Aerial surveillance vehicles augment security at shipping ports

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ABSTRACT

With the ever present threat to commerce, both politically and economically, technological innovations provide a means to secure the transportation infrastructure that will allow efficient and uninterrupted freight-flow operations for trade. Currently, freight coming into United States ports is "spot checked" upon arrival and stored in a container yard while awaiting the next mode of transportation. For the most part, only fences and security patrols protect these container storage yards. To augment these measures, the authors propose the use of aerial surveillance vehicles equipped with video cameras and wireless video downlinks to provide a birds-eye view of port facilities to security control centers and security patrols on the ground. The initial investigation described in this paper demonstrates the use of unmanned aerial surveillance vehicles as a viable method for providing video surveillance of container storage yards. This research provides the foundation for a follow-on project to use autonomous aerial surveillance vehicles coordinated with autonomous ground surveillance vehicles for enhanced port security applications.

Keywords: Aerial Surveillance Vehicles, Ground Surveillance Vehicles, Port Security, Unmanned Vehicles, Autonomous Vehicles

1. INTRODUCTION

In Fiscal Year 2005, United States Customs and Border Protection processed 20 million sea, truck, and rail containers entering the United States and 29 million trade entries [1]. These vast numbers of sea, truck, and rail containers pose a tremendous security risk both from an economical and political perspective. With as many as 30,000 containers entering the United States every day, physical inspection of all cargo would effectively shut down the entire U.S. economy, with ripple effects far beyond the seaports [2].

1.1 History

After September 11, 2001 the United States government took measures to enhance security at port facilities. There are 361 public ports in the United States through which 95 percent of the overseas trade passes [3]. The Maritime Transportation Security Act (MTSA) was passed in November 2002 which recognized that ports "are often very open and exposed and susceptible to large scale acts of terrorism that could cause a large loss of life or economic disruption [3]." One of the technological advances required by this act was the development of an Automatic Identification System (AIS) that provided vessel identification and location information to port authorities for ships operating in the navigable waters of the U.S. This constant monitoring provides some level of security for ships while under sail.

Currently, freight coming into U.S. ports is "spot checked" upon arrival and stored in a container yard while awaiting the next mode of transportation. The unloading, staging, and storage of these containers require fleets of trucks, large areas of land for staging and storage, and countless numbers of transportation and security personnel to move and secure these containers. Today, video surveillance, vehicle detection, fences and gates, and foot patrols are the usual means for securing the port facilities. Through the creative use of technological innovations, more effective means to secure the transportation infrastructure can be achieved that will allow efficient and uninterrupted freight-flow operations for trade. This research will demonstrate the use of available off-the-shelf technology to provide advanced capabilities that will enhance port security.

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Fig. 1. Port of Philadelphia and adjoining CSX rail yard. Location 1 is the dock area for ship loading and unloading, location 2 is the container staging area where containers are stored awaiting pick-up, location 3 is the CSX container storage area where containers are picked-up or dropped-off as needed by rail operations, and location 4 is the CSX rail line used for loading the train cars and building trains for departure [source of aerial photo – Google Earth].

2. CURRENT PORT SECURITY MEASURES

Large ports, like the Port of Philadelphia shown in Figure 1, encompass large areas of land for the staging and storage of containers and other freight that are off-loaded from international carriers for U.S. consumption. The distance from the dock where the containers are off-loaded (Figure 1, location 1) to the point where they are loaded onto trains for shipment (Figure 1, location 4) is greater than 2 miles (3.2 km). In Mega ports like the Port of Long Beach, the distance could be greater than 4 miles (6.4 km). This distance is significant because this area is also used for the staging and storage of these containers (Figure 1, location 2 and 3, respectively). Therefore, most ports encompass a large physical area to keep secure while enabling the safe and efficient movement of goods.

2.1 Fences and gates

The first line of defense for any security measure is physical security. Fences and gates provide basic physical security, but there is not a means to detect breaches of these deterrents by themselves. Technology exists for passive monitoring of perimeters through the use of motion detection or similar devices, but these are not fool proof and therefore easily defeated.

2.2 Foot patrols

Roaming security patrols driving around in vehicles or on foot provide additional security measures. The frequency of these patrols and their routine can be calculated through observation and therefore overcome with time. Response from roaming patrols is faster than waiting to be dispatched, but still not entirely effective.

2.3 Cameras

Traditionally, video surveillance systems require many cameras to cover large areas, requiring large networks and great computation and manpower to analyze [4]. These cameras are either fixed or pan-tilt-zoom (PTZ) cameras, and they are either analog video or Internet Protocol (IP) encoded video. All the camera video is fed to a central security center for display on a single monitor or at best, a video wall. These camera systems provide situational awareness over a vast area and require constant monitoring by trained personnel. This process of manually monitoring many cameras is tedious, ineffective, and expensive [5]. Fixed cameras provide a "quick glance", but the effective operation of a PTZ camera would require the operator to control the camera while viewing the video, this is less effective since the operator is not able to view other camera feeds simultaneously. Automatic panning of cameras provides some relief, but over time, moving images blur and become less effective to the operator or observer if not focusing on the video image. There is an urgent need for enhanced computational capability to keep pace with the many "eyes" that are being installed and their required analysis [6].

2.4 Vehicle detection

Technology advances over the past several years have enabled vehicle detection and recognition to play a bigger part in security. The use of vehicle detectors: pavement loops, X-Band RADAR traffic detectors, and video detection, is well suited for traffic signal timing and sequencing based on vehicle presence and therefore useful for monitoring vehicle entry and exit at port facilities. These triggers can signal the security officer to train their attention to a particular video display when a vehicle presence has been detected.

3. PROPOSED ENHANCEMENTS TO PORT SECURITY MEASURES

Fences and gates, foot patrols, cameras, and vehicle detection are the mainstays of port security measures. The next logical step is to enhance these capabilities using existing technology. Computational capabilities have increased to allow for near real-time video image processing. Research into tracking, correlation, and identification of targets using fixed and mobile cameras has produced quantifiable results [7]. With this ever improving video surveillance capability, proper care must be taken to protect the rights of the people under surveillance. This imaging capability is a source for great public concern over personal privacy and loss of control of the information leading to potential negative use (i.e., voyeurism, espionage, oppression, etc.) [8].

3.1 Fixed and PTZ video cameras

The use of video to secure shipping ports is essential. Situational awareness of the vast staging and storage areas is time consuming and manpower intensive and leads to missed opportunities for detection and interdiction. Through the use of adaptive surveillance, selecting the right mix of cameras, angles, and Field-Of-View (FOV) is the first step. Employing object detection and tracking, object and color classification, alert definition and detection, database event indexing, and search and retrieval will enable the cameras used for security to be 'smart, useable, and scalable' [9]. Replacing older low resolution cameras with high-definition cameras will greatly improve the detection capabilities and require fewer cameras to cover the same area by increasing resolution at greater distances while zooming. Infra-Red (IR) cameras provide a whole new capability for surveillance and detection by turning night into day for the observer. Military applications of target detection and tracking using IR capabilities in missile seekers have been used for many years effectively.

3.2 Video detection and tracking

Video detection and tracking offer many security enhancements to existing camera security measures by reducing the workload on security personnel. This workload reduction is accomplished by alerting and identifying them to activity of interest and training them to that activity through camera selection for video display and highlighting. For this paper, we will define video detection and video tracking as follows: Video detection is the ability to identify objects in images that appear or disappear from selected areas of interest. Video tracking is the ability to locate and highlight objects that move with respect to the background. Video detection and tracking will be an area of further research in the next phase.

Current research is being done on the process of acquiring video through different inputs and detecting stationary and moving objects present in different video frames. Vehicles and pedestrians are important objects to detect and identify when it comes to port security. A multi-object detection approach [7] uses a multi-view/multi-category object recognition detector to detect vehicles and pedestrians in video images. For every frame, model selection is performed to achieve tracking of moving objects. In the research performed by B. Leibe [7], two scenarios are explored: a typical surveillance-type scenario with fixed camera installations and a mobile scenario where the video is coming from the inside of a moving vehicle.

Another approach shows the development of an object tracking algorithm which is based on Bayesian estimation of dynamic layer representation [10]. These layers are extracted from real-time aerial and ground video to track vehicles and pedestrians. An object is found in one of five cases: new object appearance, object disappearance, moving object, stationary object, or occluded object. Extensive experimentation shows that the system provides good confidence and ability in detecting several objects simultaneously.

In the work performed by B. Nelson [11], the use of more than one camera to collect the input video recordings was investigated. A multi-camera system was designed for the purpose of tracking people and their normal and abnormal trajectories. Background suppression and an appearance-based probabilistic approach were used for the purpose of detection and tracking. Two types of cameras were used, both fixed and Pan-Tilt-Zoom cameras. The classification of person or not person is determined using background suppression that analyzes the geometric shape and size of the moving objects.

Vehicle detection studies vary in the use of technology and the mathematical analysis used for image processing. In [12], automatic vehicle detection can be achieved using infrared sensors that capture a binary image. This image is then processed and chopped into several segments. The segments are differentiated according to their histograms; if the histograms show a considerable number of pixels above a defined threshold then the corresponding image probably contains the target. A fuzzy inference system then uses the feature sets given by the histograms to output a target confidence value.

In [13], automatic vehicle detection is characterized through statistical approaches that are based on local features found in the image. This novel approach shows great tolerance to geometric variances and partial occlusions which degrade the detection process.

3.3 Aerial video surveillance

As early as 1849 when Colonel Laussedat of the French Army Corps of Engineers [14] used aerial imagery for topographic map development, kites and balloons have been used to take cameras into the air. This birds-eye view has also proven useful for surveillance since World War I. Past uses of aerial imagery have used still cameras using film and lately using digital photography. This process requires collecting many frames of information for later analysis by people scanning and viewing the images looking for small changes or objects that look out of place.

Modern surveillance utilizes Moving Target Indicator (MTI) ground surveillance Radar and/or Synthetic Aperture Radar (SAR) platforms and processing capabilities. MTI and SAR platforms are multi-million dollar ventures reserved for military applications and out of the reach of local or regional port authority budgets. Recent advances in video camera technology are producing higher quality images in smaller cheaper cameras. The Sony HDR-CX12 is an example of a 1080p high-definition video camera weighing only 450 grams [15]. This camera has a 12X optical zoom, image stabilization, internal flash memory storage, and external output for connection to a video transmitter for real-time video downlink.

Much research has been accomplished that validates the hypothesis that aerial video surveillance and autonomous aerial vehicles can be combined as a viable option to MTI and SAR systems for applications where speed, accuracy, and low cost are program requirements. The work done by R. Kumar, et al. [16] defined an integrated aerial video surveillance system as one utilizing an Unmanned Aerial Vehicle (UAV) and would require sensors and processing components on-board the UAV and additional processing and displays at an operator control station on the ground. These requirements would make the size and power requirement of the UAV large and more costly but certainly applicable to military applications as they intended.

There are three basic modes of flight for aerial vehicles: manual, semi-autonomous, and full-autonomous. Manual control of an Aerial Surveillance Vehicle (ASV) would require less computational power than that proposed by Kumar while still providing the birds-eye view desired for aerial surveillance. Manual control, however, would require a certain level of pilot competency to control the ASV and maintain stable video on the area of interest. A combination of manual control coupled with an autonomous flight control system should reduce the training and proficiency necessary to accomplish the surveillance mission. This semi-autonomous aerial video surveillance vehicle with video downlink capability is what is proposed and demonstrated by this research. The application of detection and tracking capabilities, coupled with full-autonomous flight where the ASV is controlled by the detection and tracking system, are areas for further research and demonstration.

4. DEMONSTRATION PROJECT

This demonstration is designed to show the use of available off-the-shelf technology to augment security measures at a port facility. We will demonstrate the use of a semi-autonomous ASV equipped with a high-definition video camcorder and wireless video downlink to provide a birds-eye view of the port facility to security control center and security patrols on the ground.

4.1 Tulsa Port of Catoosa

The Tulsa Port of Catoosa shown in Figure 2, near Tulsa, Oklahoma is located on the McClellan-Kerr Arkansas River Navigation System. This system is a 440-mile waterway linking Oklahoma and the surrounding five-state area with ports on the nation's 25,000-mile inland waterway system, and foreign and domestic ports beyond by way of New Orleans and the Gulf Intracoastal Waterway. Because of its south central location, the waterway is operational year-round, regardless of weather conditions. The waterway travels 445 miles along the Verdigris River, the Arkansas River, the Arkansas Post Canal and the White River before joining the Mississippi at Montgomery Point. New Orleans is 600 miles south. There are 18 locks and dams on the McClellan-Kerr. Each of these dams creates a reservoir, or what is called a navigation pool. The system of locks and dams can be likened to a 440-mile staircase of water. In an average year, 13-million tons of cargo is transported on the McClellan-Kerr by barge. This ranges from sand and rock to fertilizer, wheat, raw steel, refined petroleum products and sophisticated petrochemical processing equipment.

Fig. 2. Port of Catoosa. Location 1 is the dock area for ship loading and unloading, location 2 is the Port Headquarters Building and Helipad, location 3 is the Container Storage Yard Demonstration Area, and location 4 is the Card Gate for truck entry and exit. All four locations are equipped with a wireless mesh network for data and video demonstrations [source of aerial photo – Google Earth].

4.2 The aerial surveillance vehicle

The ASV platform shown in Figure 3, is an Express G from Neural-Robotics, Inc., and is based on a gas-powered Vario Benzin Trainer helicopter. The ASV is capable of carrying ten pounds of payload for 60 minutes. The operator transmitter/controller is a Futaba 9C Super operating at 72 MHz. The ASV includes basic avionics components consisting of a PC/104 computer running the guidance and control software, an Attitude and Heading Reference System (AHRS), a Global Positioning System (GPS) receiver, and a heading-hold gyro. The standard off-the-shelf transmitter (the Futaba 9C Super), included with the basic system, is used as the ground controller for manual mode operation. A laptop, which runs the Ground Control System (GCS) software, is coupled with a joystick and a 900 MHz spread-spectrum (frequency hopping) modem shown in Figure 4, and provides semi-autonomous and full-autonomous flight capabilities. The camera gimbal is the E4 model from Helicam Solutions with retractable landing gear and gyro stabilized pan and tilt capability. The camera gimbal is controlled by an RC controller which is a Futaba 6EX operating at 2.4 GHz. The video camcorder is a Sony HDR-CX7 providing 1080p high definition video with internal flash memory storage and composite video output. The camcorder is connected to a RangeVideo 900 MHz FM video transmitter for downlink to the ground control station. At the ground control station, the video is encoded and connected to the wireless network allowing video access to security personnel.

4.3 Manual control of the aerial surveillance vehicle

In the manual flight control mode, the helicopter is simply a remote controlled vehicle. Pilot proficiency and situational awareness play a key role in the safe takeoff, flight, and recovery of the vehicle. Using the supplied RC controller, throttle, pitch, roll, and yaw can be controlled by the two joysticks to maneuver the helicopter to takeoff, fly to the designated area, hover, return, and land. In this mode, the helicopter requires constant operator input to maintain stable hover, thus requiring a second operator to control the video gimbal and camera. An additional RC controller is used to manually steer the gimbal mounted camcorder to provide the desired view with pan and tilt commands.

Fig. 3. The Aerial Surveillance Vehicle used for the demo project. A Vario Benzine trainer equipped with Global Positioning System, Altitude and Heading Reference System, Global Positioning System, modem, and Camera Gimbal.

Fig. 4. The ground control station for semi-autonomous and full-autonomous flight control of the aerial surveillance vehicle. The laptop communicates joystick inputs to the Aerial Surveillance Vehicle through a modem. Live video from the Aerial Surveillance Vehicle is transmitted to the ground control station monitor for viewing.

4.4 Autonomous control of the aerial surveillance vehicle

There are two modes of autonomous flight control, semi-autonomous and full-autonomous. Full-autonomous flight is accomplished without operator intervention after takeoff, while semi-autonomous requires basic operator input (or "direction") throughout flight.

In the semi-autonomous mode, the ASV is self-stabilized using neural network-based flight control algorithms and inputs from the on-board avionics. In this mode, the GCS joystick provides basic high level flight control commands to the ASV such as; up, down, rotate left, rotate right, forward, and backward. The attitude and stability of the ASV is controlled by the onboard avionics and sensor suite. This is the mode that is demonstrated since it provides the most flexibility and ease of use in situations where situational dynamics are unknown (e.g., flight paths, areas of interest, and targets are dynamic based on the situation).

For the fully-autonomous flight mode, the ASV utilizes a GPS waypoint flight plan, where the operator uploads a flight plan to the ASV via a laptop computer, using GPS waypoints. In this mode, the operator starts the ASV, engages the Flight Control System (FCS), commands the ASV to take off and turns all flight operations over to the FCS. The operator can regain manual control of the ASV at any time by going back to the semi-autonomous mode. If the ASV flies out of RC range, the onboard avionics will turn the helicopter around and come back within range automatically.

5. RESULTS

The integration of the camera gimbal and helicopter provided a stable platform for demonstration of aerial video surveillance. Frequency conflicts between the ground control station and the video down link were quickly resolved with smart channel selection. RC controller conflicts with the NovAtel GPS receiver were catastrophic until it was realized that the GPS receiver sensitivity was such that during alignment, the RC controller, operating at 72 MHz prevented the GPS receiver from finding satellites. By having the operator maintain an acceptable distance from the ASV during the alignment process, this problem was quickly resolved.

In manual flight mode, the ASV performed as expected, constant operator input was required to maintain stable flight and hover. The gyro stabilized camera gimbal compensated for most ASV flight instability and produced acceptable video quality. Camera control was accomplished by a second operator. Figure 5 shows still images from the camcorder during manual flight. Image quality and resolution were adequate for security personnel to identify objects and individuals in the down linked video on the monitor.

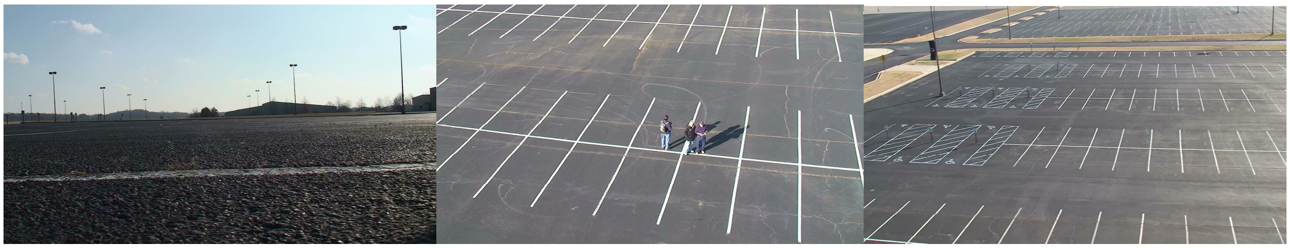

Fig. 5. Images from the video camcorder mounted on the gimbal below the aerial surveillance vehicle in manual flight mode. The left image is while the ASV is idling on the ground. The center image is at 60 feet (18.3 meters) and 45 degrees of down camera angle. The right image is at 60 feet (18.3 meters) and 15 degrees of down camera angle. The images are still images from the recorded video file.

In the semi-autonomous flight mode, the ASV performed flawlessly and helicopter control from the GCS was straight forward. After arriving at the point of interest, releasing the joystick provided a stable hover through the FCS. Camera control was easily accomplished by use of the second controller while viewing the video on the GCS monitor. This video was encoded and transmitted over the wireless network and displayed at the security control center. During semi-autonomous flight, the camcorders optical zoom capability provided the ability to resolve license plate numbers, container numbers and the security personnel were able to identify personnel at the demonstration area. Optical zoom has a negative effect by reducing the field-of-view producing the "soda straw" effect. This effect described in Kumar [16] and others, requires constant attention as objects of interest quickly move into and out of the image. Figure 6 shows images captured from the camcorder during semi-autonomous flight of the ASV.

Fig. 6. Images from the video camcorder mounted on the gimbal below the aerial surveillance vehicle in semi-autonomous flight mode. The left image is while the ASV is idling on the ground. The center image is at 40 feet (12.2 meters) and 45 degrees of down camera angle. The right image is at 30 feet (9.1 meters) and 15 degrees of down camera angle. The images are still images from the recorded video file.

6. CONCLUSIONS

Today, fences and gates, video cameras, and security patrols protect the container storage yards of our ports. With the use of off-the-shelf technology, port security personnel can be provided with tools to enhance their capability. High definition video cameras and Infra-Red video cameras should replace existing low resolution cameras. In the near future, 'smart' surveillance capabilities will become available to analyze video to reduce the workload. This research has demonstrated the use of aerial surveillance vehicles equipped with video cameras and wireless video downlinks to provide a birds-eye view of port facilities to security control centers and security patrols on the ground. This off-the-shelf capability can enhance existing security measures and help secure the port facilities. Future research is planned to link the full-autonomous flight capabilities of the ASV with GCS based object tracking and to provide interaction with other ground surveillance vehicles for autonomous surveillance.

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