Video-Based Surveillance for Chem-Bio Protection of Buildings

Ioannis Pavlidis
University of Houston
Dept. of Computer Science
Houston, TX 77204-3010
pavlidis@cs.uh.edu

Christos Stathopoulos
University of Houston
Dept. of Biology and Biochemistry
Houston, TX 77204-5001
Christos.Stathopoulos@mail.uh.edu

Tony Faltesek
Honeywell Laboratories
3660 Technology Drive
Minneapolis, MN 55418
tony.e.faltesek@honeywell.com

Abstract

We propose a layered security concept for the protection of buildings' air-intakes from chemical and biological attacks. The concept is focused on prevention, early warning, and effective evacuation. One of the pillars of our concept is the inclusion of a video-based surveillance subsystem that improves the early warning capability of the protection system. Our video-based surveillance subsystem features a motion detection and tracking module based on DETER – an algorithm that we described previously. We have tested our video surveillance system on various possible attack scenarios with perfect detection results. The current weak point of our solution is that it cannot differentiate between benign and malicious human activities. We are working on incorporating a human activity recognition module, which will endow the video surveillance subsystem with threat assessment capabilities.

1. *Introduction*

In the wake of recent global events the threat of a **che**mical and **bio**logical (chem-bio) attacks became very real. The community of technology and policy experts has recognized this threat way ahead of its time and a very extensive treatise of the matter can be found at [1]. There are various scenarios that the terrorists may follow to stage a chem-bio attack. One such scenario by testimony of one terrorist is to attack through the air-intakes of commercial or Government buildings. In July 2001, the terrorist Ahmed Ressam described in his court testimony how the training he and many others received in Al-Qaeda camps included attacking buildings with chemical agents ([2]). In particular, he detailed how he was trained to use cyanide and sulfuric acid to create deadly fumes and how to inject these fumes into building air-intakes. The targeting of air-intakes meant to maximize the number of deaths in the building without creating a risk for the attacker.

The possible attack scenarios to air-intakes are low-tech and invariably involve a human. In a typical scenario the terrorist approaches the building air-intakes and unleashes the lethal load in the immediate proximity. Since human motion and activity is involved, it is possible to design a video-based surveillance system to automatically detect and report a possible threat. The threat will be reported on the guard's console. Ideally, if the level of threat is high, the system should also shut down the HVAC air handler to minimize casualties (**HVAC** stands for **H**eating, **V**entilation, and **A**ir **C**onditioning system). The staging of a chem-bio attack in a building is anticipated to last at most a few minutes. Therefore, an automated video surveillance system can provide only short notice. Nevertheless, even this short notice may make the difference between life and death if the air-hander of the building is shut down on time and the agent is blocked.

In this chapter we first describe the paralyzing effects of certain chem-bio agents (Section 2). Then, we describe various attack scenarios that an air-intake protection system should be capable of addressing (Section 3). In Section 4 we propose a system architecture for the protection of air-intakes. In Section 5 we describe the hardware and software components that we have developed so far and their performance. In Section 6 we conclude the chapter by outlining the additional hardware and software components that we are planning to develop and incorporate to our current baseline system.

2. *Chem-Bio Agents*

Although there are more than forty chem-bio agents that could be used as weapons [3][4], the most probable ones to be used in attacking building air-intakes are the following five: hydrogen cyanide, anthrax, botulinum toxin, plague, and smallpox. All five are highly toxic or infectious after inhalation and have been weaponized by nations or individuals in several reported cases.

i. **Hydrogen Cyanide:** It s an extremely flammable, colorless gas or liquid. It gives off toxic fumes in a fire and is highly explosive. Exposure irritates the eyes, the skin and the respiratory tract. Symptoms are burning and redness for the skin and eyes. Inhalation causes confusion, drowsiness and shortness of breath, leading to collapse. The substance can affect the central nervous system, resulting in impaired respiratory and circulatory functions. Exposure can be fatal. Recommended antidotes include exposure to fresh air in the case of inhalation and rinsing with plenty of water in the case of skin or eye exposure.

ii. **Anthrax:** It is an acute infectious disease caused by the Gram-positive bacterium *Bacillus Anthracis*. There are several forms of human anthrax, but the serious ones are inhalation anthrax, cutaneous anthrax, and intestinal anthrax. Symptoms of the disease usually occur within seven days after infection. Initial symptoms of inhalation anthrax infection may resemble a common cold but after a few days they usually progress to severe breathing problems and finally death. Infection of persons exposed to anthrax can be prevented by early antibiotic treatment, given within hours after the exposure to the bacteria, or vaccination [5][6][7].

iii. **Botulinum Toxin:** It is a muscle-paralyzing disease caused by a toxin produced by a Gram-positive bacterium called *Clostridium Botulinum*. The botulinum toxin is the most toxic chemical compound known; just 0.075 micrograms can kill the average man. Symptoms of botulism will appear in 6 hours to 2 weeks and include double vision, blurred vision, nausea, muscle weakness and eventually paralysis of breathing muscles; unless assistance with breathing is provided, the infected person will stop breathing and die. If the infected person is kept breathing and alive until the antitoxin is administered to him, there is a good chance that he will eventually recover after weeks to months of supportive care (in this case only one in twenty people will die) [5][7][8].

iv. **Pneumonic Plague:** It is an infectious disease caused by the Gram-negative bacterium *Yersinia Pestis*, a bacterium found in rodents and their fleas. Pneumonic plague occurs when Y. pestis infects the lungs and usually takes one to six days to develop after infection. The first symptoms of the disease are fever, enlarged lymph nodes, headache, and cough. Without early treatment, pneumonic plague usually results in respiratory failure, shock, and rapid death. To prevent the deadly outcome of the disease, antibiotics should be given within 24 hours of the first symptoms. There is no available vaccine against plague. Pneumonic plague can be transmitted from person to person through inhalation of *Y. pestis* particles in the air [5][7][9][10].

v. **Smallpox:** It is caused by the variola virus. Smallpox was officially eradicated from the world in 1977. Currently there are only two places in the world where smallpox is held: one is the CDC center in Atlanta, Georgia, and the other is the Research Institute for Viral Preparations in Russia.

Initial symptoms of the disease occur in 7-17 days and include high fever, fatigue, and head and backaches. They are followed by a rash and development of pus-filled lesions. The majority of patients recover, but death occurs in up to thirty per cent of cases. The disease can spread from person to person by infected saliva droplets. In aerosol, viruses can survive for twenty-four hours or more and they are highly infectious at even low concentrations. Administration of the vaccine within four days after infection can lessen the severity or even prevent illness [3][7][10].

3. *Chem-Bio Attack Scenarios for Building Air-Intakes*

We will outline two possible attack scenarios: one chemical and one biological. They both involve a person carrying the lethal material very close to the building air-intakes. The chemical attack scenario may require some short preparation on site. The biological attack scenario typically does not require any on site preparation. For modern western buildings the most deadly attack scenario is the chemical one. In the biological attack scenario the HVAC filtration system is expected to block most of the agents and minimize immediate casualties even if the building is lightly protected.

One likely chemical attack scenario to building air-intakes has already been spelled out in the testimony of Ahmed Ressam ([2]). The scenario refers to an attacker approaching the air-intakes of a building carrying a backpack and a shallow wide container. Once under the air-intakes, the attacker has to pour a liquid solution in the shallow container. The liquid solution can be kept in thermos in the attacker’s backpack. Finally, the attacker drops dozens of large pills into the liquid, thus forming the chemical agent, and walks away. Wind direction and speed is very critical for the success of the attack. The way this chemical attack is planned points to Potassium Ferrocyanide that exists in pill form. When Potassium Ferrocyanide is mixed with a strong acid such as Sulfuric Acid, it creates the deadly chemical agent Hydrogen Cyanide.

Hydrogen Cyanide is lighter than air and harms or kills in medium concentrations. A lethal dose is 2,500-5,000 mg/min/m^3. Therefore, it renders itself as the chemical agent of choice for a “light” chemical attack. A single person can produce very quickly lethal quantities of Hydrogen Cyanide and it is highly dispersible in the atmosphere.

A biological attack scenario may involve the dispersion of a powdery substance near the air-intakes of a building. The powdery substance may have characteristics similar to weapon grade anthrax. One should expect that the natural static charge of the powdery material has been eliminated to make the agent highly dispersible. About 8,000 spores are required to infect a person. Weapon grade anthrax features 15,000 spores per mg and therefore a small amount carried by a single person can have a deadly effect, especially if the filtration system of the building is outdated.

4. *Architecture of An Air-Intake Protection System*

An effective protection system for a building's air-intakes has to be layered and geared towards prevention, early warning, and effective evacuation. A successful protection design has to take into account the architecture of the building's HVAC system. Figure 1 depicts a typical HVAC architecture of a modern building.

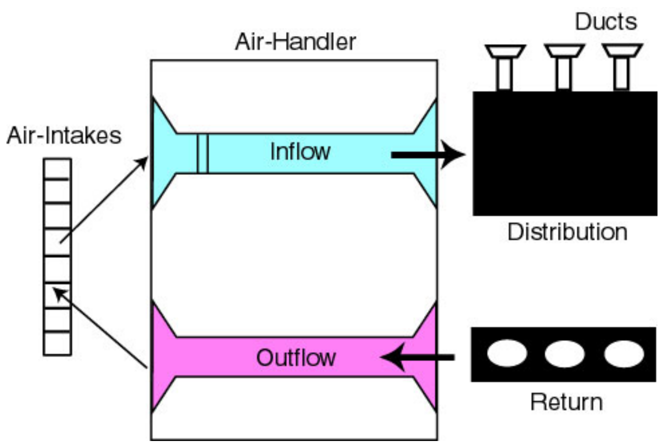

Figure 1: Architecture of a typical HVAC system in a modern building.

Atmospheric air flows through the air-intakes to the air-hander where it is filtered, tempered, and pumped to the distribution network of the building. From the distribution network the air flows eventually through the ducts to the building's interior living space. The critical flow path starts from the air-intakes and runs all the way to the ducts. In a chem-bio attack the warning from the protection system has to arrive in time for the pump of the air-handler to be stopped and the ducts to be blocked so that no contaminated air makes it into the building's living space.

We have run two tests with two different air-handlers from typical medium size commercial buildings to draw an idea about the reaction times required. The first test involved an air-handler that draws air from the outside at a speed of $v_n = 500\, fpm$ (*f*eet *p*er *m*inute). The total travel path of fresh air from the air-intake until the first duct has been measured at $s_t = 110\, ft$. The latency of this air-handler has been timed at $t_l = 13 \sec$. During the shut down process we assume that the reduction of air speed is linear and goes from $v_n = 500\, fpm$ to $v_n = 0\, fpm$ within $t_l = 13 \sec$. Therefore, the average shutdown speed is $\overline{v}_n = 250\, fpm$. This means that during the shutdown process incoming air travels another $s_s = \frac{\overline{v}_n}{t_l} = \frac{250}{13} = 32.5\, ft$. The worst case scenario has to assume that contaminated air goes undetected for the first $s_r = s_t - s_l = 110 - 32.5 = 67.5\, ft$ within the air handling system at the nominal speed ($v_n = 500\, fpm$). That means that the protection system has to issue the shutdown order to the air-handler within $t_c = \frac{s_r}{v_n} = \frac{67.5}{500} = 13.5 \sec$ from the time the agent entered the air-intake or else contaminated air will leak into the living space of the building. A similar reaction time requirement was ascertained for a different air-handler.

It appears that the effective reaction time for an air-intake protection system has to be in the order of a quarter of a minute from the time the agent is released under the building's air-intakes. This is a very challenging detection requirement for a typical chem-bio sensor. As we have described in Section 2, particularly in the case of a chemical attack the terrorist has to undergo a preparation stage nearby the air-intakes before the agent is released. During this preparation time the terrorist's presence and movements are exposed to visual surveillance. Assuming that the terrorist's activities will last at least several seconds in the vicinity of air-intakes an automated video surveillance system will at least double the advance warning time that any chem-bio sensor can offer. It follows from the previous analysis that video surveillance technology has to be part of an effective security solution.

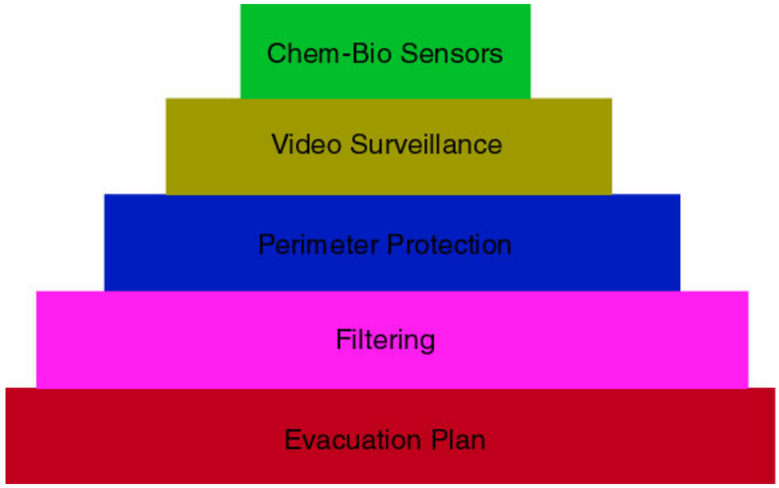

Figure 2: Proposed layered security architecture for the protection of buildings' air-intakes from chem-bio attack. Layers at the bottom of the pyramid represent more basic components that have to be implemented first if the management of the building is working on a step by step approach.

Our overall proposal for a layered security design for the protection of buildings' air-intakes is shown in Figure 2. Specifically:

1. **Perimeter Protection:** Whenever possible the area around air-intakes has to be physically protected with barbed wire or other fencing measures. This, however, is not always possible because sometimes air-intakes are over public sidewalks. This is typically the case of commercial and Government buildings in downtown areas. In suburban settings, the layout is different and air-intakes typically face an area belonging to the building campus. Fencing is far easier here because the area surrounding the air-intakes is private. The only hindrance is aesthetic. For both urban and suburban settings the most attractive case is when the air-intakes are placed at the roof of the building. Roof air-intakes are more protected by virtue of their location. They can also cater a far greater variety of preventive perimeter measures. In our view, it should be instituted that all new buildings place their air-intakes at the roof and not at their side.
2. **Video Surveillance:** While physical protection of the perimeter will make access to the vicinity of air-intakes more difficult, it will not make it impossible. An advanced video surveillance system is required to detect the presence and movements of the suspect in real-time. The purpose of video surveillance is dual: a) to provide early warning during the preparation stage of the attack and b) to record the suspect's identifiable silhouette and movements for prosecutorial purposes. The video surveillance system should feature a high degree of automation given the limited span of human

attention. At the very minimum it should detect and record automatically object motion in the vicinity of the air-intakes. At the same time it should provide instant warning to the guard about the presence of the suspect. In turn, the guard should assess the situation based on the live video feed and take appropriate actions (e.g. shutdown of the air-handler). We envision a much more sophisticated video surveillance system with threat assessment capabilities. We will describe our work and vision in the next two sections.

3. **Chem-Bio Sensors:** We consider the existence of chem-bio sensors of paramount importance. Their role is also dual: a) to cross-validate the existence of a chem-bio attack signaled earlier by the video surveillance system and b) to pinpoint the type of agent released, so that appropriate decontamination measures are effected. The combination of video surveillance with an array of chem-bio sensors constitutes the pillar of the advance warning capability of our proposed protection architecture.
4. **Filtering:** Current high performance bio-filters are extremely efficient in removing bio-particulates. Buildings that are not currently equipped with such filters should consider an immediate upgrade. Although, bio filtering is of very little use in a chemical attack it can provide an effective protection in the case of a biological attack by blocking the agent in the air-handling system for a significant amount of time. Therefore, it is a preventive measure that extends the grace period within which the warning system has to respond.
5. **Evacuation Plan:** The main purpose of all the previous measures that we outlined is to provide enough time for the occupants of the building to evacuate safely. If there is no effective evacuation plan then even an on-time warning can go wasted. The evacuation plan should be hatched in advance and it should be the brainchild of a mixed group of experts encompassing facility management and security experts. The plan should be communicated to the occupants of the building and rehearsed periodically.

5. *Video Surveillance System*

We follow our proposed architecture in implementing the security shield for the protection of our building (Honeywell Labs Camden Building in Minneapolis, MN), which serves as our test-bed. So far, we have implemented the two bottom layers as shown in Figure 2: Evacuation Plan and Filtering. We have chosen not to implement the third layer from the bottom (Perimeter Protection) for aesthetic reasons. We are actively working in implementing the Video Surveillance layer. Currently our video surveillance system performs effective motion detection only. It is based on the motion detection and tracking algorithms of DETER that we have developed preciously and described in [11]. DETER has introduced a new philosophy in the design of video-based surveillance systems. Any development of the surveillance system itself is predated by a rigorous system design. The objective of the system design phase is to pinpoint the optimal number, type, and location of cameras and computational resources. The system design amounts to the solution of an optimization function (see [11]). On one hand, the optimization function ensures complete optical coverage of the surveyed area, sufficient resolution for the machine vision algorithms to perform the prescribed tasks, and enough computational power for real-time operation. On the other hand, the optimization function ensures that the technical constraints are satisfied at a minimum expense in terms of hardware units and configuration. Figure 3 shows the resulting optimal camera configuration for the air-intakes layout of our building (Honeywell Labs Camden building in Minneapolis, MN).

We have embedded the DETER motion detection and tracking algorithm within a broader software package called DVM (Digital Video Monitor). DVM is a commercial product of Honeywell. It allows the acquisition and display of multiple video streams as well as their processing by a motion detection algorithm (DETER). Whenever sustainable motion is detected the respective incoming video stream is time-stamped and recorded on a digital storage device (hard drive). At the same time a textual and audible alarm is issue at the central console of the system to alert the operator. The DVM system has demonstrated its capability of detecting suspicious motion under difficult environmental condition in the monitoring of an oil pipeline in Central Asia for the last several months. It's performance in the monitoring of the air-intakes vicinity of our building has been equally flawless. DVM detected all the staged chem-bio attacks in our building (see Figure 4). At the same time, it featured almost zero false alarm rate for over a month of continuous operation (24/7). Some details about the motion detection and tracking algorithms of DETER are given in the next two subsections.

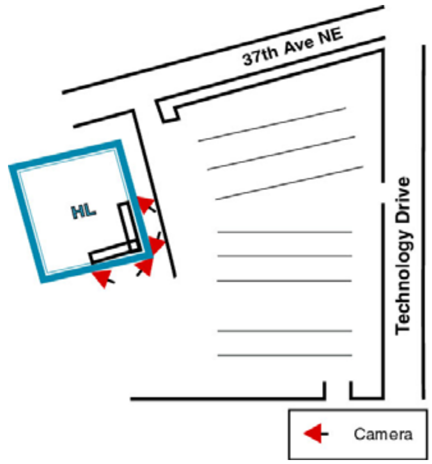

Figure 3: Camera configuration for the protection of the air-intakes of our building. The camera placement is the result of an optimization process. Four cameras provide full coverage in the vicinity of the air-intakes, which are placed on the side of the building and face an area belonging to our campus.

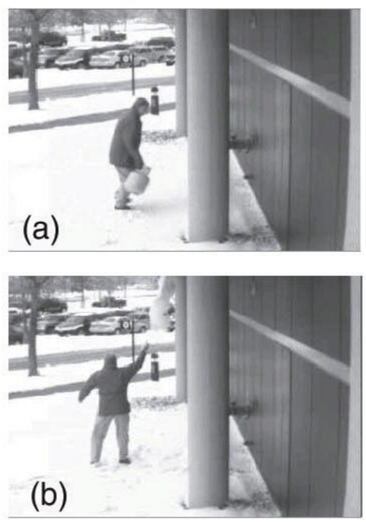

Figure 4: (a) Staged chemical attack. (b) Staged biological attack. Both images were captured automatically by DVM.

5.1 Motion Detection Algorithm

The DETER motion detection algorithm is based on a multi-Normal mixture model that is updated dynamically. The update mechanism is based on the incoming evidence (new camera frames). Several things could change during an update cycle:

1. The form of some of the distributions could change (weight π_i, mean μ_i, and variance σ_i^2).
2. Some of the foreground states could revert to background and vice versa.
3. One of the existing distributions could be dropped and replaced with a new distribution.

At every point in time the distribution with the strongest evidence is considered to represent the pixel's most probable background state. Figure 5 presents a visualization of the mixture of Normals model while Figure 6 depicts the update mechanism for the mixture model.

The update cycle for each pixel proceeds as follows:

1. First, the existing distributions are ordered in descending order based on their weight values.
2. Second, the algorithm selects the first B distributions that account for a predefined fraction of the evidence T: $B = \arg\min_{b} \left\{ \sum_{i=1}^{b} w_i > T \right\}$, where $w_i, i = 1...b$ are the respective distribution weights. These B distributions are considered as background distributions while the remaining $3-B$ distributions are considered foreground distributions. We have experimentally established that the optimal value for threshold T is $T = 0.80$.
3. Third, the algorithm checks if the incoming pixel value can be ascribed to any of the existing Normal distributions. The matching criterion we use is the Jeffreys (J) divergence measure [12] and is a key differentiator of our approach from other similar approaches.
4. Fourth, the algorithm updates the mixture of distributions and their parameters. The nature of the update depends on the outcome of the matching operation. If a match is found, the update is performed using the method of moments [13]. This is also a key differentiator of our approach. If a match is not found, then the weakest distribution is replaced with a new distribution. The update performed in this case guarantees the inclusion of the new distribution in the foreground set, which is another novelty of our method.

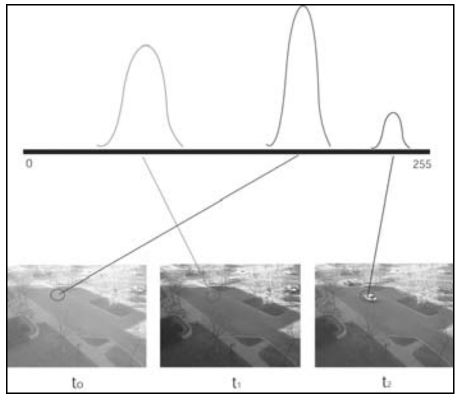

Figure 5: Visualization of the mixture of Normals.

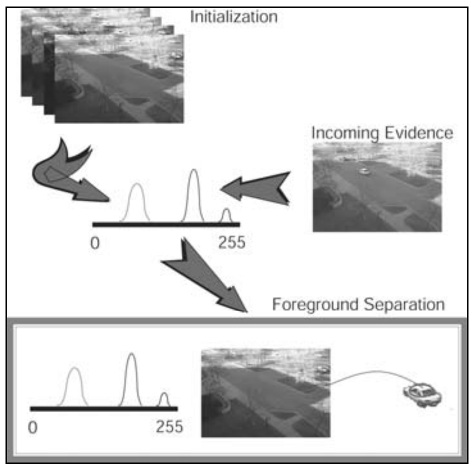

Figure 6: Visualization of the mixture model update mechanism.

5.2 Tracking Algorithm

In the previous section we described a statistical procedure to perform on-line segmentation of ***foreground pixels*** corresponding to moving objects of interest, i.e. people and vehicles. In this section, we describe how to form trajectories traced by the various moving objects. Figure 7 shows a snapshot of the output from the various computer vision modules of DETER. The basic requirement for forming object trajectories is the calculation of blob centroids (corresponding to moving objects). Blobs are formed after we apply a standard 8-connected component analysis algorithm to the foreground pixels. The connected component algorithm filters out blobs with area less than $A = 3 \times 9 = 27$ pixels as noise. According to our optical computation this is the minimal pixel footprint of the smallest object of interest (human) in the camera's FOV.

A ***Multiple Hypotheses Tracking (MHT)*** algorithm [14] is then employed that groups the blob centroids of foreground objects into distinct trajectories. MHT is considered to be the best approach to multi-target tracking applications. It is a recursive Bayesian probabilistic procedure that maximizes the probability of correctly associating input data with tracks. Its superiority against other tracking algorithms stems from the fact that it does not commit early to a trajectory. Early commitment usually leads to mistakes. MHT groups the input data into trajectories only after enough information has been collected and processed. In this context, it forms a number of candidate hypotheses regarding the association of input data with existing trajectories. Figure 8 depicts the architecture of our MHT algorithm.

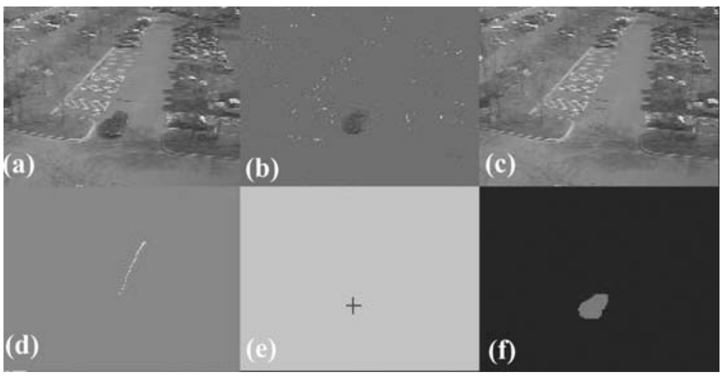

Figure 7: Visualization of the computer vision operation of DETER. (a) Live video feed. (b) Segmented moving object. (c) Dynamically updated background.(d) Trajectories of the current moving objects. (e) Centroids of the moving objects. (f) Results of the blob analysis.

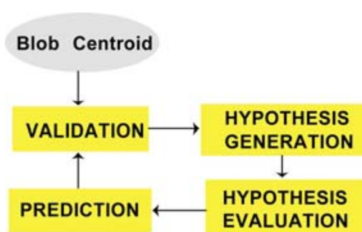

Figure 8: Architecture of the MHT algorithm.

6. *Ongoing Work*

We are currently working on expanding the baseline air-intake system we have developed so far. We focus our efforts into two areas: a) enhancement of the video-based surveillance system and b) incorporation of additional layers of protection as described in Section 3.

The primary flaw of our current video-based surveillance system is that it does not perform any sort of substantial threat assessment. Whenever it detects motion it alerts the guard but it cannot differentiate between different types of motion. For example, the level of threat when a person passes by the vicinity of air-intakes on his way to his vehicle is trivial. But, the threat becomes significant when a person stops near the air-intakes, starts unpacking things, and finally he goes away leaving some "stuff" behind him. Therefore, we are working on designing a computer vision algorithm that will comprehend "preparation" type activities and scenes involving people leaving objects behind them.

To the question if the enhanced threat assessment system should issue a shut down order to the air-handler without waiting for the operator's assessment we respond by the development of a two-fold strategy. If the confidence from the threat assessment module is high and the environmental conditions are accommodating to a chem-bio attack, the video surveillance system will issue a shut down order before consulting with the operator or sampling the chem-bio sensors. Otherwise, the shutdown will be delayed until the operator and the chem-bio sensors weigh into the decision.

General environmental conditions in the area mean very little for this application. What matters is very localized information. This includes the wind speed and direction, the amount moisture in the air, and the temperature in the immediate vicinity of the air-intakes. The only way to continuously acquire this information in order to make real-time decisions is by incorporating into the system a computerized weather station.

Acknowledgements

We kindly acknowledge the contribution of Dr. Morellas in the tracking algorithm of DETER.

References

[1] *Countering Biological Terrorism in the U.S.: An Understanding of Issues and Status*, Siegrist D.W. and Graham J.M. Editors, **Oceana Publications**, Dobbs Ferry, New York, 1999.

[2] *Witness: Terrorists Train with Poison*, **Associated Press**, September 26, 2001.

[3] *Threats in Bioterrorism I: CDC Category A Agents*, R.G. Darling, C.L. Catlett, K. D. Huebner, and D.G. Jarrett, **Emerg. Med. Clin. N. Am.** , Vol. 20, pp. 273-309, 2002.

[4] *Threats in Bioterrorism II: CDC Category B and C Agents*, G.J. Moran, **Emerg. Med. Clin. N. Am.**, Vol. 20, pp. 311-330, 2002.

[5] *Germs. Biological Weapons and America's Secret War*, Miller, J., Engelberg, S., and Broad, **W. Simon and Schuster Publications**, New York, 2001.

[6] *Anthrax as a Biological Weapon, 2002. Updated Recommendations for Management***,** T.V. Inglesby, et al., **JAMA**, Vol. 287, pp. 2236-52, 2002.

[7] *Mechanisms of Microbial Disease*, Schaechter, M., Medoff, G., and Eisenstein, **B.I. Williams and Wilkins**, Baltimore, 1993.

[8] *Bacterial Pathogenesis. A Molecular Approach*, Salyers, A.A. and Whitt, D.D., **ASM Press**, Washington, D.C., 1994.

[9] *Killer Germs. Rogue Diseases of the Twenty-First Century*, Moore, **P. Carlton Books Limited**, London, 2001.

[10] *Biological Terrorism: Understanding the Threat, Preparation, and Medical Response*, D.R. Franz and R. Zajtchuk, **Dis. Mon.**, Vol. 48, pp. 493-564, 2002.

[11] *Urban Surveillance Systems: From the Laboratory to the Commercial World*, Pavlidis I., Morellas V., Tsiamyrtzis P., and Harp S., **IEEE Proceedings,** Vol. 89, No. 10, pp.1478-1497, October 2001.

[12] *Theory of Probability*, H. Jeffreys, **University Press**, Oxford, 1948.

[13] *Mixture Models Inference and Applications to Clustering*, G.J. McLachlan and K.E. Basford, **Marcel Dekker**, New York, 1988.

[14] *An Efficient Implementation of Reid's Multiple Hypothesis Tracking Algorithm and Its Evaluation for the Purpose of Visual Tracking*, I. J. Cox and S. L. Hingorani, **IEEE Transactions on Pattern Analysis and Machine Intelligence**, 18, 138--150, 1996.