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Innovations Deserving
Exploratory Analysis Programs

Transit IDEA Program

Bandwidth Expansion and Real-Time Surveillance for Security on Transit Buses

Final Report for Transit IDEA Project 37

Prepared by:
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Pittsburgh, PA

May 2005

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Innovations Deserving Exploratory Analysis (IDEA) Programs Managed by the Transportation Research Board

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Transportation Research Board
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Final Report

Transit IDEA Project TRANSIT-37

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Acknowledgement

We are deeply indebted to all participants of this Transit IDEA project 37. Special thanks go to Professors Dan Stancil and Mel Siegel of Carnegie Mellon University for their expertise and guidance, and to Richard Schneider, Vehicle Procurement Specialist, Paul Skoutelas, CEO, William McArdle, Chief Police Officer, and John Koenig, Manager of Bus Maintenance Support at the Port Authority of Allegheny County, Pittsburgh, PA, for their participation in design, test and review of the progress reports. We appreciate the contract funding from Transit IDEA Program of the Transportation Research Board (TRB). We especially thank Senior Program Officer Harvey Berlin of TRB for his guidance and support throughout the period of this project.

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Executive Summary

The purpose of this project was to develop a real-time video surveillance technology for enhanced security on transit buses. The system uses digital cameras on buses, and adds a broad-bandwidth wireless network modem and software to expand the bandwidth for the wireless transmission of streaming digital video. This project was carried out by Carnegie Mellon University, with participation by the Port Authority of Allegheny County, the major transit operating agency in Greater Pittsburgh, PA.

From the field tests and analysis, the investigators found that the system design is feasible and economical. The prototype system can transfer the digital video at resolution 640 x 480 at a speed of more than one frame per second. Based on existing wireless hot-spots in an urban area, the prototype system can transfer video to a server on Internet. Users can view the video on a computer with a web browser. Our experiments also show that at the speed of 1 frame per second (fps), the wireless network used less than 25% of connection capacity. The speed and format of video are compatible with what the Port Authority of Alleghany is using.

The investigators also tested the system at clear weather and raining weather conditions and data recovering from interruptions and obtained satisfactory results. The tests also showed that the 'line-of-sight' of the wireless signal is more important than distance, which was an original concern. This finding is useful in designing the wireless antenna and determining locations of the wireless repeaters.

It is estimated that the cost for installing the access-points along the route can be around \$0.40/meter to \$1.00/meter. In many large cities, such as Boston, WiFi will cover the whole city. Therefore, it is possible to obtain free wireless accesses. In addition, the system can adapt the facial recognition algorithm to live video streams from transit buses.

Background

Terrorist attacks on transit systems have increased worldwide during the past decade. The tragic events of Sept. 11 and the continuing threat of terrorism prompted U.S. transit agencies to take stock of their security procedures and prepare for future potential security situation.

In this project, we developed wireless real-time video surveillance technologies for security on transit buses. The system will expand the bandwidth of the wireless transfer of digital video. It includes a broad bandwidth network radio modem (with the new IEEE standard 802.11b), an affordable digital camera, a wavelet-based video compression algorithm and unique user interface software for application to transit buses. The system addresses appropriate standards, such as IEEE. Many transit vehicles have installed on-board video recording systems. While those systems may help to track crimes and incidents, the video surveillance systems are limited, as on-board recording and do not have real-time wireless monitoring and alert functions. Our system would have such real-time monitoring functions. We would develop a low cost technology for bus transit systems in metropolitan areas. The system won't require expensive equipment and components.

A few organizations have been trying to develop remote video surveillance technologies for transit vehicles, for example Bombardier and Washington Metropolitan Area Transit Authority. Some technologies have been explored, such as the "leaky line" based transmission, induction-based transmission, etc. They were mainly for underground subway trains. Experiments have shown the weaknesses of current approaches, for example, too expensive, low bandwidth, poor video quality, unstable signals, etc. For open air and above ground video transmission from buses, there are more factors to consider, such as obstacles and noises, etc.

The purpose of this project was to develop a real-time video surveillance technology for enhanced security on transit buses. The system uses digital cameras on buses and adds a broad-bandwidth wireless network modem and software to expand the bandwidth for the wireless transmission of streaming digital video. This project was carried out by Carnegie Mellon University, with participation by the Port Authority of Allegheny County, a major transit operating agency in Greater Pittsburgh.

1. Data Interface Design

1.1 Video Stream Data Format

The investigators have discussed with Port Authority of Allegany County staff the current data format and designed a data interface that is compatible with the available data. At this stage, we use an image size of 640 x 480 pixels, RBG color images with JPEG 2000 compression format.

There are two major methods for digital video streaming: 1) individual frame based and 2) continuous streaming based. Frame based video has been widely used in surveillance systems, which provides clear still images at any given time. However, it is not compressed over time and not optimized for network bandwidth, especially the wireless network based video stream. The continuous video streaming methods, such as MPEG-4, normally are compressed over time for optimal networking bandwidth. However, the quality of individual images at any given time is not guarantied. Under the

condition of the low frame rate streaming, the individual frame based method is actually more efficient than continuous video streaming methods, in terms of networking bandwidth and image quality.

To prove this theory, the investigators setup a set of empirical experiments in the laboratory environment at Stage II. The following cases were studied: continuous video stream with MPEG-4 format over Internet, individual frame based image streaming over Internet with the frame rate at 1fps (frame per second), 4 fps, 8 fps, and 16 fps.

Table 1. Continuous Video Streaming vs. Individual Frame Streaming

	Continuous	**1 fps**	**4 fps**	**8 fps**	**16 fps**
Average network traffic load per connection	17.51%	10%	12.68%	19.8%	20%

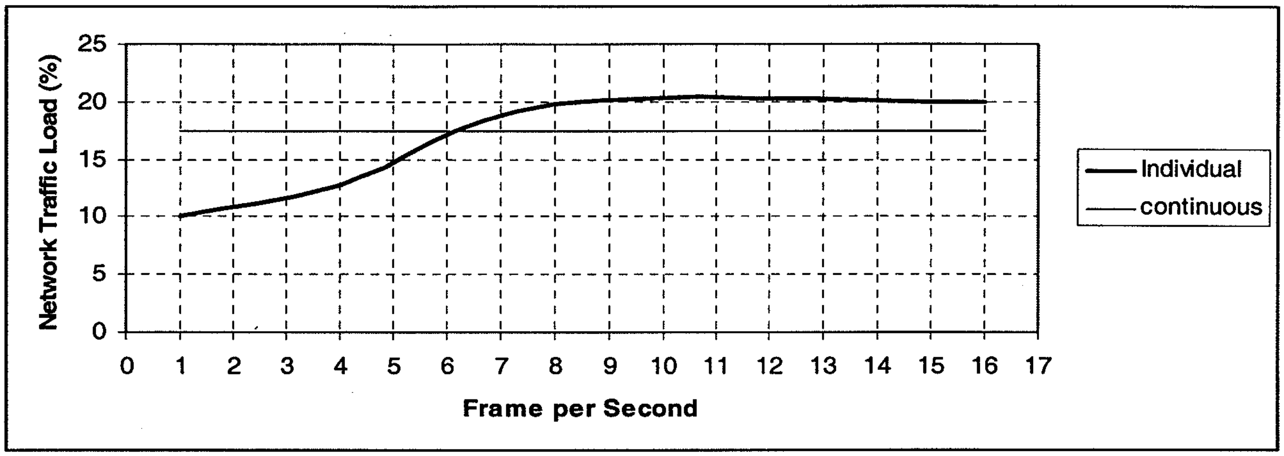

Figure 1. Continuous Video Streaming vs. Individual Frame Streaming

From the empirical experiments, it was found that the individual frame streaming is actually more efficient than the continuous video streaming at a frame rate between 1 fps and 6 fps. This frame rate is compatible to the current frame recording speed for the systems on the Port Authority's buses: 1 frame per second. Therefore, one frame per second individual frame streaming is recommended for the video streaming format.

1.2 Wireless Connection Architecture

There are two major wireless connection approaches: 1) "hot-spots" (client-server), and 2) "ad-hoc". The "hot-spots" based connection uses available 802.11 wireless servers in a metropolitan area. The advantage of this method is that it needs less investment in wireless network infrastructures. However, it is also limited by the available technologies and locations at the hot spots. For example, most of current hot-spots use an 802.11b connection rather than the newest standard 802.11g. Also, hot-spots are normally not available in rural areas. On the other hand, the "ad-hoc" method is more flexible in terms of technology upgrading and locations. No network server is needed for ad-hoc communication. However, an ad-hoc connection needs additional traffic management software to maintain the optimal data flow. To develop such kind of wireless network protocol software can be very expensive and is beyond the scope of this project.

1.2.1 The 'Hot-Spot' Connection

The 802.11b connection is used as a test network infrastructure because the 'hot spots' service is available on the campus of Carnegie Mellon University. The system is illustrated in Figure 2. In this design, the buses communicate with the central control station with WiFi connections via 'hot spots.' Those hot-spots transfer the data to a data server on Internet. With regular Internet browsers, users can view the video in real-time. In addition, the facial recognition software can automatically monitor the video stream and detect any suspected subjects.

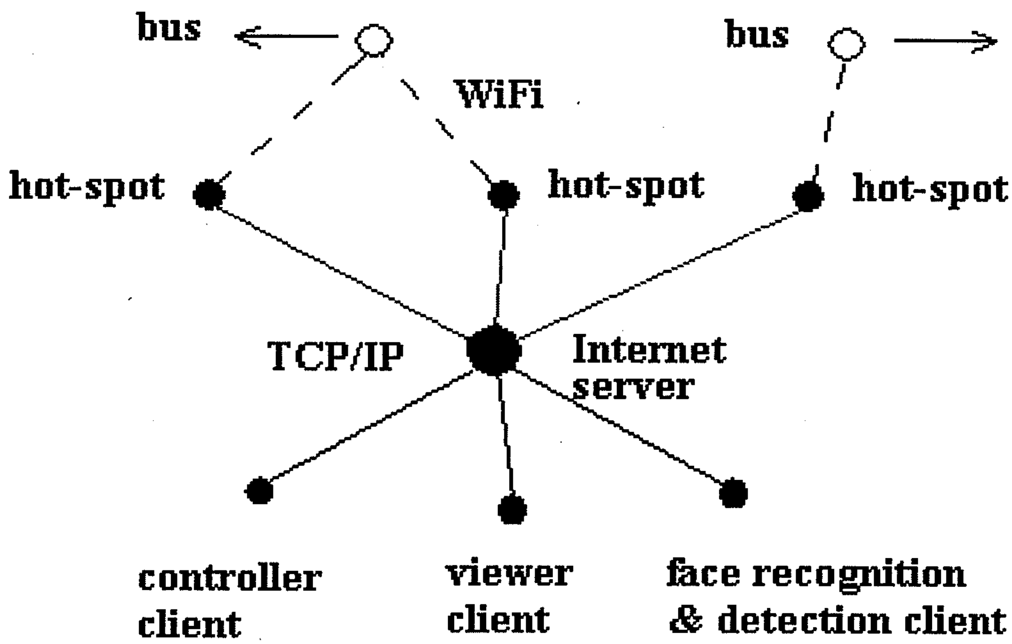

Figure 2. Network Connection Architecture

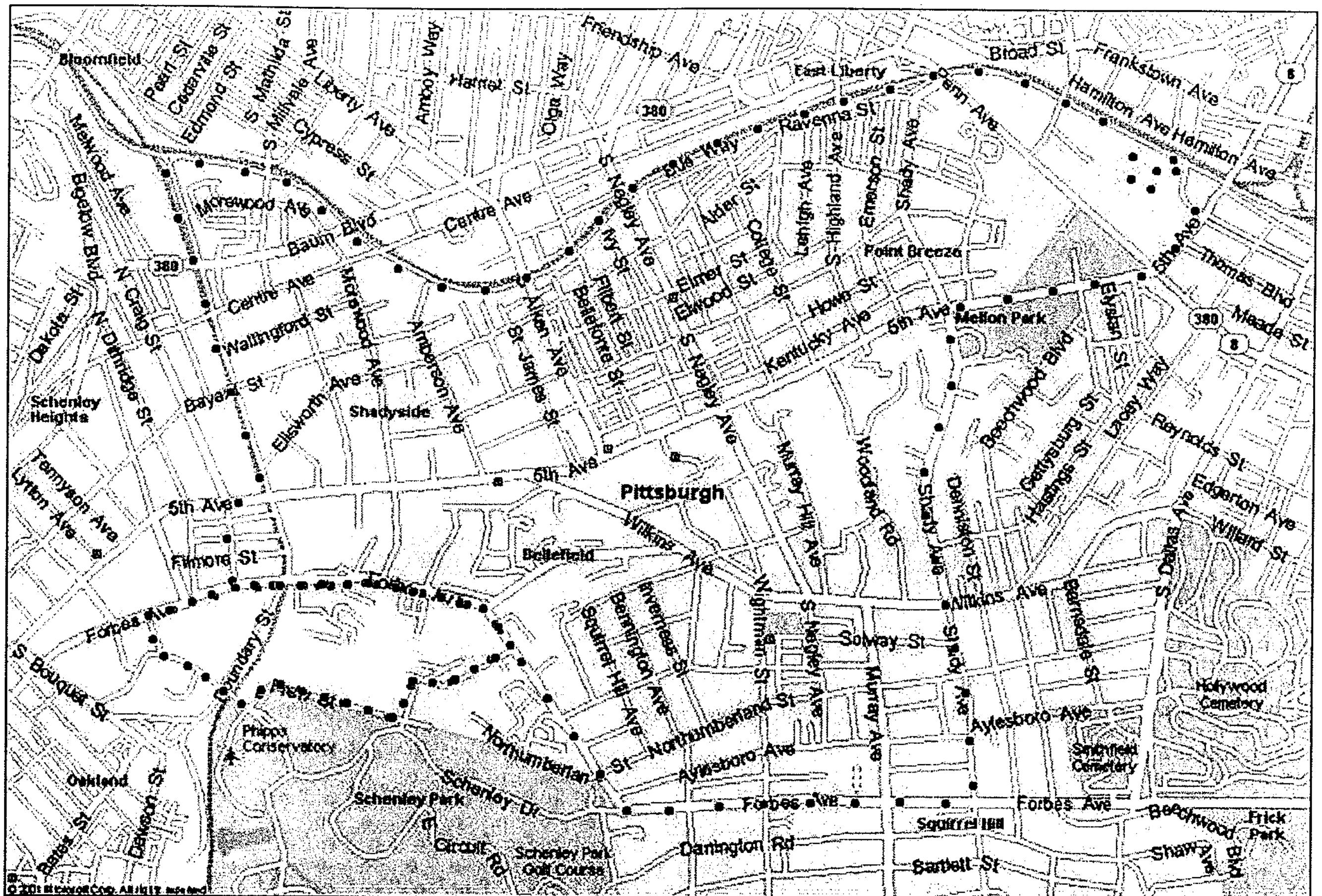

Figure 3. Test Route Around Carnegie Mellon Campus. The black Dots Represent the Bus Path

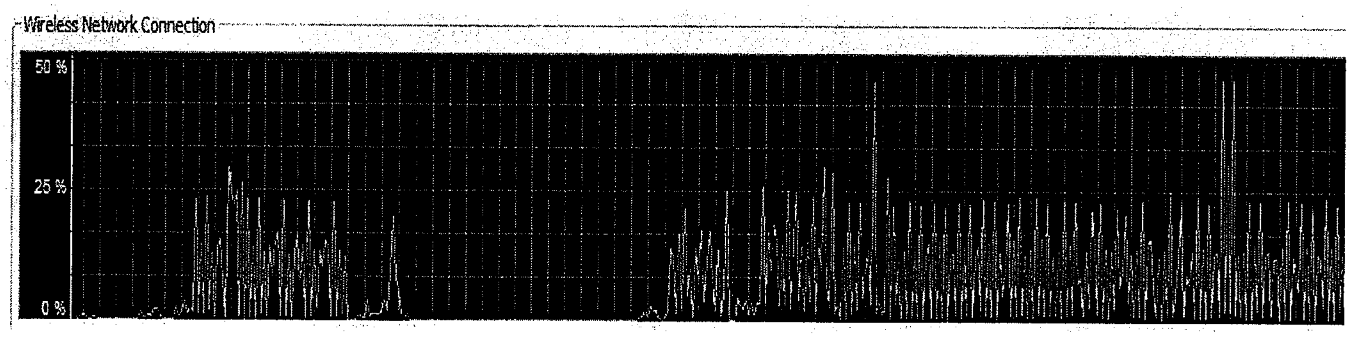

Figure 4. Network Traffic Along the Test Route. The Missing Signal Area Indicates the Gap between 'Hot-Spots'

1.2.2. The 'Ad-Hoc' connection

Investigators also considered the ad-hoc network structure. Two laptops are connected directly using the utility which comes with the 802.11b Wireless cards. Two different modes of video transfer are used. The first one is continuous video transfer. It is tested using Skywire webcam edition (http://www.astaskywire.com). The output frame rate and picture quality depend heavily on the distance between the two laptops and the link quality. Therefore, at far range, the output video is

distorted and not acceptable. The second method investigators used is individual frame transfer. The same ad-hoc setting is used in two laptops. However, the video is captured into separate frames. Individual frames are transferred sequentially using a simple Java program written by the investigators.

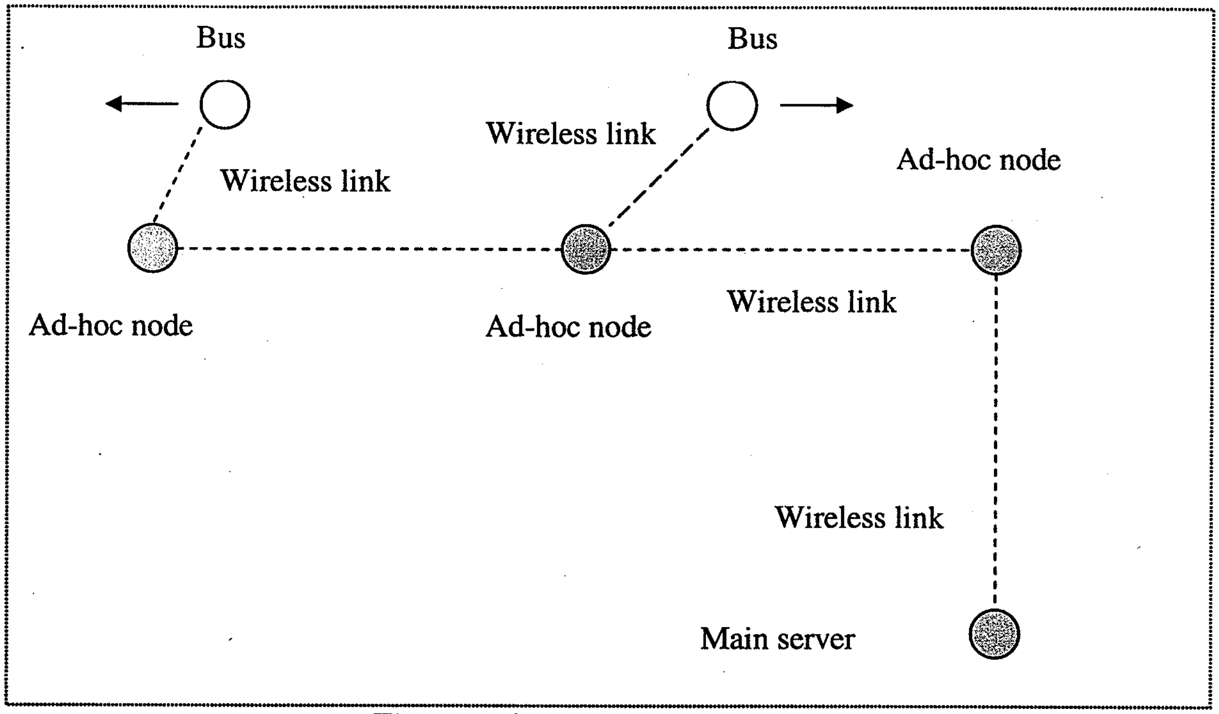

Figure 5. Ad-Hoc network architecture

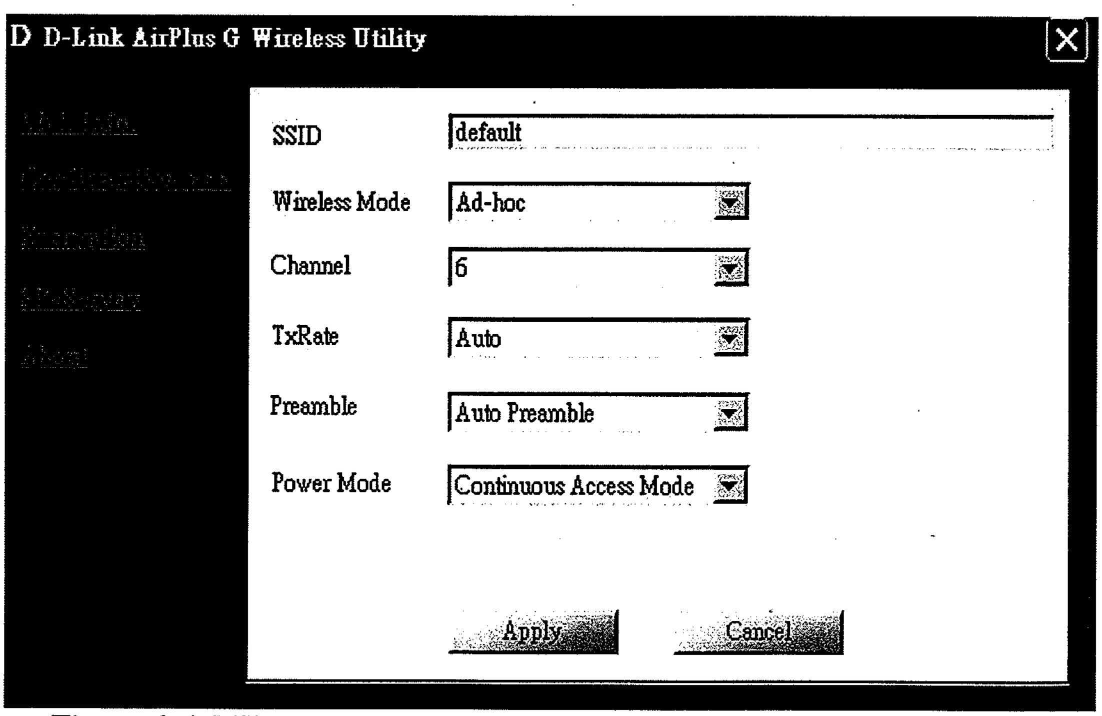

Figure 6. Ad-Hoc network settings for D-Link AirPlus G Wireless Utility

The investigator tested frame-based streaming methods at Carnegie Mellon University in March, 2004. The first test shows that the frame-stream can reach at least 350 feet at the line-of-sight in the open field with an ad hoc connection between two wireless modems. Ten files were transferred. They combined to a total file size of 605kb. There is a two-second pause after each successful file transfer. The second experiment shows the impact of distance and line-of-sight on the quality of image and time elapsed for the image transferring.

With our latest tests, the speed of streaming reached 10 frame per second using 25 %– 50% of the network connection capacity.

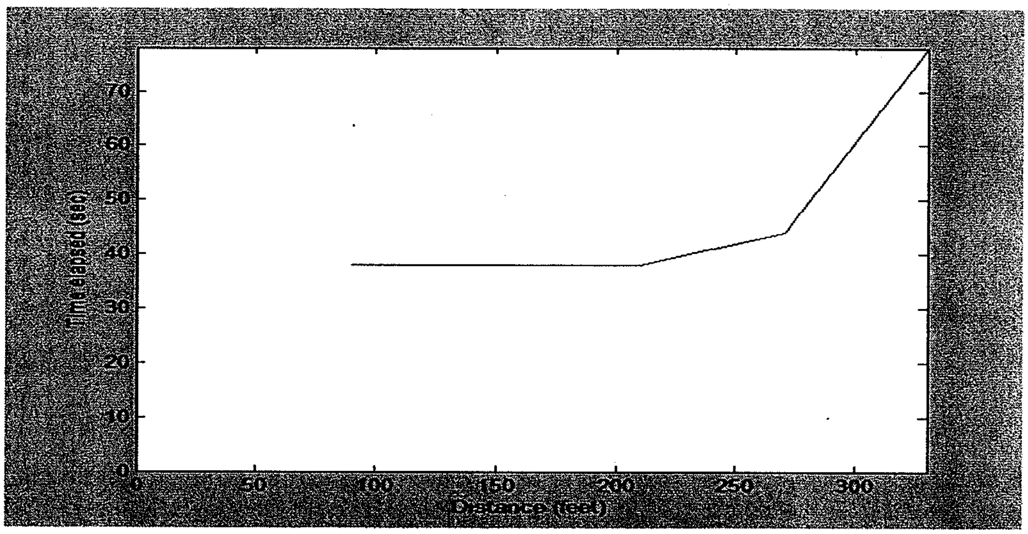

Figure 7. Distance vs. Time Elapsed

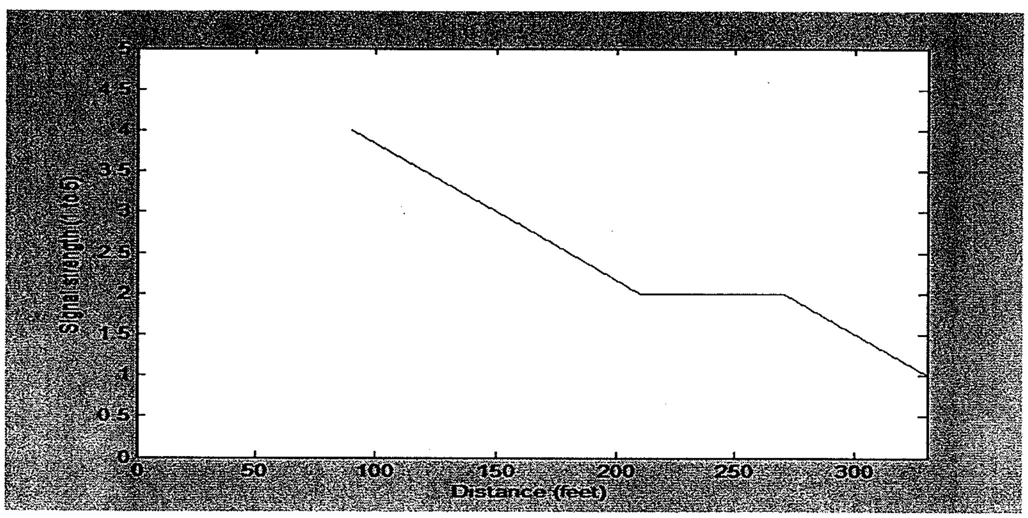

Figure 8. Distance vs. Signal Strength

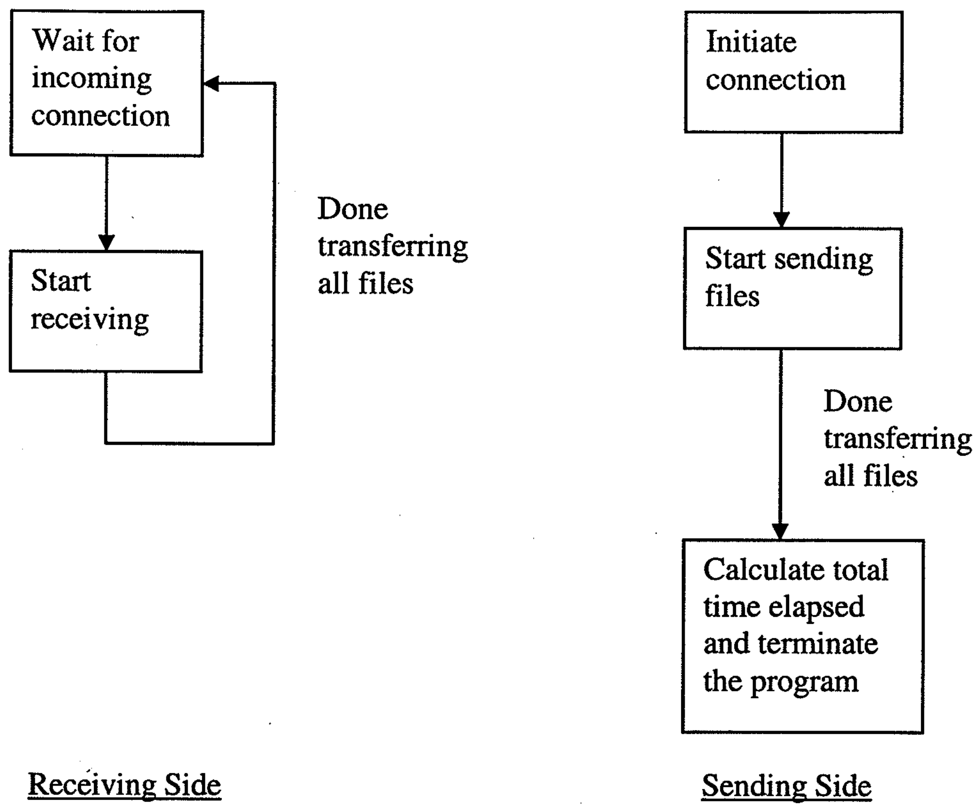

Figure 9. Sending and Receiving programs

1.3 Data Error Handling in Frame Transferring

In this project, File Transfer Protocol (FTP) is used to upload individual frames obtained from the camera. A Java program is designed to upload the files to an FTP server. One of the significant problems in wireless data transferring is error handling during the data transmission. A regular File Transfer Protocol (FTP) is designed to transfer data as accurate as a single bit. If FTP encounters a data error, it would try to resend the data package for a few times until the preset number is reached. To ease the wireless network bandwidth, the investigator disabled the error checking in the FTP software to avoid the repeated package transferring. In addition, in the no-signal areas, FTP usually exits the program itself. To remedy this situation, the investigators wrote a special program to handle the error message. The flowchart is illustrated in Figure 10.

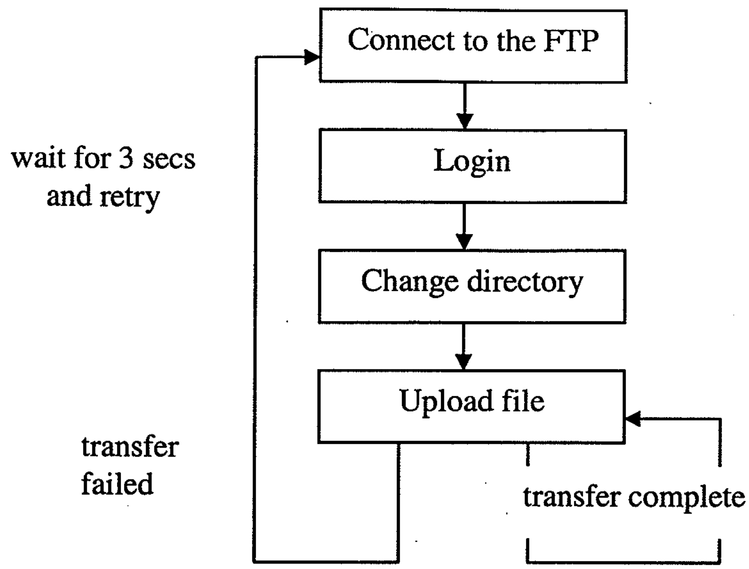

Figure 10. Error handling procedure

1.4 Video Acquisition Protocol

There are two methods for video stream acquisition: 1) "pushing" method - automatically transferring video streams from each bus, and 2) "pulling" method – the video from a bus is transferred only upon the request from an operator at the Center Control Station. The problem for the "pushing" method is that it overloads the wireless network bandwidth easily. It is impractical to transfer hundreds or thousands of video streams simultaneously. Besides, there are not enough human operators or robotic monitors to watch the video anyways.

The investigators have discussed with Port Authority and worked out a 'pulling' video acquisition protocol for them. However, the "pushing" method, the automatically transmitting video method, can be implemented in other transit agencies to serve their needs.

At a normal state, the onboard computer just stores collected video data locally without wireless transferring. Upon a request from the controller client computer, the video is transferred from a specific bus to the data server in real-time. The detailed user interface design is discussed in the section 3. User Interface Design.

2. Enhanced Antenna Design

2.1 Factors Affecting Range and Performance of all WiFi Systems

Range estimates are typical and require *line-of-sight*. Each wireless transmitter will need a clear unobstructed view of the antenna from the remote point in the link.

Walls and obstacles limit the operating range and could even prevent a link from being establishing. Signals generally will not penetrate metal or concrete walls. Trees and leaves are obstructions to 802.11 frequencies so they will partially or entirely block the signal. Other factors that will reduce range and affect coverage area include metal studs in walls, concrete fiberboard walls, aluminum siding, foil-backed insulation in the walls or under the siding, pipes and electrical wiring, furniture and sources of interference. The primary source of interference in the home will be the microwave oven. Other sources include other wireless equipment, cordless phones, radio transmitters and other electrical equipment. Due to the increased gain, installing range extender antennas in the presence of interference could actually yield equal or worse range.

2.2 RE05U-MC Antenna Specifications

The investigators selected the omni-directional wireless antenna RE05U-MC. The specifications are listed as following:

Frequency	2400-2500 MHz
Gain	5 dBi
Impedance	50 Ohm
VSWR	< 2.0:1 avg.
Maximum Input Power	10 W
Weight	< 1.0 lbs.
Length	6"
Polarization	Vertical

2.3 Antenna gain patterns

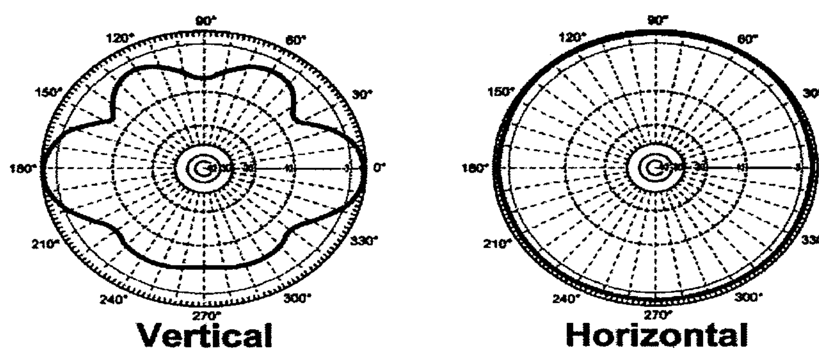

Figure 11. Antenna gain patterns

Two experiments were done to show the signal strength and wireless link usage of the file transfers. In the first experiment, investigators used 3Com's 802.11b wireless card. The signal strength obtained is mapped in Figure 12. The thickness of the blue line indicates the signal strength. In the second experiment, we added an external antenna to the wireless card. Figure 12 shows the improvement in signal strength after the antenna is added. From the two experiments, the investigators found that the

omni-directional antenna can extend the wireless bandwidth range about 15%. In addition, it increased the wireless signal strength about 20% on average.

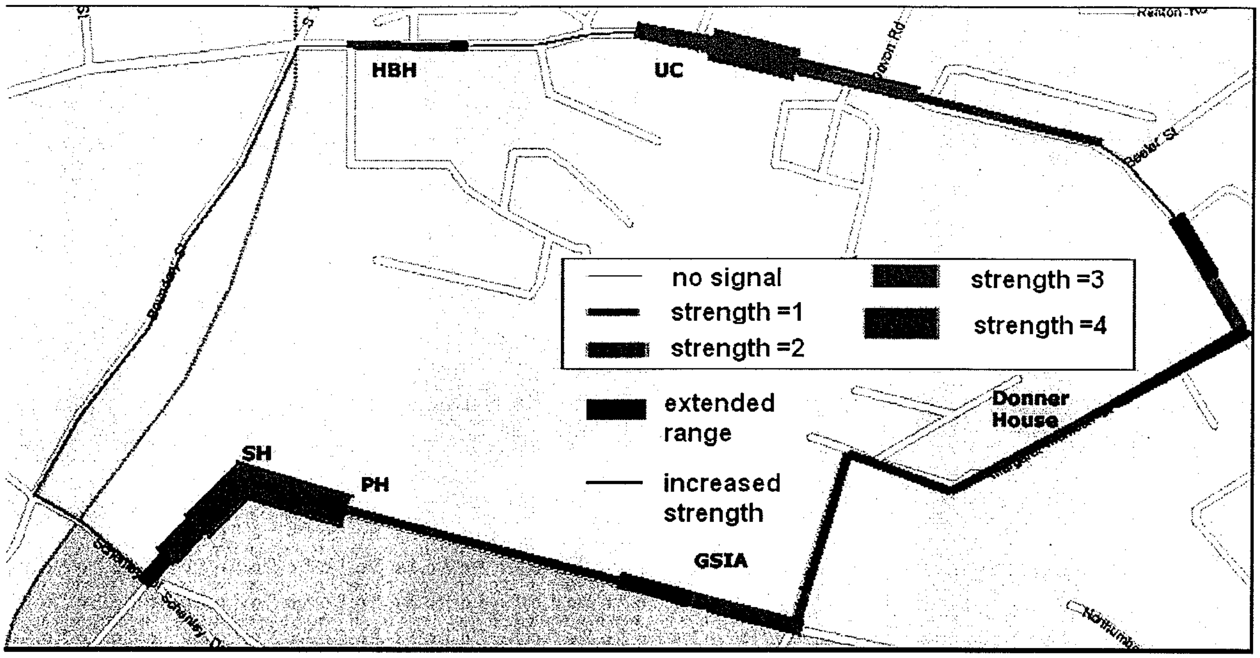

Figure 12. Comparison of before and after adding the antenna

In Figure 15, the wireless link usage plot is obtained from Microsoft Windows's Networking Utility.

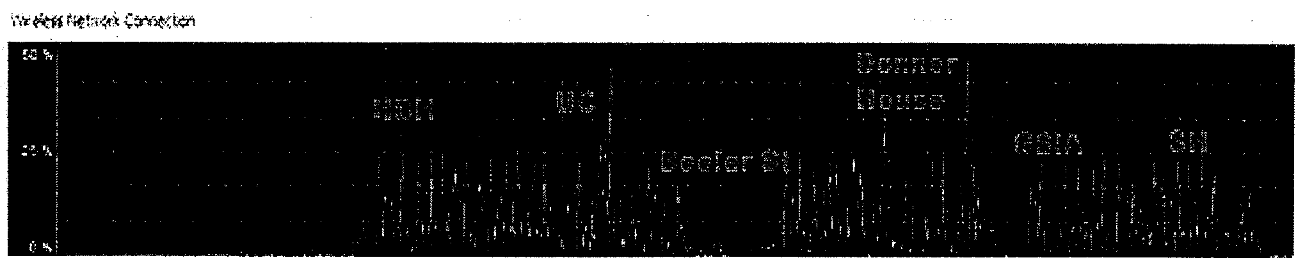

Figure 13. Network traffic per connection after adding the antenna

3. Camera View Design

The view of the camera system was designed to make sure that it fits the environment of transit buses. In addition, the design should be compliant with Union regulations and optimized for face recognition.

3.1 Four Camera Location Design.

According to the union regulation, the driver and the front window scene can not be video taped. Here is the layout:

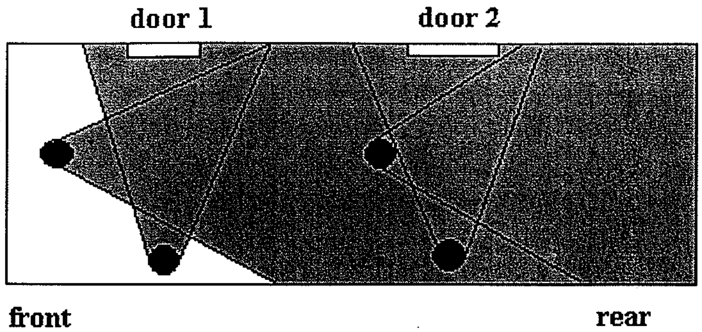

Figure 14. Camera Layout

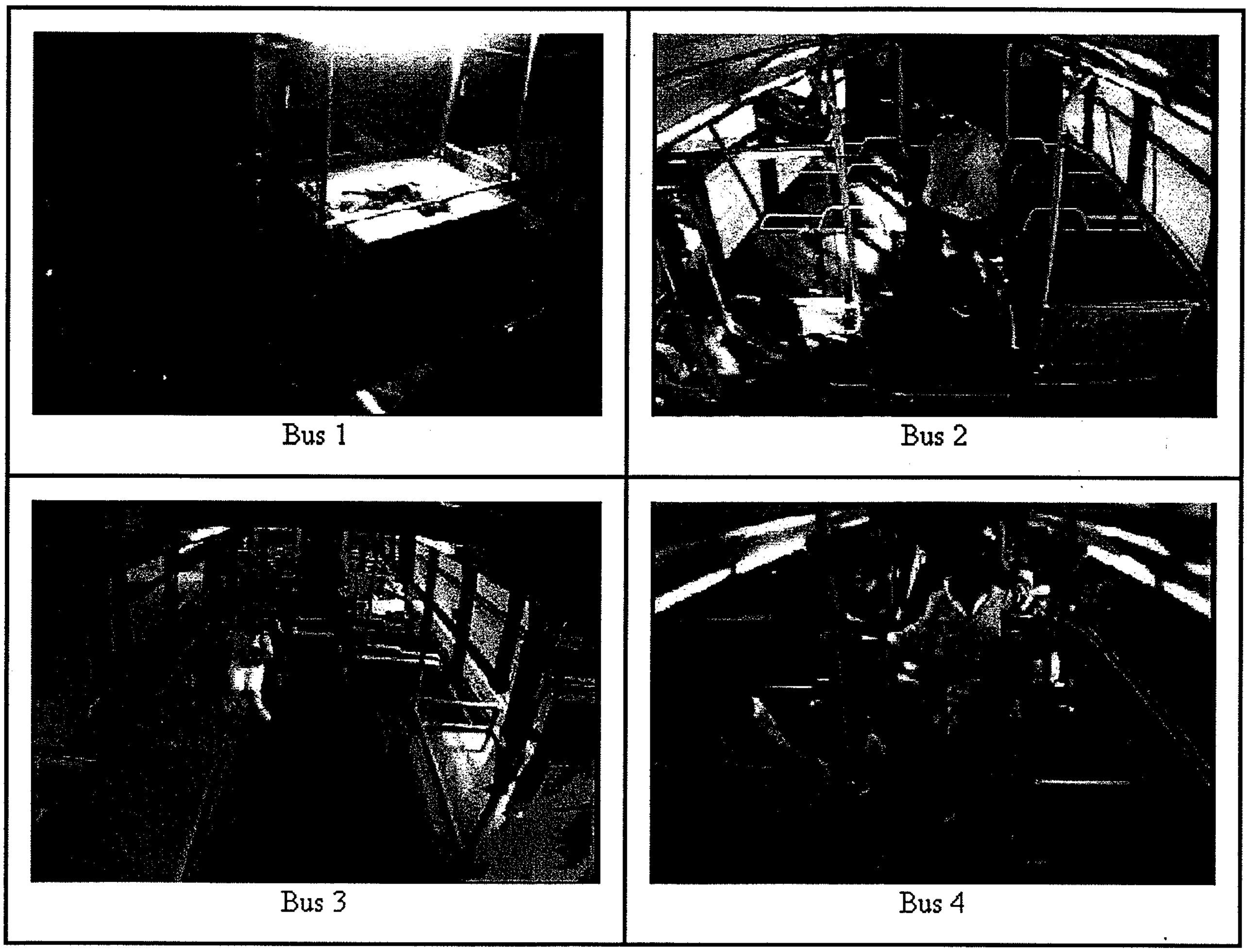

Figure 15. Four views of the cameras on a bus

3.2. Enhanced Lighting

For better image quality, lights are added. The viewing angles are maximized by optimizing the camera location and camera settings.

4. User Interface Design.

4.1. Operator Interface Design

The investigators have developed a web based user interface so that a user can view the real-time images from regular web page. The page displays real-time video of four different buses. Clicking on an individual picture will show an enlarged version of the picture. The page reloads itself every 3 seconds or users can refresh the page manually by clicking on the "refresh" button. A screenshot of the interface is shown in Figure 16. Also, the human head recognition software is under development for automated video processing.

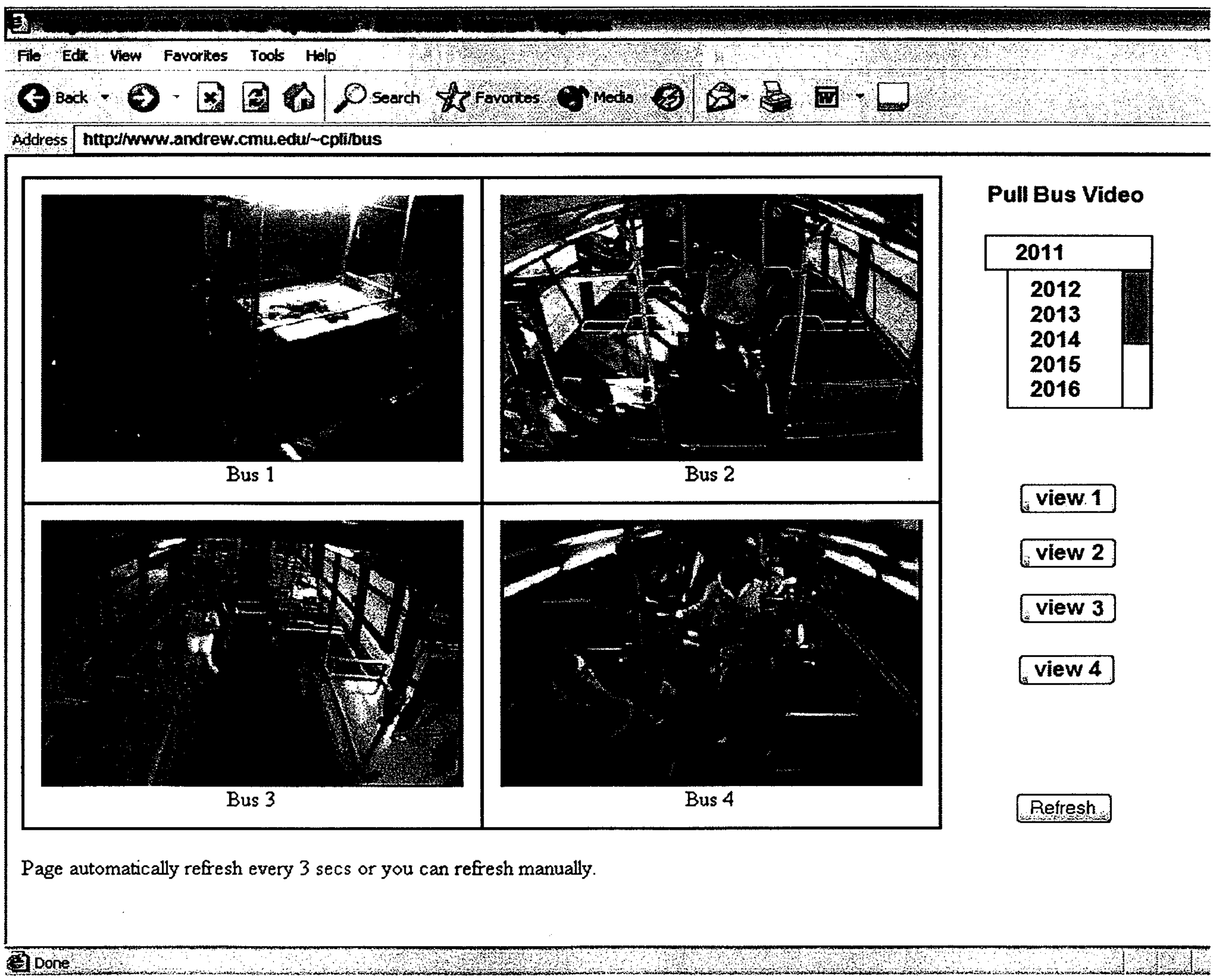

Figure 16. Operator interface design

Figure 17. The Quality of the Transferred Video Image (color, 640 x 480 pixels)

4.2 Automated Event Detection

Several techniques have been tested to detect human head from the captured bus video. We used the optical flow of the individual frames to test the models. An algorithm for optical flow computation is based on the search for successive approximations of a displacement field between two images that minimizes the distance between them while satisfying certain continuity and regularity constraints. For this, images are sliced in parallel with overlapping strips. Each strip of an image is optimally aligned with the corresponding strip of the other image. Iterations are performed alternatively with horizontal and vertical slicing while the strips spacing and width is reduced at each step. The displacement field adjustment is therefore carried out alternatively for the horizontal and vertical components with an improving accuracy. This method is related to classical correlation-based methods for optical flow computation. The difference is that correlation is searched here between elastic strips rather than being searched on rigid squares.

5. Hardware Integration and Software Integration.

The investigators used commercially available parts, e.g. 802.11b and wireless enhanced antenna RE05U-MC, for the preliminary experiments. The real image frames from buses have been used for data streaming experiments. The software is developed in house for video uploading, video downloading and viewing. Specifically, two video streaming methods are articulated: 1) video streaming with individual frames, and 2) video streaming with continuous flow. The investigator will test both methods and compare the bandwidth occupancies. To make a fair comparison, the investigators develop a method to convert the video to individual frames with the same visual quality.

6. Field Test

The investigators have worked with the Port Authority using their buses to drive around CMU campus and tested the video streaming quality and the wireless network traffic. The Port Authority arranged a bus with Mr. Richard Schneider, the IT specialist, onboard. The range extension antenna was mounted at one side of the bus with magnetic base without rewiring any circuit on the bus. The investigators carried a laptop and wireless connector on the bus. The investigators tested the video transmission from the bus at the normal service speed of 15 mph. The bus' traveling distance and location was marked on the map and input into the database as Figure 3 illustrates. Also, the network traffic and image transmission status was recorded as shown in Figure 4.

7. Cost Analysis

From our experiments, we assume a 802.11b access point (Hot-Spot) can cover 100 meter. If one access-point costs $100 per unit. The cost for a route would be $1.00/meter, if we install a new Hot-Spot. However, if we have the access to available Hot-Spots (60% of the route) in a city, then the cost can be reduced to $0.40/meter or lower. In many large cities, such as Boston, WiFi will cover the whole city. Therefore, it is possible to obtain a free wireless access. In addition, many buses have had cameras onboard, the cost for the wireless antenna would be around $50 per bus.

8. Conclusions

From the field tests and analysis, the investigators found that the system design is feasible and economical. The prototype system can transfer the digital video at VGA resolution at a speed of more than one frame per second. Based on existing wireless hot-spots in urban area, the prototype system can transfer video to a server on Internet. Users can view the video on a computer with a web browser. Our experiments also show that at the speed of 1 fps, the wireless network is less than 25% of connection capacity. The speed and format of the video are compatible with what the Port Authority is using. The investigators also tested rain conditions and data recover from interruptions and obtained satisfactory results. The experiments also showed that the 'line-of-sight' of wireless signal is more important than distance, which was originally considered of highest concern. This finding is useful in designing the wireless antenna and determining the locations of the wireless repeaters. Because the Port Authority used frame-based video transfer protocol, we had not have the chance to test the continuous video streaming mode It is estimated that the cost for installing the access-points along the route can be around $0.40/meter to $1.00/meter. In many large cities, such as Boston, WiFi will cover the whole city. Therefore, it is possible to obtain a free wireless access. In addition, the system can adapt the facial recognition algorithm to live video streams from transit buses.

9. Profile of Principal Investigator

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10. References

Leslie Davis, "Transit Steps Up Security," Metro Magazine, November/December 2001, http://www.metro-magazine.com/t_featpick.cfm?id=90502972

Kalate Company, "Interlogix Announces Up to $6 Million Contract Award from Chicago Transit Authority for Digital Video Surveillance Systems" http://www.kalatel.com/kal-news/press/press-feb-22-2001.html

Kessler, A., "Goodbye Lucent, Hello Wi-Fi," The Wall Street Journal, April 9, 2001.

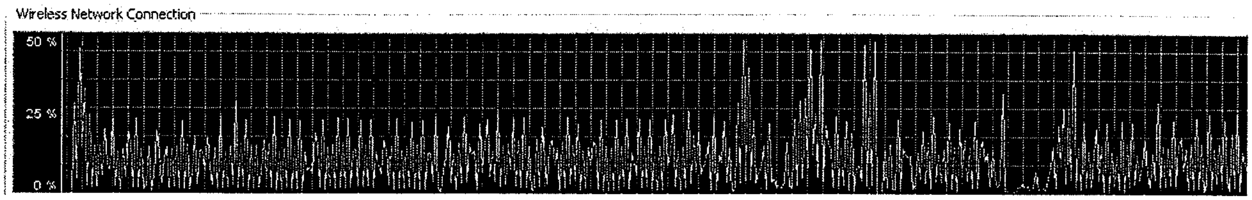
Slater, D., Panoramic Photography with Fisheye Lenses, Panorama, Vol. 13, No. 2, 3, International Association of Panoramic Photographers, (1996)

Snyder, An Album of ap Projections, U. S. Geological Survey Paper 1453, U. S. Government Printing Office, Washington, DC (1989)

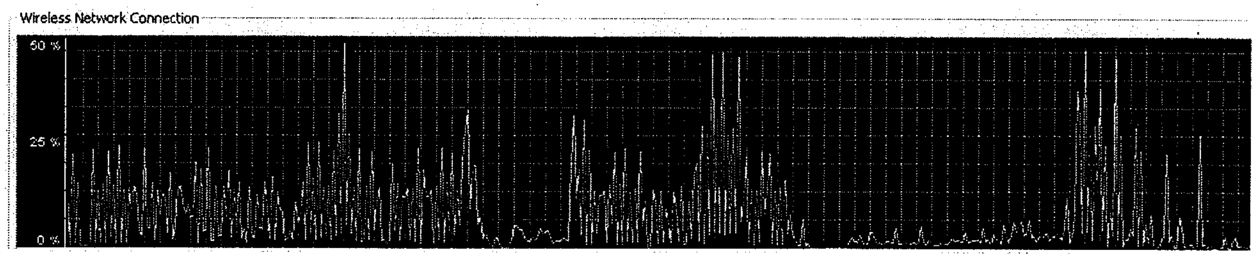
Washington Metro, http://www.wmata.com/

Wertz, J., ed., Spacecraft Attitude Determination and Control, D. Reidel Publishing Co., Boston, MA (1978)

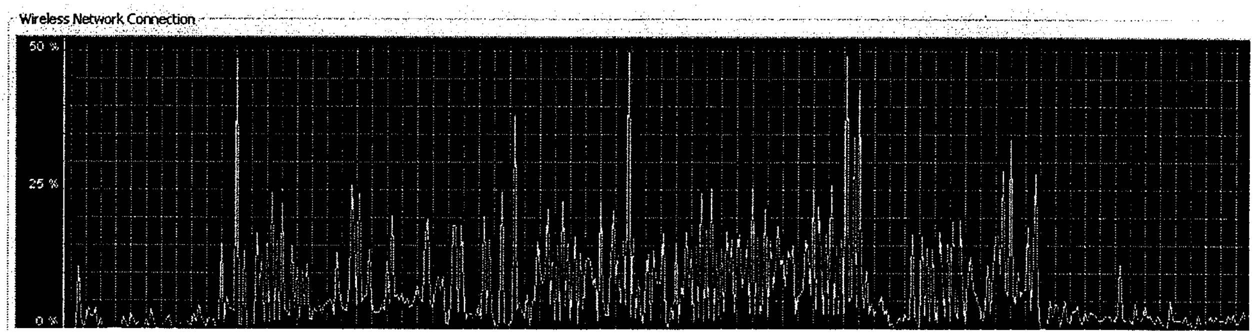
Appendix. Network Traffic Monitoring Per Connection.



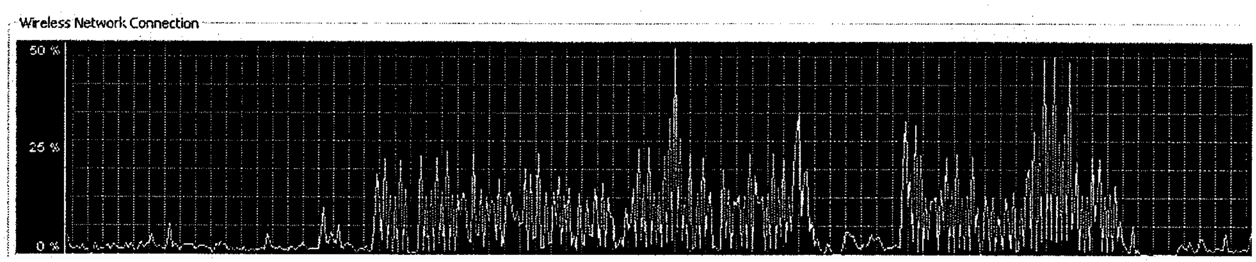
Hot-Spot test at 1 fps at 10 mile per hour near CMU stadium (300 feet from the hot-spot)



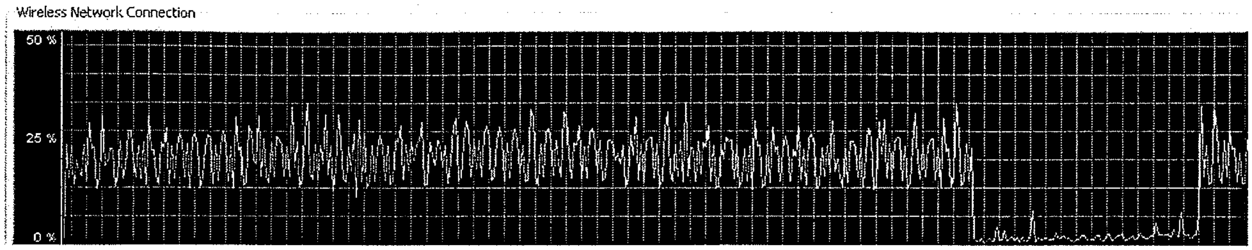
Hot-Spot test at 1 fps at 10 mile per hour near CMU-Forbes Bridge



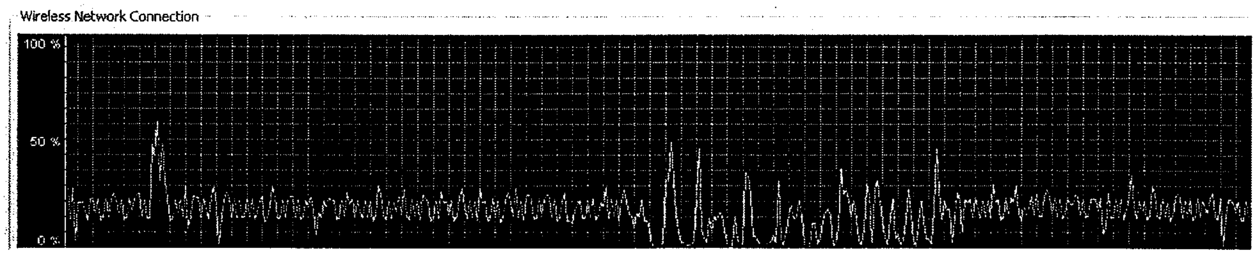
Hot-Spot test at 1 fps at 10 mile per hour near Morewood Ave.



Hot-Spot test at 1 fps at 10 mile per hour near CMU Hamburg Hall



Frame-based net traffic study at 16 frame/sec



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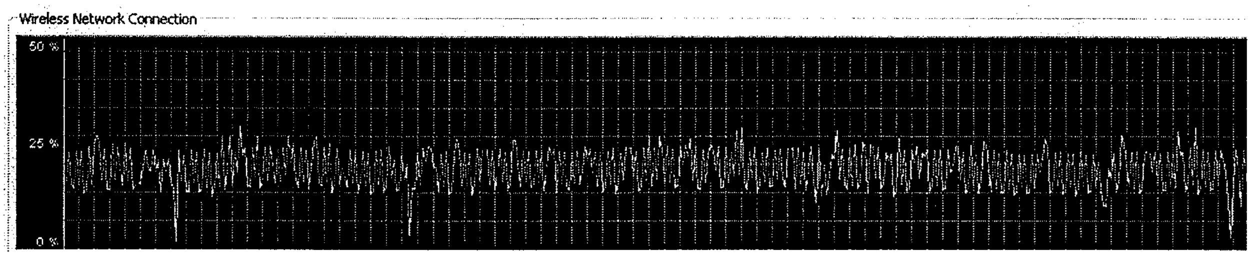
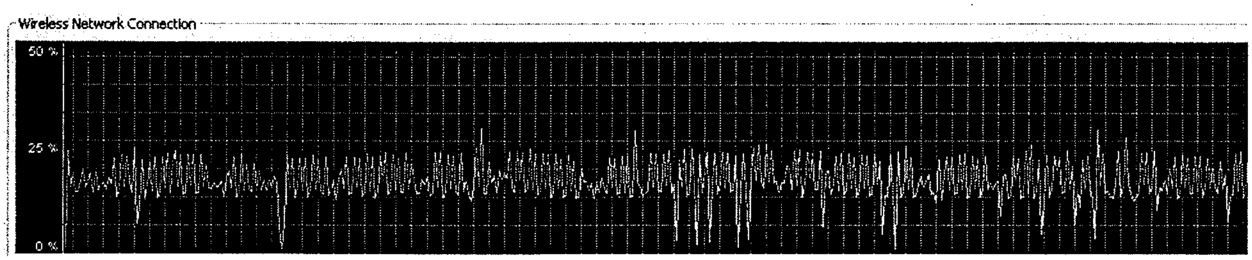
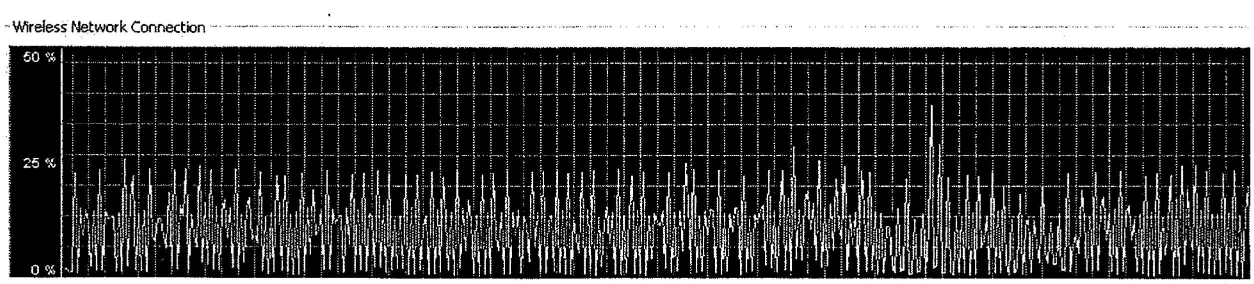


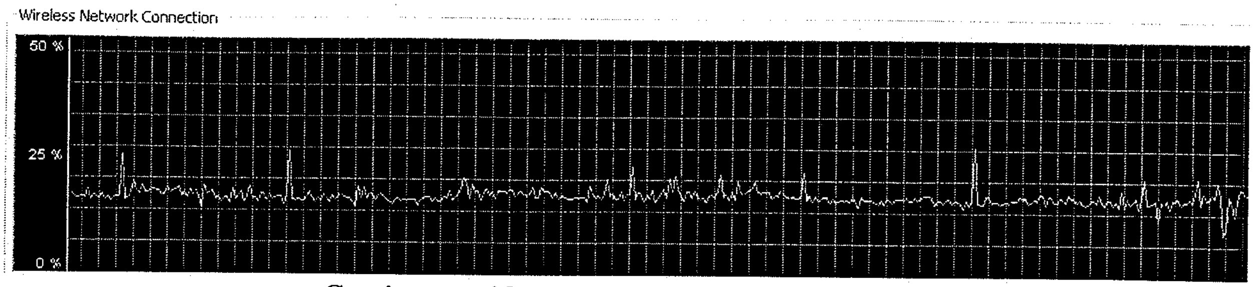
Frame-based net traffic study at 8 frame/sec



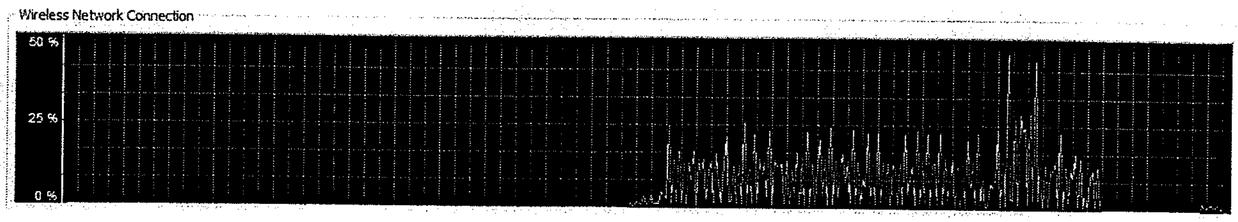
Frame-based net traffic study at 4 frame/sec



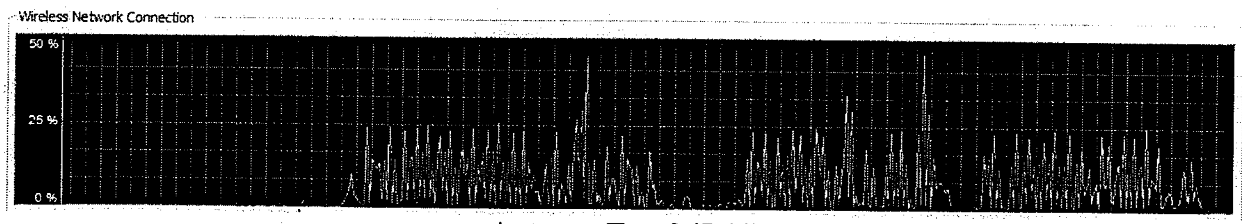
Frame-based net traffic study at 1 frame/sec



Continuous video stream based net traffic study



Antenna Test 1 (5-11)



Antenna Test 2 (5-11)