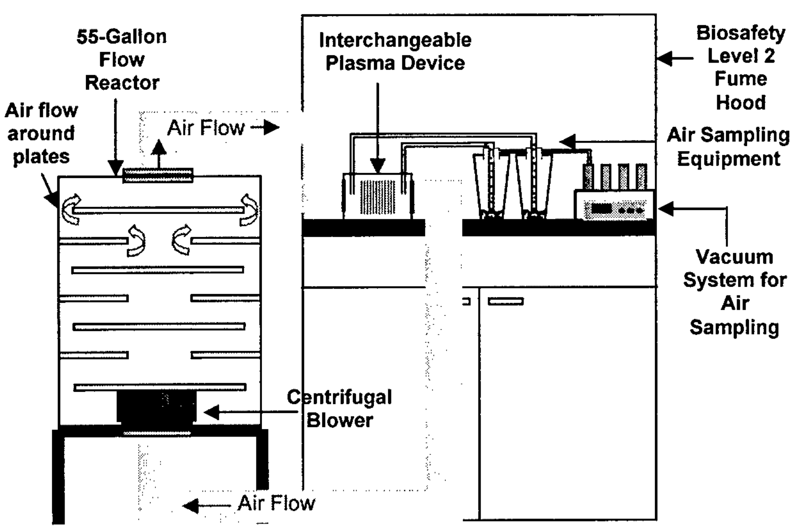


Figure 2. Pathogen Detection and Remediation Facility (PDRF)

through the system, is approximately 10 seconds. An air sampling system is included in the PDRF and was designed to take as large volume air sample as possible (~ 1 liter) in a short period of time (~ 1 second) so that we do not disturb the flow inside the system and can evaluate the viability of the bioaerosol as a function of treatment time. Many calibration experiments were performed to characterize the efficiency of the air sampling system and to understand aerosol losses during flight in the PRDF system. This was to ensure consistent, reproducible results when performing air sterilization experiments. The results of these calibration experiments are described in the following sections.

Air Sampling Equipment

Liquid impingement was chosen as the air sampling method for our system, as opposed to filtration or impaction, because it minimizes desiccation stress and allows for the direct deposition of the microorganism into growth media. The AGI-30 liquid impinger is a commonly used bioaerosol sampler and it operates by drawing a sample of air through an inlet tube submerged in a solution, thereby causing the air stream to strike the liquid bed trapping aerosols in the solution through forces of inertia [7]. The AGI-30 impinger contains a critical orifice that contains one exit port and limits the maximum air sampling rate to 12.5 liters per minute [8]. To accommodate our desired sampling rate of 1 liter per second, we modified the AGI-30 by increasing its overall volume and replacing the standard critical orifice with a hollow spherical tip with several exit ports. Several calibration experiments performed with these modified AGI-30 impingers demonstrated reproducibility in terms of sampling efficiency. In these experiments, a Collison nebulizer was connected directly to the modified liquid impinger and after five minutes of continuous sampling in each trial, we obtained a stable sampling efficiency rating of 3.5%. To some this may seem as a low efficiency rating, however, when sampling bioaerosols, reproducibility is often considered more important than the efficiency rating because the final conclusions are derived from internal comparisons between various data collected using the same samplers [8].

Plasma Sterilization Facility - Calibration experiments

Several additional calibration experiments were performed in which cyanobacteria aerosol was injected into the Pathogen Detection and Remediation Facility (PDRF) not for the purpose of sterilization, but to identify all bioaerosol losses from diffusion, inertia, and evaporation, thereby establishing accurate controls before non-thermal plasma is introduced. Cyanobacteria culture was initially used to calibrate the PDRF system because these bacteria are non-pathogenic, readily available, and comparable in size (1 micron) to the Influenza A virus (0.1 to 0.3 microns). In these calibration experiments, a Collison nebulizer was used to generate the bioaerosol, the air flow rate was fixed at 25 liters per second, and the lifetime of droplets was measured by periodic air sampling with two modified liquid impingers. For these experiments, the system was prehumidified with sterile de-ionized water until the internal surface of the system walls were wet prior to input of the bioaerosol. Initial results showed a very poor recovery of viable cyanobacteria aerosol from the PDRF in comparison to air sampler calibration experiments. The effect of small droplet evaporation was identified as the greatest source of aerosol viability losses because the liquid saturation pressure around a small droplet is high in comparison to the saturation pressure near the wet walls of the system. This causes small aerosolized droplets to begin to evaporate and the cyanobacteria within the droplet experiences lethal desiccation stress. To test the effect of evaporation on the survivability of cyanobacteria aerosol, we performed two experiments: the first (Experiment A) in which additional humidity was applied continuously with the bioaerosol using an additional nebulizer with sterile de-ionized water, and the second (Experiment B) without additional humidification. Our results, which are described in figure 3 below, show that additional humidification reduces small droplet evaporation and the rate of inactivation of aerosolized cyanobacteria by desiccation stress, as compared to the results of experiments without additional humidification.

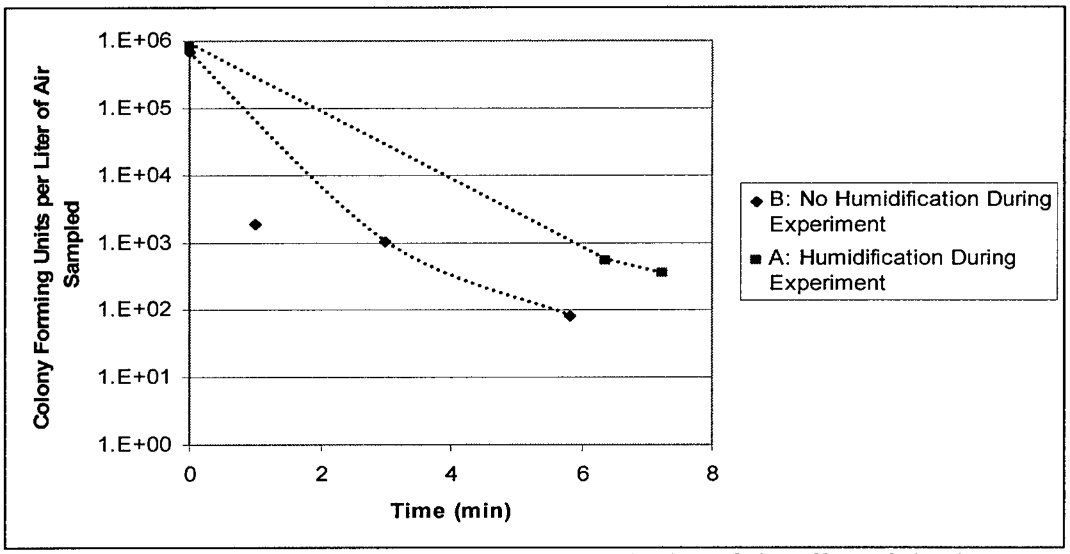


Figure 3. PDRF calibration test results: Evaluation of the effect of droplet evaporation on the survivability of aerosolized cyanobacteria. Experiment A minimizes evaporation by providing constant humidity.

The experimentally estimated maximum lifetime of aerosolized Cyanobacteria is 10 minutes, which is far below the estimated diffusion time of droplets to the walls of the system. To determine if the droplets were indeed still present in the air flow after 10 minutes, we added a laser to the system to characterize the optical density of the bacterial aerosol over time. Figure 4 shows an image of the illuminated laser beam at the first minute of the experiment when the concentration of viable Cyanobacteria is high. Illumination from the laser beam slowly decayed over a period of nearly 2 hours indicating that aerosolized bacteria were still present in the air stream, however, they were non-viable. Similar results were reported by Ehresmann & Hatch, who described the optical density of aerosolized unicellular bacteria lasting up to

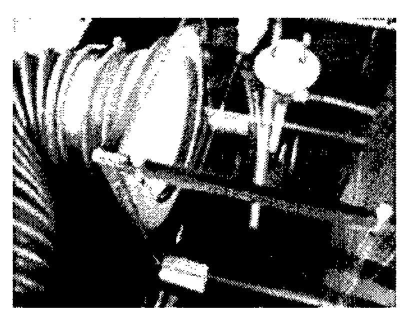


Figure 4. A laser beam illuminates the dense concentration of bioaerosol

four hours at high humidity (92-94%) with viability lasting only minutes [9]. These calibration experiments with Cyanobacteria provided us with a basic understanding of the flow characteristics of the Pathogen Detection and Remediation Facility and efficiency of our air sampling system and allowed us to find the optimal conditions regarding the lifetime of viable aerosolized cyanobacteria. We desire to have the ability to recover viable aerosolized cyanobacteria over an extended period of time (tens of minutes) so that when we perform sterilization experiments with non-thermal plasma, we have enough time to take several air samples and thus acquire many data points to accurately describe the rate of inactivation. This was a necessary step before working with viral bioaerosols because immunoassay detection methods used to quantify viruses are less accurate than the serial dilution methods used to quantify Cyanobacteria and we now have a fundamental understanding of the detection limits of this system so that we may better interpret data in future experiments.

Activities 4, 5, 6: Air sterilization experiments with Dielectric Barrier Discharge (DBD), Variation of DBD parameters to optimize sterilization efficiency, Analyze the complete bio-disintegration effect

Air sterilization experiments using Dielectric Barrier Discharge (DBD) plasma were initially delayed because of difficulty of establishing accurate control samples using cyanobacteria, as was explained in the previous section describing plasma sterilization facility calibration experiments. Several sterilization experiments were performed using Cyanobacteria, but yielded little useful results. In addition to high-flow rate air sterilization experiments within the Pathogen Detection and Remediation Facility (PDRF), low-flow rate experiments were performed in which cyanobacteria aerosol was forced through the DBD device with a near-zero velocity and an increased air sampling time of one minute. A schematic of these experiments is shown in figure 5 below. The purpose of this type of experiment is to examine the sterilization effect of dielectric barrier discharge plasma as droplets are passed once through the discharge zone. After the aerosol passes through the discharge zone, it is immediately drawn through the air sample port and into the liquid impinger. In this experimental configuration, there is very little time for the bioaerosol to make contact with ozone and other long-lived active chemical species generated by the discharge. The outcome of these experiments will yield an alternative means of de-coupling the destructive effects of the discharge itself and downstream interactions with these oxidative species. The results of these experiments will be available in early June 2005.

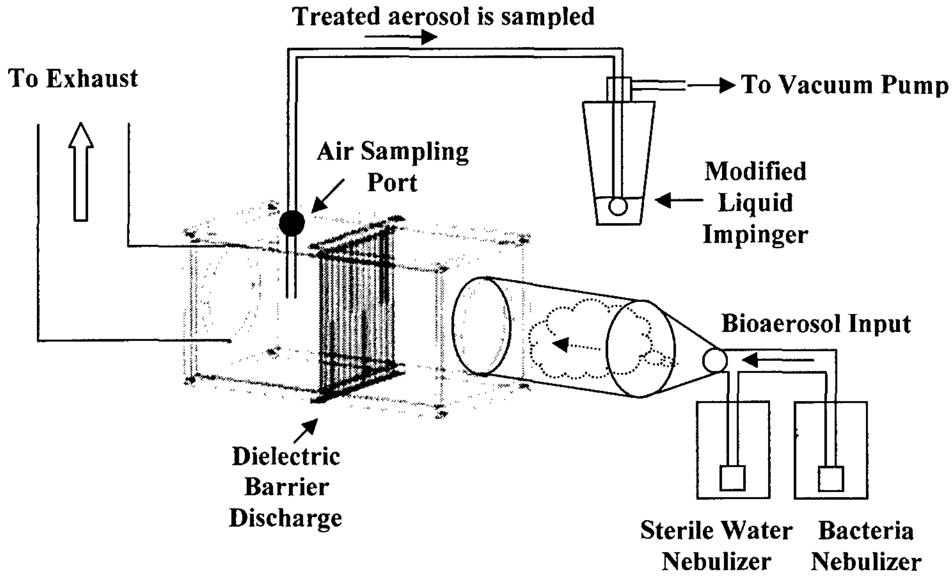


Figure 5. Low-flow rate experiments with Dielectric Barrier Discharge (DBD) plasma

<u>Influenza A Virus Experiment Delays</u>

Experiments with the Influenza A virus were delayed for several months because of administrative issues within the Drexel Medical College and Bioscience and Biotechnology department. Drexel University requires submission, review, and approval of a Biosafety protocol for all experiments involving the Influenza A virus, which is a Biosafety Level two (BSL2) agent. The Biosafety protocol defines all procedures, locations, and personnel involved with experiments related to BSL2 agents. The Biosafety protocol was submitted in November 2004 and approved in January 2005, however, there were still significant delays concerning the release of an Influenza A virus sample for use in experiments and training of the virus detection techniques of immunoassay and real-time PCR. The development of these detection techniques has begun and air sterilization experiments with Influenza A virus are scheduled to begin in early June 2005. The Pathogen Detection and Remediation Facility (PDRF) including the air sampling equipment and the plasma devices are in the process of being moved to a different location, which has a BSL2 fume hood, as was stipulated in the Biosafety Protocol. Results from these experiments are expected in mid-June 2005.

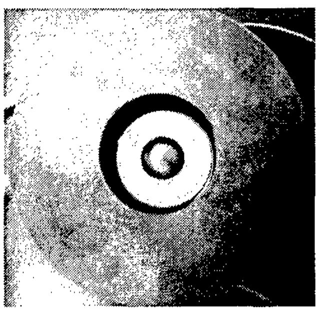


Figure 6. Prototype of the Magnetic Gliding Arc Device

<u>*Activities 7, 8, 9: Design and manufacture the Magnetic Gliding Arc device for plasma sterilization, Combine the Gliding Arc device with the sterilization facility*</u>

The magnetically-rotated Gliding Arc was the second non-thermal plasma device designed and manufactured for this project. It generates a transitional non-thermal plasma and has a relatively low translational gas temperature with a high electron temperature. This Gliding Arc system uses a strong magnetic field to rotate and elongate an initial thermal arc resulting in rapid convective cooling, keeping the passing air flow near room temperature. This type of discharge has a large power density that can work at atmospheric pressure, but is still very efficient in providing active species. Figure 6 shows a prototype of Magnetic Gliding Arc device was developed to test the basic plasma characteristics at various air flow rates. The discharge area of the prototype is approximately two inches in diameter and is surrounded by 4.5 inch diameter ceramic magnets, which provide the force required to rotate the arc and provide plasma discharge area for treatment of contaminated air. The Gliding Arc device used in air sterilization experiments was designed to be eight inches in diameter to keep air velocity low allowing for greater uniformity of treatment. In figure 7, the arc is partially elongated at the center electrode.

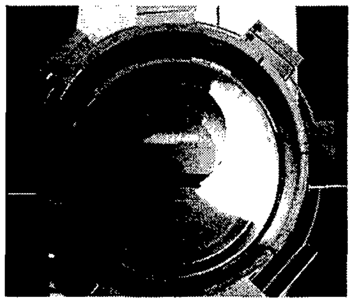


Figure 7. Magnetically Rotated Gliding Arc

Activity 10: Experiments on plasma sterilization with Gliding Arc device

Experiments with plasma sterilization using the Magnetically-rotated Gliding Arc device are currently in progress and we expect results in mid-June 2005.

Activity 11: Compare sterilization effect in DBD and Gliding Arc

Shortly after experiments with the Gliding Arc device are completed, a evaluation will be performed comparing the sterilization effect of DBD and Gliding Arc plasmas. To further understand the sterilization effect of non-thermal plasma on airborne microorganisms, a physiochemical model was developed that is capable of predicting the oxidizing effects of the active chemical species generated by plasma on viruses, spores, and bacteria. In this model, we are investigating the individual sterilizing effects of hydroxyl radicals (OH), ozone (O_3), ultraviolet radiation (UV) as there is a large amount of empirical data regarding the role of each of these components for the sterilization of various microorganisms. The model combines this data with the chemical kinetics of non-thermal plasma to predict the rate of destruction of microorganisms under varying conditions. The results from our experiments with the Pathogen Detection and Remediation Facility (PDRF) will be used to verify the plasma chemical sterilization model [10].

Key research accomplishments

- Development of a Pathogen Detection and Remediation Facility (PDRF) that is capable of analyzing various concentrations of bioaerosols under different air flow conditions.
- Design and Manufacture of two non-thermal plasma devices, Dielectric Barrier Discharge (DBD) and Magnetically-rotated Gliding Arc, capable of sterilizing air at high flow rates

- Design and Manufacture of a rapid air sampling system based on liquid impingent technology
- Development of a physiochemical model describing the destruction of aerosolized microorganisms in non-thermal plasma [10].

Reportable Outcomes

Abstract and Poster Presentations:
International Conference on Plasma Science (ICOPS), June 28 – July 1, 2004, Baltimore, MD
Topic: Medical, Biological, and Environmental Applications of Plasma
Abstract title: Non-Thermal Plasma Applications in Air Sterilization
Authors: Michael Gallagher, Gary Friedman, Alexander Dolgopolsky, Alexander Gutsol, Alexander Fridman

Gordon Research Conference on Plasma Processing Science, August 15-20, 2004, Holderness School, Plymouth, NH
Abstract title: Atmospheric Pressure Plasma Sterilization of Air
Authors: Michael Gallagher, Gary Friedman, Alexander Gutsol, Alexander Fridman

SMART Tech Trends Conference (sponsored by IEEE), August 4-5, 2004, Pittsburgh, PA
Poster title: Non-Thermal Plasma Applications in Air Sterilization
Authors: Michael Gallagher, Gary Friedman, Alexander Dolgopolsky, Alexander Gutsol, Alexander Fridman

Rural Homeland Defense Technology Exposition, October 21-22, 2004, Johnstown, PA
Poster title: Non-Thermal Plasma Applications in Air Sterilization
Authors: Michael Gallagher, Gary Friedman, Alexander Dolgopolsky, Alexander Gutsol, Alexander Fridman

Publications:
Gallagher, M., Gutsol, A., Friedman, G., and Fridman A. Non-Thermal Plasma Applications in Air-Sterilization, ISPC-17, August 7-12, 2005, Toronto, Canada.

References

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[10] Gangoli, S., Gallagher, M., Dolgopolsky, A., Gutsol, A. and Fridman A. Sterilization of Microorganisms using Non-Thermal Dielectric Barrier Discharge Plasma – Statistically based Chemical Kinetics Model, ISPC-17, August 7-12, 2005, Toronto, Canada.

Assessment Physical Scale Models for Development of Room Decontamination Design Criteria

1. Introduction

Motivation behind the project is related to the 2001 anthrax attacks. These incidences have revealed the inadequacy of our knowledge and experience in swift preventive responses to biological contamination incidents. The main objective of this work is to develop a comprehensive numerical model to address all major components (fluid dynamic, transport, chemical deactivation etc.) of the biological agent release in an apartment complex and subsequent disinfection process. A follow-up objective is to obtain relationships for the inactivation time as a function of the various parameters of the problem through scaling studies of the numerical experiments. Such relationships would help in determining the impact of scales on the predicted behavior of the biological agent distribution and disinfection by variation of parameters. The computational models are comprised of sub-models for simulating room air flow, anthrax spores distribution and transport, disinfectant transport and inactivation of anthrax spores.

2. Methods: Numerical Model for anthrax spore distribution and inactivation

Computational fluid dynamic (CFD) models were developed for simulation of the distribution and transport of anthrax spores and its inactivation in an apartment complex. The numerical model utilizes CFD and kinetic data for the disinfection process, thus combining fundamentals of fluid mechanics and reaction kinetics to predict the inactivation rate. The numerical algorithms are described in detail in this section.

An Eulerian-Lagrangian approach is employed for the prediction of room air flow and anthrax spore trajectories. Fluid flow and particle transport, and disinfectant transport were implemented with the general-purpose commercial code ANSYS-CFX4 [1]; the inactivation algorithm is implemented using C++ in the Microsoft Visual Studio Environment.

The steady-state three-dimensional reactor flow field was simulated with the use of a low Reynolds number (5000 – 30000) k-ε turbulence model [2]. The flow field was calculated using a finite volume method. Disinfectant mass fraction was calculated by solution of a convective/diffusive mass transport equation. Disinfectant decay was included by invoking a chemical kinetics model in which reaction for first order decay of chlorine dioxide was incorporated. Kinetic decay constants were obtained from the regression analysis of the data obtained by from experimental studies.

3. Key Research Accomplishments

The following is a list of key accomplishments emerging from the research:

- development of micron-size particle transport in room air flow
- development of a disinfectant transport and decay model
- development of anthrax spore deactivation model based on anthrax spore and disinfectant (chlorine dioxide) transport models
- scaling analyses based on a significant number of (numerical) case studies

A detailed description of each of the above key accomplishments is given below:

- Particle transport

An Eulerian-Lagrangian approach is employed for the prediction of anthrax spores trajectory in the present study. The flow field and disinfectant distribution are considered as continuous functions of space and time (Eulerian) [3, 4]. The general Eulerian-Lagrangian algorithm for the simulation of spores' inactivation is:

1) Establish the flow field in the apartment complex by Eulerian numerical simulation solving the Navier–Stokes equations
2) Predict the particle trajectories within the apartment for a statistically significant particle sample size; trajectories are predicted by particle physics and by a probabilistic model.

Particle trajectories are calculated by solving equations of motion for a particle, established using a force balance as:

$$m\, du/dt = F_D + F_P + F_G$$

where m is the mass of particle, F_D is the force on the particle due to drag exerted on the particle by the continuous phase, F_B is the force due to gravity and F_P is the pressure gradient force.

Particle drag force determines the direction and speed of the particle. Gravitational force and force due to pressure gradient are very small for this case where spores are micron sized. The drag coefficient in the above equation is given by Stokes law. *Cunningham correction factor* corrects the Stokes drag coefficient to take into account the slip of particles between the gas molecules (due to small size of anthrax particles) [3, 4].

To represent the actual scenario, the conceptual model of anthrax spore dispersion used for the simulation assumes that:

1) The particles are initially uniformly distributed over the control surface, which is 100 cm from the edge of the floor; to take into account the fact that boundary layer is not resolved accurately.

2) Anthrax spores are spherical, 1-5 micron in diameter, having a density same as the water. For this simulation, it is assumed that each anthrax spore has a diameter of 1 micron and therefore, the mass of one spore is 7×10^{-15} kg. 100 representative spore class sizes are tracked through the indoor space.

3) Particle tracks are computed based on the assumption that presence of the particle does not influence flow field, i.e. there is only a one-way coupling to the particle transport. The airflow affects the particles, but the particles do not affect the airflow.

3) Particles are tracked in steady state flow field (present limitation).

4) Coefficient of restitution for particle interaction with wall is set to be 1 i.e. when an anthrax spore strikes wall, it bounces off the wall without losing any of the momentum.

5) Particle-particle interaction are neglected

6) The volume displaced by the particles is neglected, since the mass of each particle is very small.

- Disinfectant transport and decay

The transport of a chemical species in a flow field can be described by a general convection-diffusion equation, expressed in the form:

$$\frac{\partial \phi}{\partial t} + U_i \frac{\partial \phi}{\partial x_i} - \left(D + \frac{\mu_t}{\rho \sigma} \right) \frac{\partial^2 \phi}{\partial x_i^2} - k_{decay} \phi = 0$$

where Φ is concentration of the species (chlorine dioxide in this case), D is the molecular diffusivity of the species, σ is the turbulent Schmidt number of the species. Decay of chlorine dioxide has been taken into account and it has been incorporated as separate sink term in the above equation. It has been assumed that ClO_2 decays into ClO_2* where ClO_2* has no disinfection capacity, but it has the same thermo-physical properties as ClO_2.

$$aClO_2 \rightarrow cClO_2^*$$

It decays according to first order reaction with a reaction rate:

$$r_{decay} = d(ClO_2^*)/dt = - d(ClO_2)/dt = k_{decay}[ClO_2]$$

where the rate constant k_{decay} = 0.285 hour^{-1} [5, 6].

- Kinetics of inactivation

Inactivation rate equation for the reaction between anthrax particles and the disinfectant are derived based on the study of kinetic reactions involving chlorine dioxide[6]. In the above study, chlorine dioxide gas was used to sterilize *Bacillus subtilis* spores under controlled humidity, gas concentration, and temperature at atmospheric pressure. Based on the findings of above study and analogous water disinfection of microorganisms, inactivation rate equation can be generalized by first order disinfection kinetic model, initially proposed in the early 1900s by Chick and later modified by Watson as:

$$r_{inact} = -k(T, RH, ...)C^n f \qquad [7]$$

where r_{inact} is the reaction rate defines above. In the present study, it is assumed that reaction rate is constant (and not a function of temperature and relative humidity). Concentration C (of the deactivation agent) will be strong function of position within the contaminated zone and f is the viability of the anthrax spore. Inactivation rate equation for the reaction between anthrax particles and the disinfectant has been generalized in this study as:

$$r_{inact} = k\, C^n f$$

where k is reaction constant [k = 0.271 (L/mg)$^{0.5}$s^{-1}], and n is 0.471 [5, 6].

4. Results

Figure 1 below shows full scale test room set up using CFX, with dimensions 5 x 2.4 x 3 m^3 (x, y, z). For the case considered, the ventilation air enters the room through the supply section (0.5 x 1.0 m^2) with a velocity of 0.1026 m/s which results in 5.13 air changes per hour. The exhaust section (0.5 x 1.0 m^2) is located at a low level in the room. The airflow is assumed to be incompressible and isothermal.

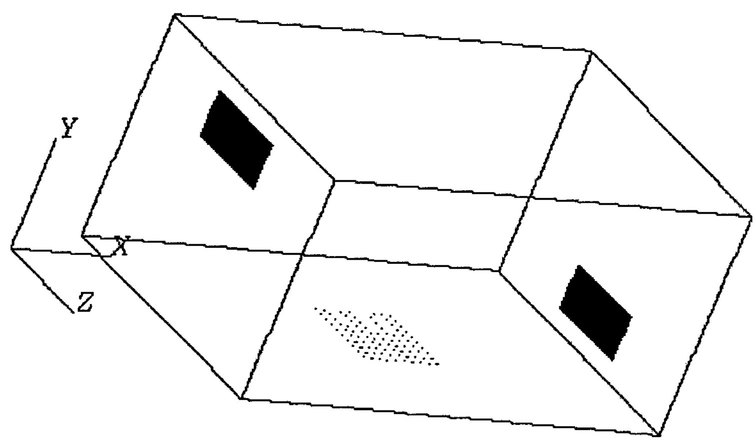

Figure 1: Test room geometry

- Room airflow simulation

Figure 2 shows velocity vectors and pressure contours along the mid-plane (z = 1.5) and plane y = 0.5 for the case described above.

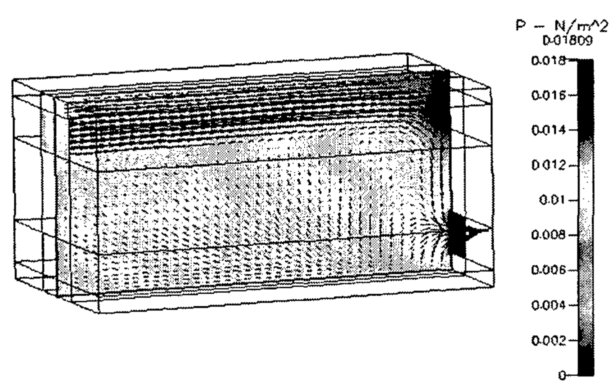

Figure 2 Velocity vectors and pressure contours at z = 1.5 m

- <u>Anthrax particle dispersion</u>

Anthrax particles (diameter = 1 micron, density = 1000 kg/m^3) are initialized around the center of the plane y = 0.1 m over an area of 1 m^2, as shown in Figure 1. Mass and distribution of spores is initially known. The anthrax spores are exposed to the airflow in the room generated by the ventilation system.

Figure 3 (a) shows the trajectory of a particle initialized around the center of the plane y = 0.1. Figure 3 (b) shows the trajectory of all the particles considered.

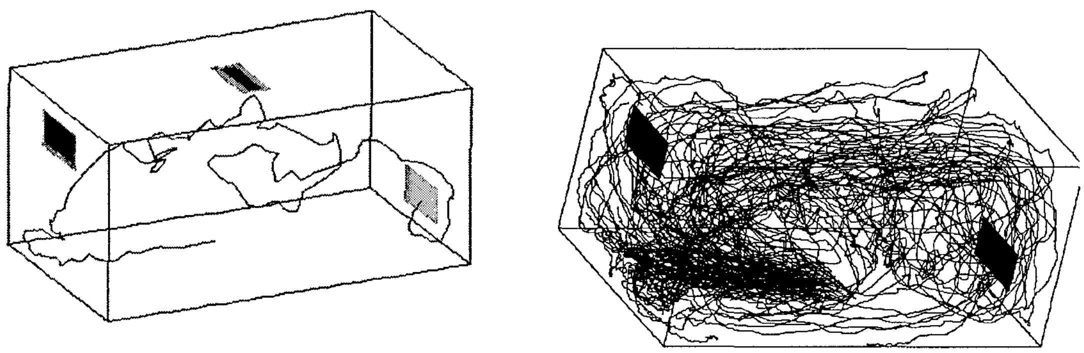

Figure 3 (a) Trajectory of 1 particle (b) Trajectories of 100 anthrax particles

- <u>Disinfectant transport</u>

Chlorine dioxide is injected into the room through the 'disinfectant' section *(envisioned like a fire-sprinkler location)* around the center of the top of apartment (y = 2.4). As chlorine dioxide enters the apartment, it starts decaying (first order decay with rate constant of 0.285 per hour). Figure 4 shows the concentration of ClO_2 along the mid-plane (z = 1.5) after 360 seconds of injection. Due to high molecular weight of ClO_2, its concentration is quite high near the bottom and quite low near the supply section due to air coming through it.

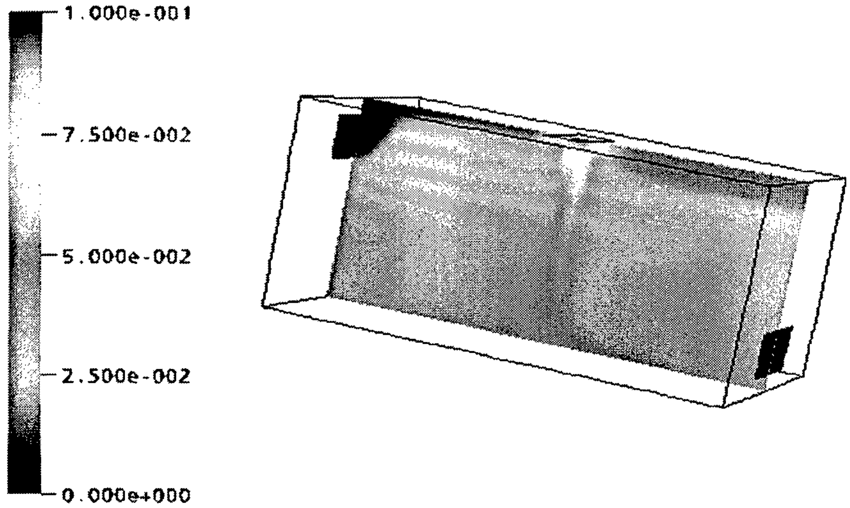

Figure 4: ClO_2 concentration (kg/kg) at mid plane

- Inactivation of anthrax spores

All the particles are initialized with viability of 1 (fully alive). Figure 5 shows the snapshot of the location of particles after 800 seconds. Particles are sized according to their viability. Some of the particles (in zone above the inlet area) are more viable (and hence more potent to cause infection) due to less concentration of ClO_2.

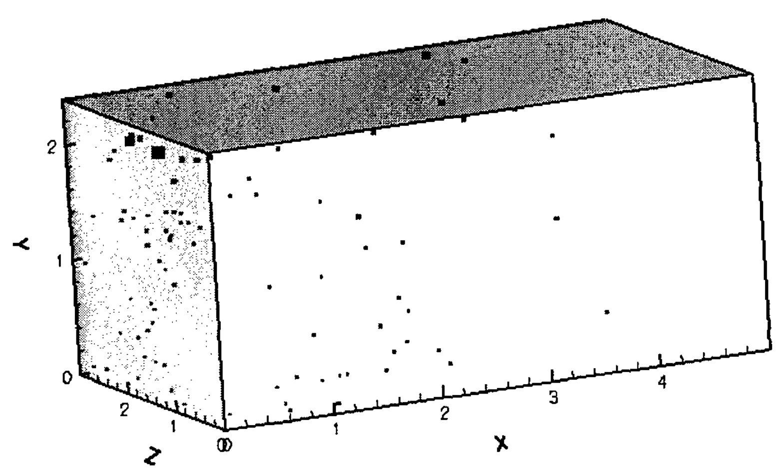

Figure 5: Snapshot of particle location at t = 800 seconds

Loss in the viability of each particle is calculated using the inactivation rate equation for anthrax spores. When the viability of all the particles reaches 0.01 or lower, the apartment is said to be "decontaminated". For this case, where particles are initialized in the full scale apartment, time require to inactivate 100 particles is 1267 seconds.

- Scaling studies

It takes about 18-19 hours to calculate distribution of spores, transport of disinfectant and calculating inactivation rate for the full scale apartment model, described in the previous chapter on an IBM PC. If the building/apartment is larger, time required to simulate will be much greater, and in those circumstances, the need of the hour would be to have an estimate of required inactivation time rather than running full simulations. Thus, it would be of value to have a relationship for inactivation time based on various parameters like the apartment dimensions, vents locations, disinfectant concentration etc. Scaling analysis will help in developing an empirical relationship for the dependence of inactivation rate on various parameters.

The main step in performing dimensional analysis and obtaining an empirical relationship is identifying the factors on which the dependent variables depend. The total time (dimensional) required for disinfection (τ), is assumed to depend on the following parameters:

1) V_{ClO2} (volumetric flow-rate of ClO_2)
2) V_{air} (volumetric flow-rate of air)
3) $A_{anthrax}$ (area over which anthrax particle are initialized)
4) L
5) H
6) W
7) k_{Cl} (rate constant for first order decay of ClO_2)
8) k_{an} (rate constant for inactivation of anthrax particles by ClO_2)
9) M (mass of particles released)

The effect of location of vent and placement of anthrax spores (patch over which anthrax spores are initialized) on inactivation rate of anthrax spores are not considered in the present analysis.

Thus, in functional form:

$$\tau = f(\dot{V}_{ClO2}, \dot{V}_{air}, A_{anthrax}, L, W, H, k_{Cl}, k_{an}, M)$$

Experiments, physical or numerical, need to be performed to determine the form of the above functional relationship. Applying Buckingham Pi theorem [8], the following relationship was obtained:

$$\left(\tau\frac{\dot{V}_{air}}{L^3}\right)=k\left(\frac{\dot{V}_{ClO2}}{\dot{V}_{air}}\right)^A\left(\frac{W}{L}\right)^B\left(\frac{A_{anthrax}}{L^2}\right)^C\left(\frac{H}{L}\right)^D\left(\frac{\dot{V}_{air}}{k_{decay}L^3}\right)^E\left(\frac{k_{inact}\left(ML^3\right)^{0.5}}{\dot{V}_{air}}\right)^F$$

where all terms within parentheses are non-dimensional quantities. The constants k, A, B, C. D, E and F were obtained via regression analysis with a significant number of cases that were analyzed numerically. Various parameters were varied systematically in numerical studies. First some numerical studies were done in which the dimensions of the apartment were varied. Subsequently, more studies were conducted where other parameters like room air flow rate etc. were varied.

Microsoft Excel's *LINEST* function, which is a linear regression function that calculates the statistics for a line by using the "least squares" was used to evaluate the correlation constants. LINEST is used to obtain the following values

k = 0.07298, A = -0.0689, B = -0.1222, C = 0.0449, D = -0.0232, E=0.54465, and F=-0.16883.

Coefficient of regression for the above relation is 0.84, which shows close agreement between the numerical model predicted inactivation time and estimated inactivation time based on the above relation. This correlation shows that the inactivation time is a strong function of the length of the room, the reaction rate constant for anthrax spore inactivation; and the inlet air flow rate. To test the correlation developed above, five more simulations were preformed and numerically computed values of the deactivation time were compared with the corresponding values given by the correlation. Close agreement between the numerically computed and correlated inactivation time is obtained.

5. Discussion and Conclusions

In this project, a three-dimensional (3D) numerical model for inactivation of biological agent (like anthrax spores) by a disinfectant (chlorine dioxide) is developed. Flow field is determined by solving the Navier-Stokes equation for mass and momentum conservation, turbulence is incorporated by including k-ε model. Lagrangian approach is employed to predict spores distribution in which trajectories are calculated by solving equations of motion for a particle, established using a force balance. Disinfectant concentration field is obtained by solving transient mass transport, convection and diffusion, equation for chlorine dioxide.

Scaling studies are done to develop an empirical relation for the dependence of the inactivation rate of anthrax spores on various parameters including disinfectant flow rate, inlet air flow rate, changing area of patch over which anthrax spores are initialized, apartment dimensions, reaction constant.

No experimental confirmation of the predicted inactivation time was done. As such data does not exist in the open literature, a follow up experimental study on a scaled unit is suggested. Also, from scaling studies it is deduced that small-scale experimental studies will be of value in predicting deactivation times for larger systems. The model developed can also be in direct use in designing and retrofitting buildings with air flow controls and decontaminant release devices to minimize the impact of potential biological contamination incidents.

6. Reportable Outcomes

A list of the reportable outcomes (to date) is given below:

1. "Simulation of Anthrax Spores Transport and Inactivation in an Apartment Complex: Scaling Studies", ASME IMECE, Orlando, Florida, November 2005 (to be presented)
2. "Simulation of Biological Agent Transport and Inactivation", S. Soni, M. S. Thesis, Mechanical Engineering and Mechanics Department, Drexel University, June 2005 (in preparation).
3. "Simulation of Anthrax Spore Transport and Inactivation", S. Soni, poster presentation, Drexel University Research Day, April 26, 2005 ("Honorable Mention" award).

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BIODEFENSE ASSESSMENT, IMPLEMENTATION AND EVALUATION

Evaluation of Skin Damage through Portable fNIR

Introduction:

Near infrared imaging represents a non-invasive optical technology able to provide quantitative information of tissue oxygenation and structure at varying depths up to a maximum of 7-8 cm. This research explores the development and use of a near infrared device to quantify skin damage by using skin samples in vitro and a wound animal model in vivo. Appropriate IRB for human study on burn patients has been submitted in April of 2005 to the Drexel IRB committee. A frequency domain instrument has been constructed during this last year, able to measure at three wavelengths, and equipped with probes of various size and configurations. Calibration standards appropriate for skin measurements were developed in our laboratories and a second generation device of less weight and smaller footprint was also completed. Our results provide the basis for ability to triage subjects according to their severity of skin damage and also monitor the healing progress in various patient populations.

Background of Near Infared (NIR) Diffuse Optical Tomography:

Diffuse Optical Tomography is based on the differential absorption of tissue chromophores in the near infrared range (Figure 1). In the range of 650 - 850nm oxygenated (HbO_2) and deoxygenated hemoglobins (Hb) are the main absorbing chromophores and this allows calculation of blood saturation with high reliability. The constructed device is able to measure optical coefficients of scattering μ_s' and absorption μ_α of the tissue at a desired depth, using two experimental quantities: amplitude and phase of scattered light. In our device no electrical component or ionizing radiation is in contact with the human subject. A fiber optic probe delivering and collecting light is the only component touching the human subject.

Research Accomplishments:

a) Developed appropriate instrument and probes

Physically, the instrument is housed in a standard 19"x 14"x9" rack, and weighs around 25 lb. Each instrument block is housed in a separate Nuclear Instrumentation Box (NIM BINs, Mech-Tronics) that provides suitable wiring for power supply, mechanical stability and most importantly good shielding against RF electro-magnetic cross talk.

b) Designed a smaller instrument of dimensions: 11"x11"x9" using different component architecture and compact laser drivers.

c) Achieved superior stability in the mobile fNIR device compared to the generation I instrument. This new device has offsets of the order of 10 μV during 2 hours, much less than that of the old generation I device. This will result in improved accuracy and more reliable measurements. The robustness and reliability of the instrument in in vitro phantoms (intralid) is excellent.

d) Measurements on skin samples of varying degrees of burn – Differentiation due to phase measurements

- We used the instrument in transmission geometry to measure the optical properties of various samples from burn patients.

- While blind samples were used, as per IRB protocol, the samples did correspond to different degrees of burn. We analyzed the data obtained from samples of burned skin using our instrument. Analysis of this data (amplitude and phase information) suggests that these samples can be easily differentiated using our instrument. (Fig. 1 and Fig. 2).

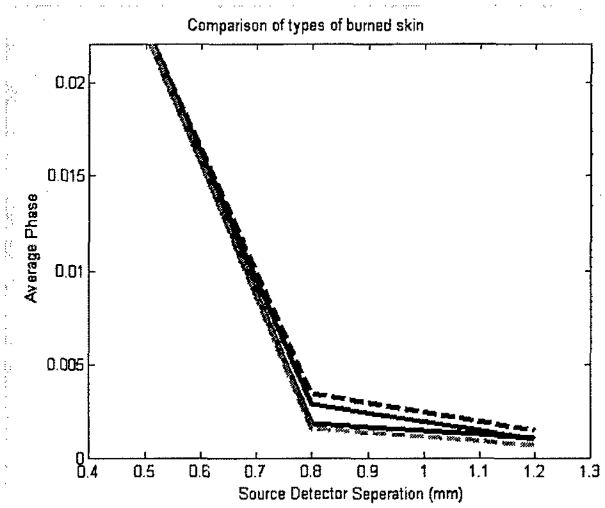

Figure 1: Average Amplitude
Various Skin Samples

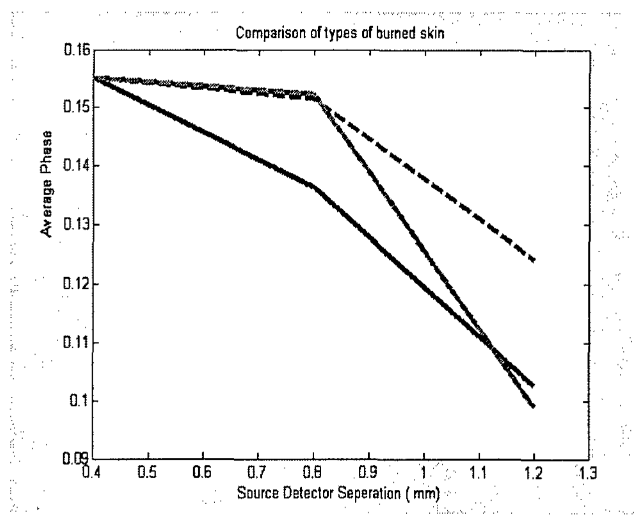

Figure 2: Average Phase shift
Various Skin Samples

From these experiments one can appreciate the need for the phase information, as this provides sensitive differentiation of skin samples. Average amplitude needs in vivo experiments to be useful – in skin samples ex-vivo the different skin structures cannot be differentiated.

Conclusions:

A reliable frequency domain near infrared instrument of decreased dimensions has been constructed and used with skin samples of varying damage. This instrument allows differentiation of skin damage – it has been used with ex vivo burned skin samples and in a wound animal model (Articles attached), allowing monitoring of the healing progress. Next steps include simultaneous hydration measurements and blood flow measurements via simple digital image capturing of the affected area. Further engineering to reduce the size of the instrument is also a possible path forward.

Predictive Syndromic Surveillance Systems

Introduction

This research explores how Predictive Syndromic Surveillance can leverage existing information technology (IT) infrastructure to improve health outcomes. Such IT infrastructure includes patient monitors with invasive and/or non-invasive sensors found in hospitals and other healthcare providers. The growing adoption of these medical systems has resulted in the growing availability of continuous physiologic data streams in real-time or almost real-time over many hours and days.

Visual monitoring of continuous data streams by medical personnel has provided the ability for improved care of critically ill patients at the critical care unit. Moreover, medical researchers can now collect patient data to look for previously unavailable clinical patterns and correlation between different parameters in a systematic and scientific manner. The availability of this data also allows the use of statistics and algorithms to be used as a powerful tool in medical science.

In our proof-of-concept research, we have accumulated a multi-channel data set of hemodynamic parameters from Philips® CMS patient monitors connected to critically ill patients with high possibility of "septicemia" or "blood poisoning" at the medical intensive care unit (MICU) at Hahnemann University Hospital (HUH), Tenet Healthcare Systems affiliated with Drexel University College of Medicine (DUCOM). Due to lack of support by medical companies, numeric data points in time resolution of 1, 5, or 30 minutes are manually printed by clinical staff and inserted into spreadsheet data file by commercially available data entry services (DES) in Baltimore, MD to prepare for statistical data analysis.

The co-movements and other patterns of interrelations (such as their various leads and lags, ups and downs) between different data channels contain significant predictive information, which is currently not reflected in treatment, prevention, and preparedness. In terms of experience by intensivists and data analysis with static and discrete data points clinical criteria has been widely accepted to identify and quantitatively classify different stages of Sepsis [1,2,3,4]. Therefore, based on the criteria, computer algorithms have been designed by incorporating new and dynamic parameters, such as degree of deviation from normal ranges, time duration below or above critical threshold and the time delay between sepsis and septic shock, obtained from continuous and multiple data streams, and to apply improved computer algorithm to predict and detect future episodes.

The benefits of such an automated algorithm, if feasible, would be tremendous. In addition to higher survival rates, it could improve response times, enable centralized early warnings even across health care facilities and bring about labor cost efficiencies.

Project Activities

#	ACTIVITY	STATUS
1	**Populate and manage integrity of database** Deliverable: database and timeline	**COMPLETE**
2	**Develop and implement high level logical design** Deliverable (s): Literature review, vendor review, baseline candidates and predictive parameters	**COMPLETE**
3 **3A**	**Perform modeling and statistical analysis** Deliverable: Quantitative criteria and list of hypotheses	**IN PROGRESS**
3B	Deliverable: Fitted statistical models	**TBD**
4	**Test and validate the developed system** Deliverable: Algorithm validation and comparative metrics	**TBD**
5	**Documentation and next steps** Deliverable: Documentation and next steps	**IN PROGRESS**

Research thus far has revealed no unexpected issues that would require steps beyond the statement of work. However, the entire process of data collection, entry, cleaning and preprocessing has required tedious and time-consuming work beyond initial expectations. This was due to unforeseen circumstances such as limited access to patient monitors by engineers, frequent changes of medical residents participating in this research, delays in IRB process and data ownership issues between Drexel and Tenet Healthcare Systems.

An initial data source, which would have provided processed data void of the issues associated with creating a data source from raw data, did not ultimately materialize. Thus, all the efforts and preparation that was expended on building the prototype around the initial data source had to be shelved.

Unexpected obstacles have challenged the team to be creative in terms of data acquisition and usage while maintaining integrity to the statement of work. After establishing clinical criteria in terms of readily available parameters, determining acceptable sample parameters, and obtaining IRB approval, a data set was created for use.

Key Research Accomplishments

1. Establishment of sample guidelines for medical data use from critical care
2. Establishment of guidelines for translating continuous biomedical parameters into concurrent clinical stages
3. Collection of a unique data set that can be used for testing and prediction.
4. Methodology for incorporating biomedical data of different observation frequency
5. Criteria for separating sample into in-sample (for analysis) and out-of-sample (for prediction)

Reportable Outcomes

ICU Patient Dataset
Software Code for Data Preprocessing and Filling Missing Data
Software Code for Predicting Septic Shock

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READINESS AND RESPONSE TRAINING
Rural Network Development

The likelihood of a catastrophic event producing mass casualties either naturally occurring or manmade remains a prominent concern within today's social and political climate. Moreover, biological, toxic industrial chemical/material (TICS/TIMS) (Cetaruk, E., 2003) weapons continue to be considered the weapons of choice due to their availability, difficulty to detect and alignment with "terrorist objectives" to directly threaten the foundation of America, her people, her democratic way of life, and her economic prosperity. (DHS/AWR-160, 2005). Worldwide and national efforts to improve the overall readiness and response for such an event have continued to focus largely on metropolitan and populated suburban areas. As a result, rural preparedness and response will continue to suffer and has changed marginally since 2001. There is a clear lack of sufficient medical infrastructure, specific educational materials, individualized core healthcare training, and material readiness to achieve minimal competency for rural medical preparedness for mass casualty events today (Pittsburgh Tribune, 2004).

Rural Medical Experts - Test Bed

The Rural Medical Experts Test Bed draws participants from the Rural Response Network, Task Force and Rural test bed and encompasses a broad membership including private industry, hospitals, first responder organizations and additional university-based resources. The Rural Medical Experts represents the overarching umbrella of collective resources, organizations and personnel of the CIMERC rural response component. The primary function of the Rural Medical Experts/Test-bed is to plan and coordinate resources and response within two large regional areas of rural Pennsylvania. This area is comprised of 21 counties and over 36 individual response organizations including, but not limited to:

- Region 13 Counter Terrorism Task Force
- South Central Mountains Regional Counter Terrorism Task Force
- 20 Hospitals/ EMAs within the South Central Mountains Regions
- 8 Hospitals/EMAs within Region 13
- The Southern Allegiances Regional EMS and The Regional Medical Reserve Corps
- 2 Red Cross Disaster Groups
- 2 Public and Mental Health organizations
- Home Nursing and the VA Home

In addition, they are committed to develop and implement a multi-jurisdictional and multi-agency communications, preparedness and response plan utilizing both technological solutions as well as traditional methods. Each task force feeds the overall network and test bed with data. As "select" partners, hospitals and emergency medical service providers within the test bed, who voluntarily test and evaluate the products and services, provided or recommended by CIMERC. The rural test bed has one essential focus: to provide continuous feedback and evaluation regarding CIMERC projects.

Dynamic Intelligence Delivery Portal
CIMERC strives to develop and implement a multi-faceted education delivery program to create a highly trained and coordinated civilian response force to effectively prepare, respond and recover from a MCI through the use of web based training and education tools. This is accomplished in part by:

- Engaging experts to provide a strategic plan for scenario simulation
- Researching off-the-shelf training and education products
- Evaluating course content for Con-Ed, CME or CEU credit as needed
- Planning and executing dynamic portal and modify as necessary
- Update Strategies For Incident Preparedness Guidebook (SIP)
- Update Hospital Self Assessment Tool

Accomplishments/Outcomes:

- WMD Modular Training Program
  http://chief.cimerc.org/nmetc/awareness/start.htm

  http://chief.cimerc.org/nmetc/clinicians/start.htm

  http://chief.cimerc.org/nmetc/commander/start.htm

  http://chief.cimerc.org/nmetc/responder/start.htm
- 2005 Multimedia Version of SIP Guidebook http://www.wixpix.com/CiMeRC
- 2005 Hospital Self Assessment Tool http://cimweb1.cimerc.org/hsat/hsat_register.php
- CIMERC maintains regional Continuing Education Sponsorship Authority http://www.cimerc.org/content/2005/continuing.html

Traditional Training and Facilitation Programs

- CIMERC offers DHS/ODP, AWR-160, WMD Awareness Level Certification Training
- CIMERC offers Disaster Management Interoperability Certification Training
- CIMERC offers Hospital Emergency Incident Command System Training
- CIMERC offers Facilitation for Hospital Preparedness Table-Top Exercises

Rural Infrastructure and Technology
Routine upgrades to hardware and software was completed February 2005 to enhance the CIMERC web service and it companion systems. Two servers were designated specifically for the web service (Apache), while two additional servers house the back-end Sybase database engine that provides a repository for the MCI Education Forum and

IDB. Each production system is connected to an uninterruptible power supply (UPS) system to provide clean power and to protect against short-duration power outages or brownout conditions and its own back-up generator system.

General statistics regarding www.cimerc.org are as follows:

Unique Visitors	12,407
Total Web Site Hits	63,689
Homepage Hits Average per day	110
Webpage Views Average per day	517
Unique Visitors Average per day	90
Strategies for Incident Preparedness	5,173 Downloads
Hospital Preparedness Self Assessment Tool	1,728
News Page	10,080
Events Page	1,185
Education Page	2,086
Traffic Patterns on Web Site	Weekend (6.1%), Weekdays (93.9%)

CIMERC at Saint Francis maintains multiple connections to the Internet (one via the new Internet-2 infrastructure) and the other (via a dedicated T-1) to provide redundant access to the backbone of the nations information super highway.

Rural Technology Evaluation and Improvement

Enhancing the web-based information, education and remediation process offers the opportunity to bolster individual and organizational preparedness. CIMERC has made available via its website multiple web-based information guides, educational materials and assessment tools to aid in the overall organizational preparedness of the rural component. As consultants in incident preparedness and response, CIMERC has deployed a technology survey instrument to evaluate the rural components computer and Internet service provider (ISP) material readiness.

Accomplishments/Outcomes:

- Received IRB approval
- Created web/paper based survey
- Research data collection underway (May 2005)
- Rural Technology Survey Instrument (http://cimweb1.cimerc.org/rts/rts_welcome.php)

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Mass Casualty Incident (MCI) Education Forum

Together The Forum and the Informatics Database (IDB) provide rapid development, dissemination and recall of new information, policies and preparedness issues concerning effective response and remediation to a bioterrorism or other mass casualty incident (MCI) event within a secure, virtual environment. The Forum and IDB leverages identified strengths of other interactive learning services as well as the identified needs of the target population to provide a value added educational and training venue. The community leaders, expert mentors and users of the Forum and IDB will be able to:

- Evaluate response skills and accelerate skill acquisition and remediation from a trusted network of professionals
- Benefit from specialized and targeted information delivery, content and services that are based upon evolving user interaction and peer-to-peer discovery learning
- Accelerate just in time learning, meet rural and urban preparedness challenges, strategies and program goals through effective multi-level response
- Searchable informatics database consisting of collection of interactions, collaborations, and published content, promoting cross pollination of diverse professional groups

Today's technology combined with the employment of an "anytime, anywhere" strategy in distance education and training is enhanced by the secure, web-based collaborative learning environment offered by the Forum and the respective IDB supplements. In an online community, the participants construct their own knowledge while building a knowledge resource for the entire community. "As student-centered activities are increasingly facilitated by emerging technology, the role of the faculty member or instructor shifts to facilitator, coach, or mentor who provides leadership and wisdom in guiding student learning." (Bonk and Wisher, 2000, p. 18).

Upgrades Forum Software and Code

A subcontractor and additional staff member were hired to enhance the Forum core software over this period of performance. The most recent, most adaptable, and most easily maintained code is the foundation for new Forum software. The Forum technical team developed the applications software for ease of maintenance, manageability, security, and to facilitate rapid development and deployment of the software.

Multi-tiered security development was a "cornerstone need" expressed by both the urban and rural constitutes during the initial evaluation process to ensure maximum safeguard to content. Development addressed security on four levels: 1) physical, 2) network, 3) system level and 4) application software. CIMERC staff provided physical and network security, while a consultant implemented system level and applications software security and planned for future applications security.

Achievements/Outcomes:

- Robust and secure base code
- Provides secure "break-out" capabilities
- Provides multiple discussion string participation
- Architecturally expandable and scaleable to fit community
- Populates a secured informatics data base (IDB)
- CIMERC's MCI Education Forum Web Site and Informatics Database (IDB)
- https://chief.cimerc.org//forum_main.html *(Login: cimerc Password: cimerc)*

Recruit, Train and Maintain Experts

Recording and reorganizing the interactions of online subject matter experts enables knowledge-base development while simultaneously enhancing security through a system of accountability to peers as well as providing a system that rewards helpful and supportive online etiquette. This process developed a foundation for cultivating leadership, responsibility, and direction from within the response community. The key to building a successful knowledge community is a balancing act of seeding the community with resources and stimulating experiences, while nurturing the activity and initiatives of the members. The success of the community hinges on training, quality and extent of the members' contributions. This, in turn, depends on their perception that this forum and its resources has been built for and with others like themselves. Thus, permitting them to overcome the critical threshold between disengagement and the willingness to surmount the learning curve. (Renninger and Shumar, 2002).

To maintain relationships and remain engaged in the day-to-day needs of civilian medical responders and planners, members of CIMERC participate in task forces and working groups hosted by members of the target audience. Through these venues and through industry articles, the need for a learner-constructed curriculum clearly emerged. As a result, a plan to effectively present the forum to the potential end user has been designed. The implementation plan includes the components identified in the list of accomplishments.

Accomplishment/Outcome

- Forum vision and description with user-centered benefits
- SWOT Analyses of the Forum and potential competitors
- Peer evaluation system
- Identification of potential forum partnerships
- Identification of potential risks to the Forum and how to mitigate them
- Established Forum success criteria and related metrics

Obstacle:

- Recruitment and training are restrained due to pending IRB approval.

The nature of the forum development is primarily software and technical. However, the small human component of this project suggested the possibility of Institutional Review Board (IRB) involvement. On 14 January 2005, Drexel University IRB was asked to determine if the forum development project was considered research. It was determined that this project was not research in early April. USAMRMC Office of Research Compliance was asked to make this determination on 07 April 2005 for intra-agency consistency. They made the determination that this project was, in fact, research on 12 May 2005. The project meets the criteria for an exempt research project under paragraph 2 of the federal regulation. A modification to the original IRB application is presently being prepared and will be submitted to Drexel University's IRB and MRMC's IRB upon approval of the university board.

Forum Test, Evaluation and Improvement

Initial testing and evaluation of the MCI Education Forum (The Forum) website including hardware, software and program code was successfully completed over a period from December 2004 to February 2005. The test and evaluation process centered on the overall visual design and navigation of the Forum.

Accomplishments/Outcomes

- Implemented an overall process improvement plan
- Adopted customer driven consensus improvement strategy
- Created user feedback tools for Forum member http://cimweb1.cimerc.org/feedback/forum_feedback.php
- Created a prioritized modifications, changes and improvements list

Obstacle:

- Comprehensive user testing, evaluation collection and feedback for consensus driven improvement have not been completed due to IRB restraints.

Real-Time Incident Preparedness Simulation (RIPS/R1)

CIMERC collaborated with the SIMGroup at the Center for the Integration of Medicine and Innovative Technology (CIMIT) to utilize one of the scenarios from "Strategies for Incident Preparedness: A National Model" as a base to layer the advantages of real-time collaboration and augmented learning developed by the SIMGroup on top of the MCI research conducted by CIMERC. The following objectives were established to guide the development of a more powerful and interactive tool for incident preparedness and training:

- Develop a system that can run on the existing CIMERC server configuration
- Establish a set of standardized user profiles to create a framework
- Evaluate and integrate with the existing Forum security policies
- Provide design input for interface usability
- Allow users to select a specific role to play
- Allow users to select a specific locale.

- Enhance one of the existing SIP scenarios a interactive simulation layer
- Graphically indicate the averaged user path through the scenario branch points
- Provide CIMERC with a sound concept for augmenting the Forum with real-time simulation technology

Outcomes/Accomplishments

- Provide CIMERC with a sound concept for augmenting the Forum with real-time simulation technology
- Provide a functional proof-of-concept demo that can facilitate future development conversations and direction.
- Successfully developed proof of concept simulation prototype
- RIPS R1 Prototype Scenario Based Simulation Project
  http://rips.medicalsim.org
  Site Username: cermusa /Site Password: remote
  Demo account: Username: cermusa / Password: demo

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