Expedited Crash Investigation - With Use of Technologies for Documentation and Processing

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Publication Date
2007-11-01

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California PATH Research Report
UCB-ITS-PRR-2007-18

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

Final Report for Task Order 6216

November 2007

ISSN 1055-1425

Final Report for

Task Order 6216

EXPEDITED CRASH INVESTIGATION
- WITH USE OF TECHNOLOGIES FOR DOCUMENTATION AND PROCESSING

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April 30, 2007

ABSTRACT

The mobility and efficiency of California highways are impeded by the recurrent and non-recurrent congestion on a daily basis. Roadway incidents, especially collisions, often result in traffic congestion and travel delays. This project is initiated to explore the use of technologies that will potentially bring direct and immediate benefits to the law enforcement officers and other personnel who are involved in the handling of collision sites and subsequent investigations. The work carried out in this project includes three major components: (1) The experimentation of integrated vehicular technology systems to provide assistance for law enforcement officers, (2) The exploration of utilizing GPS devices for vehicle and incident locations, and (3) The development of photogrammetry tool to extract supplementary information from collision scenes.

Valuable insights were gained through collaborations with the University of New Hampshire Project 54 and the City of Carlsbad, California, Public Safety Technology Programs. The key factors to successful deployment of technological systems are the easy-to-learn operation features and friendliness of user-machine interface. Integrated multiple-function capabilities and open architecture are important considerations in adopting technological systems to ensure favorable cost-benefit returns of investments from the perspectives of local jurisdictions or agencies.

KEY WORDS

GPS, Driver-Assistance Systems, Technology for Law Enforcement, Project 54, Public Safety, Collision Database, Geo-Coding, Photogrammetry

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EXECUTIVE SUMMARY

The mobility and efficiency of California highways are impeded by the recurrent and non-recurrent congestion on a daily basis. Roadway incidents, especially collisions, often result in traffic congestion and travel delays. Such congestion is mainly caused by stopped vehicles and lane closure, but it is intensified by slowing vehicles with drivers observing the accident scene. The effects of these phenomena on highway traffic are significant in terms of their direct hazards and the associated losses in travel delays, energy usage, and environmental impact.

This project was initiated to explore the use of technologies that will potentially bring direct and immediate benefits to the law enforcement officers and other personnel who are involved in the handling of collision sites and subsequent investigations. The work carried out in this project includes three major components: (1) The experimentation of integrated vehicular technology systems to provide assistance for law enforcement officers, (2) The exploration of utilizing GPS devices for vehicle and incident locations, and (3) The development of photogrammetry tools to extract supplementary information from collision scenes.

During the course of the project, the research team carried out a broad survey and assessed the availability and suitability of individual devices and packaged systems for law enforcement applications. After initial evaluation, a collaborative relationship was established with the University of New Hampshire CATlab, where Project54™ was developed. This cooperative effort allowed us immediate access to the mature and already deployed technology set that appears to be an ideal candidate to be considered for law enforcement and state agency vehicle fleets. With its wide deployment in a large number of police vehicles, Project 54 has evolved into an attractive driver-assistance system. It main features are:

(1) The system offers multiple user interfaces by voice, touch-screen, conventional switches or knobs to allow the users to activate on-board devices under various field operating conditions,
(2) The use of different user interfaces is not mutually exclusive and thus each individual user can opt for appropriate control methods at different times or under different conditions,
(3) The system has a short learning curve due to its user-friendliness,
(4) The system has a non-proprietary open architecture, which allows the flexible selection and replacement of modular components and sub-systems.

The research team also interacted with the city of Carlsbad Police Department, where a Public Safety Technology Problem was implemented with great success. Considerable resources were dedicated to implement infrastructure and vehicle renovations to provide officers with mobile office capability, including:

(1) Registration/Stolen car inquiries,
(2) Driver license checks,
(3) Wanted persons checks,
(4) Email, Reports, and Pictures,
(5) Crime analysis,
(6) Access all city and county justice systems.

Subsequently, the research team made arrangements with the University of California, Berkeley, Police Department and initiated the instrumentation of an experimental vehicle on one UCB-PD cruiser. The objectives of the experiments were to assess the following two aspects in accordance with the research plans:

(1) Exploring the technical and institutional issues in local environment when an officer-assistance system such as Project 54 is installed,
(2) Evaluating the use of vehicle-mounted GPS device for the purpose of vehicle location identification and incident reporting.

The results of GPS data experiments and Project 54 at UCB-PD can be summarized as follows:
(1) Low-cost GPS devices are readily available with decent resolutions and performance specifications for the purpose of incident reporting,
(2) GPS Data recording in the Berkeley neighborhood, a suburban region with scattered tall buildings and occasional narrow streets, was consistent and reliable for its intended usage,
(3) Mapping and navigation was a function preferred by officers during the testing,
(4) Project 54 is an easy-to-use system with minimum learning curves. However, the scale of experimentation with one single vehicle was too small to fairly assess its benefits,
(5) The radio units in the UCB-PD cruiser were not compatible with Project 54, as a result, the overall performance was significantly reduced,
(6) More training and user interactive sessions are strongly desirable.

One primary factor in the delays of incident handling is the necessary and proper documentation of incident information for legal and technical reasons. The prevailing method of scene measurement is often conducted by physically walking the scenes with wheel measures or similar tools. The common method and its conventional approach present several issues: time consumption, road hazard, limitations at site, and needs for photographic evidence. In this project, we investigated and enhanced a computer software application using photogrammetric techniques to facilitate the measurement of the aforementioned incident scenes. This software will allow the user to simply take the photographs taken at the crash sites and extract supplementary measurements in the convenience of the office, solving the shortcomings of the conventional method.

1. BACKGROUND

The mobility and efficiency of California highways are impeded by the recurrent and non-recurrent congestion on a daily basis. Roadway incidents, especially collisions, often result in traffic congestion and travel delays, in addition to the direct damage to the vehicles and the injuries to the people involved. The subsequent congestion is mainly caused by stopped vehicles or lane closure, but it is intensified by slowing vehicles with drivers observing the accident scene. The effects of these phenomena on highway traffic are significant in terms of their direct hazards and the associated losses in travel delays, energy usage, and environmental impact.

This project was initiated to explore the use of technologies that will potentially bring direct and immediate benefits to the patrol officers and operators that are involved in the handling of collision sites and subsequent investigations. The work is based on and extended from previous research that was developed under the sponsorship of California Office of Traffic Safety (**OTS**) and the collaboration of California Highway Patrol (**CHP**) with an emphasis on the deployment of technical tools. [1, 2]

One primary objective of the project is to define user specifications and useful functionalities for the use of Global Positioning System (**GPS**) that can facilitate expedient documentation of collision sites. The availability of GPS data can then be further incorporated into the data entry process and statistical analysis in collision databases such as **SWITRS** (Statewide Integrated Traffic Records System) [3] and **TASAS** (Traffic Surveillance Accident Surveillance and Analysis System) [4]. The availability of GPS data in collision reports and database will allow effective record keeping and to enable safety performance evaluation of the state-wide highway network.

1.1 Research Objectives

In the last ten years, on average more than 3,500 fatality, 200,000 injury, and 300,000 property-damage collisions occurred on California roadways every year [3]. The direct costs of these collisions are enormous, yet their impacts on highway efficiency are even more daunting considering all the resources needed to handle the consequences of roadway crashes. First of all, law enforcement officers, assisting transport vehicle and paramedics are required to attend to the people and vehicles involved in the collisions. Secondly, traffic near the crash scenes queues up quickly and often leads to congestion that may take a considerable period of time to dissipate. It is not uncommon for a single incident during the rush hours to affect traffic conditions for the whole morning or afternoon. The associated losses in personnel time, congestion delays, energy usage, environmental impacts, and secondary collisions can certainly be considered as one major culprit that leads to the deterioration of highway mobility, efficiency, and safety on a daily basis. Marginal improvements in the response and handling of crashes can result in significant benefits towards mitigating this complex problem, in spite of the enormity of the problems.

The primary objectives of this project are two-fold:
(1) Development of GPS and vehicle on-board instrumentation

The first aspect of efficiency improvements will come from the ease and expediency of handling various tasks in the field by law enforcement officers. Specifically, this project continues previous developments [1, 2] and focuses on the following options:

- Exploring integration of on-board or mobile technologies that incorporates the use of GPS, bar code and magnetic stripe reader, voice recorder, and other commercial-off-the-shelf products that can offer assistance for the process of information collection and incident handling in the field.
- Identifying user preferences and deployment options of GPS units that can enable the expedient documentation of collision locations.

(2) Software for post-processing of photographic evidence

The other improvement in crash investigation relies on the capability of examining photographs to gather additional evidence, which are either unavailable or incomplete at the time of on-site documentation. Thus, one major task in the project is to continue the development of a photogrammetry tool and to enhance functionalities on a preliminary version of such software from earlier work. [2]

1.2 Research Approaches

Based on the work of an earlier project sponsored by OTS [1, 2], the research team has established a baseline understanding of various technology devices that may be applicable for crash investigation. More importantly, through the interaction with CHP officers, we also learned about the user needs and institutional issues that are critical for field operations by law-enforcement personnel. Thus, we defined and followed a research plan with the following guidelines:

(1) Engage the users in an iterative process to ensure that the development and testing of suggested systems will be user friendly and acceptable to the intended target audience,

(2) Although stand-alone functions or devices may serve particular purposes, an integrated system that incorporates a wide choice of features can best meet the diverse needs of individual users,

(3) With the fast advancements in various technological fields, there are a great variety of commercially off-the-shelf products that can be modularly adopted and flexibility integrated without unnecessarily high development costs. . Thus, the hardware and software architecture should remain open and allow flexibility in component or sub-system redesign and replacements,

(4) Collaboration with other institutions should be a priority to leverage off previous research and existing resources,

(5) When evaluating the effectiveness of deployable solutions, the involvement of the local government agencies and relevant institutional issues should be taken into account.

2. GPS TECHNOLOGIES

One primary objective of the project is to seek solutions for the use of Global Positioning System (**GPS**) devices that can facilitate expedient documentation of collision sites. The availability of GPS data can then be further incorporated into the data entry process and statistical analysis in collision databases such as **SWITRS** (Statewide Integrated Traffic Records System) [3] and **TASAS** (Traffic Surveillance Accident Surveillance and Analysis System) [4]. The availability of GPS data in collision reports and database will allow effective record keeping and enable safety performance evaluation of the state-wide highway network.

With decreasing prices and increasing market penetration of Global Positioning System (GPS) in vehicle navigation markets and hand-held devices, GPS has gradually become a familiar household item. Furthermore, the availability of higher precision measurements by GPS will potentially spread broader implementation of advanced applications for private users as well as public agencies. This section provides a review of GPS- related technologies applicable to the subject areas of this project.

2.1 GPS Basics

The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. [5] GPS uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. In fact, with advanced forms of GPS you can make measurements to better than a centimeter.

The quest for greater and greater accuracy has spawned an assortment of variations on basic GPS technology. One technique, called **"Differential GPS,"** involves the use of two ground-based receivers. One monitors variations in the GPS signal and communicates those variations to the other receiver. The second receiver can then correct its calculations for better accuracy.

Another technique called **"Carrier-phase GPS"** takes advantage of the GPS signal's carrier signal to improve accuracy. The carrier frequency is much higher (which also implies a much shorter wavelength) than the GPS signal which means it can be used for more precise timing measurements.

The aviation industry is developing a type of GPS called **"Augmented GPS"** which involves the use of a geostationary satellite as a relay station for the transmission of differential corrections and GPS satellite status information. These corrections are necessary if GPS is to be used for instrument landings. The geostationary satellite would provide corrections across an entire continent.

2.2 US Nationwide Higher Accuracy GPS

Currently, the GPS service offers a 4- to 20-meter (m) navigational accuracy. For many land transportation uses, this accuracy is insufficient. The Nationwide Differential Global Positioning System (**NDGPS**) offers a 1- to 3-m radio-navigational service that meets the needs of many more transportation users. [6]

The High Accuracy-Nationwide Differential Global Positioning System (**HA-NDGPS**) program [7] provides the capability to broadcast corrections to the Global Positioning System (GPS) over long ranges to achieve a better than 10 centimeter (cm) (95 percent) accuracy throughout the coverage area. HA-NDGPS is currently undergoing a research and development phase. The signal is available for test purposes from Hagerstown, MD, and soon Hawk Run, PA. Application of this technology will provide advanced safety features for transportation, including lane departure warning, intersection collision warnings, and railroad track defect alerts. It also could be used for economic enhancements such as precision container tracking and automated highway lane striping.

Because greater precision is needed to support many of the safety enhancements envisioned for the future, the U.S. Department of Transportation, in conjunction with the Interagency GPS Executive Board, is supporting the development of HA-NDGPS to provide 10 cm horizontal and 20 cm vertical (95 percent) corrections to users. HA-NDGPS uses the infrastructure employed by the NDGPS service to broadcast these corrections. The addition of a diplexer and transmitter allow the existing infrastructure to broadcast the additional signal, keeping implementation costs very low. Additionally, the signal will be monitored to ensure it is providing the accuracy needed to meet safety-of-life applications.

In separate Caltrans-sponsored activities (VII California – PATH Task Order 6217), California DOT is evaluating the applicability of HA-NDGPS for a variety of safety and traffic management functions through the establishment of a high-accuracy base station in California. [8-10] Once this facility becomes available, interested parties can implement applications that require very high-accuracy positioning resolutions.

2.3 Mapping and GIS

A geographic information system **(GIS)** is a system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to the earth. In the strictest sense, it is a computer system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically-referenced information. In a more generic sense, GIS is a tool that allows users to create interactive queries (user created searches), analyze the spatial information, edit data, maps, and present the results of all these operations. Geographic information science is the science underlying the applications and systems, taught as a degree program by several universities.

Geographic information system technology can be used for scientific investigations, resource management, asset management, Environmental Impact Assessment, Urban planning, cartography, criminology, history, sales, marketing, and route planning. For example, a GIS might allow emergency planners to easily calculate emergency response times in the event of a natural disaster, a GIS might be used to find wetlands that need protection from pollution, or a GIS can be used by a company to find new potential customers similar to the ones they already have and project sales due to expanding into that market.

For the purposes of this project, the application of GIS is mainly related to the identification of collision locations. This can be utilized at two different levels:

(1) Real-time tracking of incidents

For law enforcement and traffic management functions, the missions are often time critical in responding and handling the events. For crash investigation, this means the dispatch of officers and paramedics must be routed to the scene within the shortest time possible. The GPS coordinates of patrol vehicles, when integrated with GIS, will enable a clear and rapid identification of their locations relative to incident sites. Once the location of vehicles can be seen by traffic management centers or dispatch centers, additional support from nearby patrol areas or jurisdictions can also be sent expediently. Furthermore, the reporting and documentation of site locations can be carried out easily with the activation of an on-board function by the onsite personnel. The data can then be sent wirelessly and recorded locally when desired.

(2) Post-processing

If the site information (such as GPS coordinates) can be automatically incorporated into the reports of individual incidents and collisions, an information-rich database can be gradually and increasingly established. The availability of such database will then enable powerful identification, search, and analysis of collision database, which can also be linked to a customized GIS for roadway network management.

2.4 GPS-Enabled Functionalities for Crash Investigation and Documentation

GPS is a powerful enabling technology. Specifically, its application in crash investigation and documentation includes the following categories of functions:

(1) Automatic Vehicle Location (AVL) by providing a message from the vehicles in real time.
(2) Emergency Response by locating the positions of vehicles and incidents.
(3) Site coordinate recording for crash locations.

A very relevant study was conducted in Kentucky on the use of GPS devices to record GPS coordinates for accident reports. [11] GPS equipment and training were provided to all police agencies throughout the state. The study was to evaluate the accuracy of this technology in locating traffic crashes which would be critical to having an effective safety program. The major findings from the study were:

(1) The GPS devices were capable of providing accurate location of a crash site.
(2) Substantial differences were found between the locations of some crashes with GPS vs. mile point (CRMP) data.
(3) GPS data was somewhat more accurate than CRMP information.
(4) Errors were typically operator errors rather than the equipment problems.
(5) Training and some hardware improvements would solve most of the problems encountered.
(6) The police report should be modified to reflect proper GPS data format.

From the findings of this recent study, it can be seen that user training and instructions are most critical in obtaining the correct information for the purposes of collision location recordings. Even though most updated handheld GPS devices can probably achieve the same level of accuracy as vehicle-mounted GPS ones, due to the vulnerability to entry errors they should only be used selectively for situations where the use of vehicular-based systems is limited.

Furthermore, a GPS device integrated into a vehicle on-board computing system with automated data entry options is likely to provide more consistent and reliable recordings.

2.5 Synergistic Research Activities in California

Under a project sponsored by the Office of Traffic Safety (OTS), the Traffic Safety Center at the University of California at Berkeley is undertaking an effort for the geo-coding of collision database. [12] A summarized description of the project and the related issues is given below. Each year local and governmental agencies collect and analyze California traffic collision data (SWITRS, Statewide Integrated Traffic Records System) to monitor injury rates, identify high collision locations, develop traffic safety programs, and evaluate the effectiveness of safety measures. Many SWITRS data users need to link motor vehicle collision data with exact geographical information to identify dangerous roads, intersections, and to study crash patterns on specific road and intersection types. There are currently many barriers to accurate, inexpensive, and efficient means of accesses geo-coded collision data. They are:

(1) Expense: Commercially available platforms to geo-code SWITRS data are very expensive.
(2) Ease-of-use: Commercially available geo-coding engines generally use a single data field to match addresses, and occasionally use a secondary zone field (e.g., zip code, city, county) to prevent out-of-area matches. Current location information in SWITRS, however, is represented by a collection of data fields including primary and secondary roads, qualified by direction and offset fields. Therefore, special programming is needed to precisely geo-code SWITRS data into commercially available software.
(3) Inaccuracy: Accurate geo-coding requires the use of consistent street names, correctly spelled street names, accurate “offset” and “direction” data fields estimated by the reporting officer, and a current and extremely accurate area map. Due to these barriers, most geo-coding is inadequate for use in analysis of intersection safety.
(4) Inefficiency: Even with the best software, programming and base map, some crashes will require manual geo-coding, a very labor intensive process.
(5) Redundancy: Many individual jurisdictions, county jurisdictions and some state jurisdictions are currently geo-coding crash data. The geo-coding being done may be duplicated by other researchers unaware of the overlap.

Until first responders use the Global Positioning System (GPS) to record the location of a crash, geo-coding crash location is critical for researchers and local communities to map collision occurrences. A centralized effort to provide accurate coordinates for geo-coded crashes would resolve current impediments to traffic safety research and put the State of California at the forefront of technological solutions for public health.

Currently, the California Highway Patrol is investigating possibilities for the automatic inclusion of GPS collision locations in the SWITRS data. The data can be geo-coded in two fashions. The first possibility is to equip all first-responders with GPS units and require them to report the GPS location on each collision report form. The second approach is for the CHP to use available location information to extrapolate the GPS coordinates of each collision. The former approach requires a one-time but tremendous overhaul of the collision reporting process; the later approach requires the CHP to commit to a yearly effort to geo-code all of the data using special software programs. In the current state of technology, no software program can produce 100%

accurate estimates, and most often software is unable to produce any estimate for a significant fraction of the collisions (15-20%). The resulting “mismatches” then require significant, often manual, attention. The CHP, and other states’ highway agencies, are actively researching solutions to this dilemma. Other local agencies have begun, on a piecemeal basis, to geo-code data.

3. INTEGRATED ON-BOARD SYSTEMS FOR LAW-ENFORCEMENT USERS

In the beginning phase of the project, the research team carried out a broad-based survey and assessed the availability and applicability of individual devices and sub-systems for law enforcement applications. Subsequently, the PATH researchers established a collaborative relationship with Professor Andrew Kun of the University of New Hampshire (UNH) CATlab, where Project54™ was developed. This cooperative effort allowed the project to have immediate access to a promising and field-tested technology package that appeared to be an ideal candidate suitable for law enforcement and state agency vehicle fleets. In addition, the project team also solicited inputs and received advices from Captain Dale Stockton, now retired, of the City of Carlsbad Police Department in California, where Project54 and other related technology systems are implemented. Through interaction with Carlsbad and UNH, considerable insights were gained in users' feedback as well as the keys to success of an integrated public safety program.

3.1 About Project 54 and CATlab at University of New Hampshire

The CATlab project is a collaborative research and development effort between the University of New Hampshire and the New Hampshire Department of Safety and is supported by the U.S. [13] Department of Justice, through the effort and continued support of Senator Judd Gregg. The faculty and students of CATlab work on introducing advanced technologies into the operations of the New Hampshire State Police and other law enforcement agencies.

Today's cruisers are equipped with digital radios, GPS units, computers, radars, lights, sirens, etc. Dispatch centers have become computerized, and officers on the beat and in offices access a variety of databases on a daily basis. However, these devices are most often not designed to become a part of a system of multiple devices manufactured by different companies. In other words they are not designed with integration in mind.

The integration of devices and systems is the primary interest of CATlab. Most of the work is done on integrating electronic devices in police cruisers. The integrated Project54 system allows officers to interact with equipment such as lights and siren, radar, etc. using speech input and feedback. The Project54 system also integrates police cruisers into state-wide data networks.

As of April 19, 2007, 771 law enforcement vehicles are equipped with Project54™ system in NH and 156 vehicles out-of-state are completed.

With its wide deployment in a large number of police vehicles, Project54 has evolved into a sophisticated and an attractive driver-assistance system. It main features are:

(1) The system offers multiple user interfaces by voice, touch-screen, conventional switches or knobs to allow the users to activate on-board devices under various field operating conditions.
(2) The use of different user interfaces is not mutually exclusive and thus each individual user can opt for appropriate control methods at different times or under different conditions.
(3) The system has a short learning curve due to its user-friendliness.
(4) The system has a non-proprietary open architecture, which allows the flexible selection and replacement of modular components and sub-systems.

3.2 Integrated In-Vehicle Functions and Dispatcher Center – City of Carlsbad

The Carlsbad, California Police Department undertook a major technology project that was designed to provide true mobile office capability to officers in the field. [8] In short, the police car's computer allows the officer full access to the traditional law enforcement data bases and dispatch information as well as full access to the city's network resources, email and internet functions. Using a wireless infrastructure based on CDMA EVDO technology, the project permits broadband capability from the patrol car, thus supporting a greater variety of applications. As the project design progressed, consideration was given to enhancing officer capability and safety by using voice recognition.

After extensive inquiry, the department learned of the Project54 effort. After initial evaluation, the Carlsbad technology venture was expanded to include Project54 equipment. Carlsbad PD worked with UNH to modify the Project54 software source code to perform California DMV inquiries. Carlsbad's use of the Project54 software marks the first use of the technology outside the state of New Hampshire.

Figures 1 and 2 below depict some components of the Carlsbad Technology implementation and installation.

Figure 1 In-Vehicle Components in Police Car Passenger Compartment

Figure 2 Equipment and Device Interface in Police Car Truck Space

3.2.1 Carlsbad Experience in Public Safety technology Project

Captain Dale Stockton [14] highly praised the effectiveness of Project54 after his department implemented such systems on 50 of their patrol cruisers. He pointed out that the keys to success of Project54 consist of the following factors:

- Simple non-proprietary interfaces,
- Compatibility with the widest possible range of equipment,
- Single site license for $500 to cover an agency regardless of the number of vehicles,
- Flexible and easy adaptation of desired components,
- Specialized digital array microphone for voice recognition,
- Short learning curve for new users,
- Great cost-benefit returns for agencies.

In addition to the adoption of Project54, Carlsbad's successful Public Safety Technology program can be contributed to the additional renovation of the complete Information Technology Architecture. They worked with a vendor to implement the following components and functions:

- Cellular Wireless Communication Infrastructure, (This item was not bulleted in the article)
- Mapping-GIS,
- Automatic Vehicle Locator,
- Record Management,

- Automated field reporting.

The overall system results in a mobile office capability for officers, which allows the officers to perform a variety of functions, including:

- Registration/Stolen car inquiries,
- Driver license checks,
- Wanted persons,
- Email,
- Reports,
- Pictures,
- Crime analysis,
- Access all city and county justice systems.

Carslbad PD indicates that AVL has been an effective resource management tool and it improves services to the citizens by reducing response time in critical incidents. Importantly, the system offers safety protection to officers during the execution of field operations beside the convenience in lessening the driver/officer workloads.

3.2.2 Latest Status of Carlsbad Technology Implementation and Feedback

The research team made several visits to Carlsbad and communicated with the management as well as officers who used the technology system in the field. Some highlights are summarized as follows:

- Previously the GIS-linked mapping capability was only implemented in the dispatcher center. It is now also available in the police cruiser so that officers can check the locations of reported incidents as well as others officers in the neighborhood.
- License plate inquiry is fully functional. Carlsbad PD uses Verizon Wireless Communication as the telecommunication supplier. The inquiry data is sent through a Verizon wireless modem on board when officers made the request. The data is sent through the city office server, then subsequently to the county and state data server. The return message is sent in the reverse route and arrives in the police car on the monitor screen.
- The license check function can be done by using the conventional cruiser radio, the computer keyboard, or the voice recognition interface of Project54.
- The driver license check function is more challenging in California due to the large number of people who may have the same names as others and the diversity of names from different ethnic groups.
- Under certain circumstances, it is best that officers keep their eyes on the suspects. A return to their cruisers to perform other functions may put the officers in danger. Therefore, it will be desirable if a wireless bar-code reader or an externally accessible magnetic reader can transmit the data into the cruiser for inquiries.
- The researcher team was provided with a chance to ride along with officers. One officer just had the license plate check system installed on that day. His response was "awesome," and indicated that he would exclusively use the voice-activation for license check in the future. This showed that there were few learning obstacles despite that one particular officer might be more technology inclined than others.

- The officer was particularly excited about the opportunity to use the advanced computerized system. He commented that the major advantage, besides the ease of use in the field, was the safety benefit for the officers to keep their eyes and attention more on the road and on the people that they need to watch.
- Meaningfully, based on communication with officers on duty who used the Public Safety Technology system, the system has been received favorably with very positive overall user experience.

3.3 Experimental Evaluation at University of California at Berkeley

The research team established collaborative relationships with UNH and Carlsbad after we learned of the success and advanced developments of project 54 Systems. Initially, the research team offered to provide a Project 54 system to CHP for their evaluation. However, due to the internal planning issues with CHP, the plan was halted. Subsequently, the research team contacted the University of California Berkeley Police Department and initiated the instrumentation of an experimental vehicle on one UCB-PD cruiser. The objectives of the experiments were to assess the following two aspects in accordance with the research plans:

(1) Exploring the technical and institutional issues in local environment when an officer-assistance system such as Project 54 is installed.
(2) Evaluating the use of vehicle-mounted GPS device for the purpose of vehicle location identification and incident reporting.

The detailed descriptions of various components installed in the experimental vehicle at UCB-PD are given in Appendix A.

3.3.1 GPS data recording

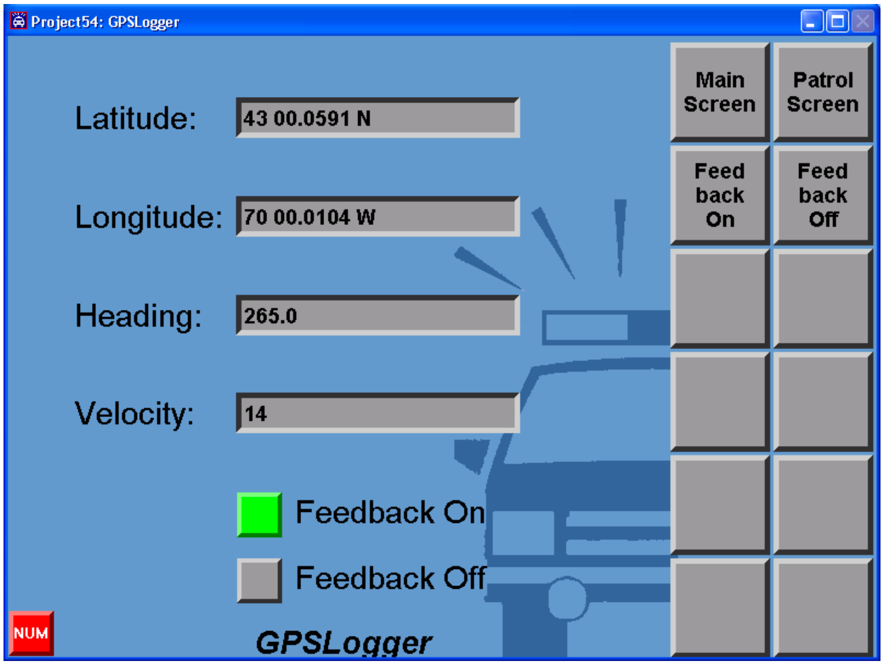

Figure 3 GPS Logger Graphic User Interface

For the purpose of GPS evaluation, the research team developed a data logger component on the experimental vehicle at Berkeley. GPS data recording is implemented in the Project 54 using C++. The data is recorded every second each time the GPS GUI is updated. Data recording starts at the beginning of the system every time the vehicle is started. Figure 3 shows the GPS Logger GUI of the system.

3.3.2 GPS Navigation

The UCB-PD requested that mapping software be installed on the experimental vehicle, as the officers indicated that navigation would be a preferred function on the vehicle. A mapping software, CoPilot, was later installed for the navigation system (Figure 4). The GPS data is received through the antenna mounted on the back of the trunk. USB GPS interface is connected through a 4-port USB HUB (See Electrical Diagram in Appendix A).

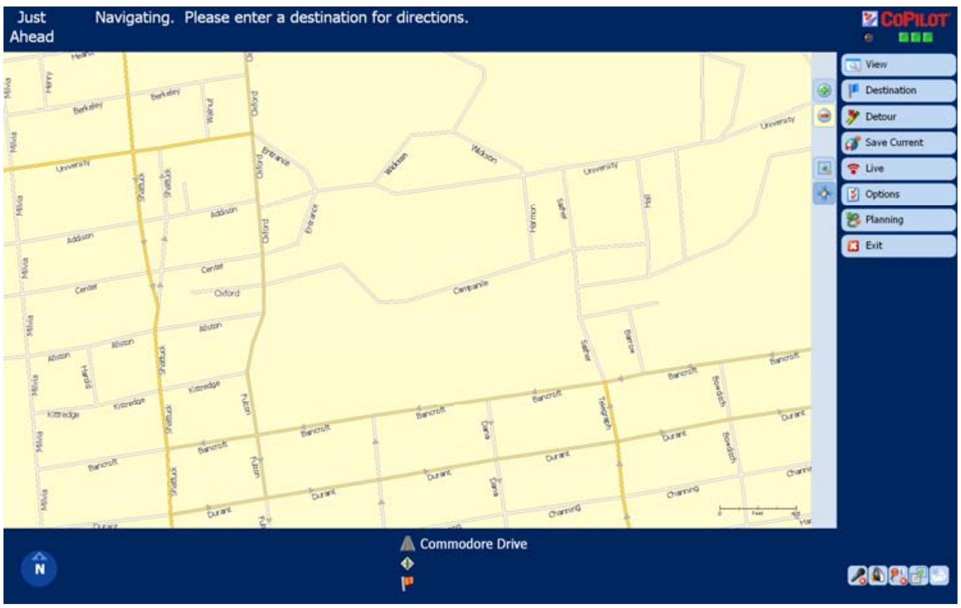

Figure 4 Mapping Software Interface

3.3.3 GPS Data Collection Format

The file name of the data was named as current date and time (military time) with extension “txt” (“yyyymmdd hhmmss.txt”, 20060918 103414.txt). There is a new file every sixty minutes, 20060918 113414.txt. There is also a new file at midnight, 20060919 000000.txt. A new file is also created when the system time is changed except when changing minute and second. For example, there will be a new file when changing system year, month, day or hour. Changing minute will not be effected in creation a new file unless minute is changed to the time before file was created or sixty minute after the file was created.

The data is written as date, time latitude, longitude, heading and velocity per line, as follow, every time a new data is updated.

09/18/06 23:34:34, N 43 0.0591, W 70 0.0104, 265.10, 14
09/18/06 23:34:36, N 43 0.0564, W 70 0.0104, 265.30, 14
09/18/06 23:34:38, N 43 0.0520, W 70 0.0205, 255.04, 16
.
.
09/18/06 23:59:59, N xx x.xxxx, W xx x.xxxx, xxx.xx, xx

3.3.4 GPS Data Display and Mapping

GPS interface is connected through 4-Port USB HUB (See Appendix A) and the location data from the GPS receiver is recorded and examined to check for their variability and consistency. Shown below in Figure 5 is an exemplar set of GPS data, which indicates a trace of the vehicle trajectory. Figure 6 depicts another set of GPS data traces with an overlap of the local street maps near the Berkeley campus.

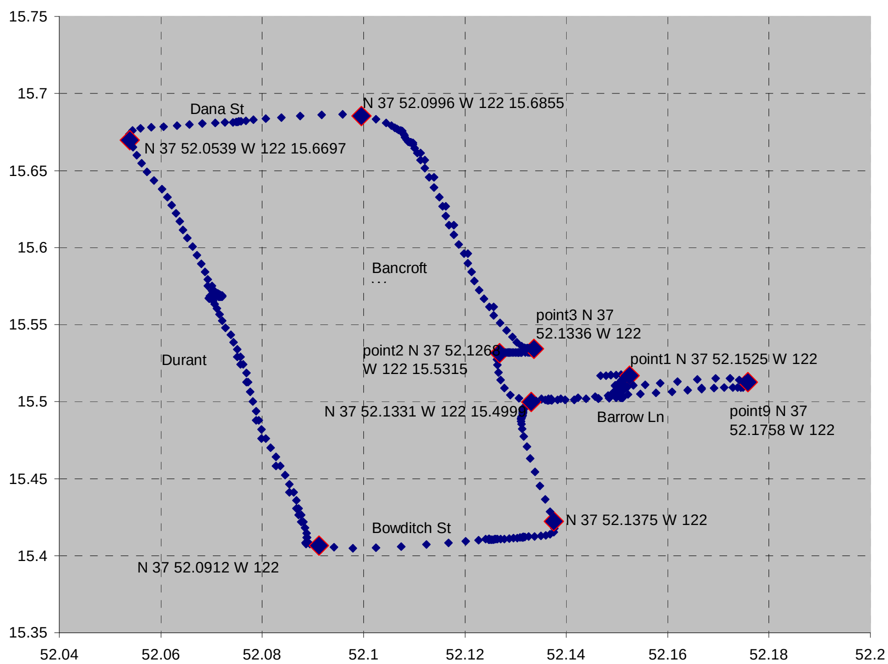

Figure 5 GPS Data Coordinate Display

Figure 6 GPS Data Display Overlapping with Local Street Map

3.3.5 Summary of UCB-PD Project 54 and GPS Evaluation

The results of GPS data experiments and Project54 at UCB-PD can be summarized as follows:
(1) Low-cost GPS devices are readily available with decent resolutions and performance specifications for the purpose of incident reporting.
(2) GPS Data recording in the Berkeley neighborhood, a suburban region with scattered tall buildings and occasional narrow streets, was consistent and reliable for its intended usage.
(3) Mapping and navigation was a function preferred by officers during the testing.
(4) Project54 is an easy-to-use system with minimum learning curves. However, the scale of experimentation with one single vehicle was too small to fairly assess its benefits.
(5) The radio units in the UCB-PD cruiser were not compatible with Project54. As a result, the overall performance was significantly reduced.
(6) More training and user interactive sessions are strongly desirable.

4. PHOTOGRAMMETRY

One primary factor in the delays of incident handling is the necessary and proper documentation of incident information for legal and technical reasons. The prevailing method of scene measurement is often conducted by physically walking the scenes with wheel measures or similar tools. The common method and its conventional approach present several issues: time consumption, road hazard, limitations at site, and the needs for photographic evidence. In this project, we investigated and developed a computer software application using photogrammetric techniques to facilitate the measurement of the aforementioned incident scenes. This software will allow the user to simply take one or a few photographs and extract all needed measurements in the convenience of the office, solving the shortcomings of the conventional method.

4.1 Photogrammetry Basics

Photogrammetry as defined by the American Society for Photogrammetry and Remote Sensing (ASPRS), in the Mapping Sciences, "*is the art, science, and technology of obtaining reliable information about physical objects and the environment through the processes of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena".* Or more simply put, photogrammetry is the technique of measure 2-dimensional and 3-dimensional objects from photographs using physics, geometry and mathematics.

For geometric analysis of crash sites, a great majority of cases will only involve the identification of points or objects on a 2-dimenaional plane. For example, occasionally it will be necessary to pinpoint the resting positions of a vehicle by reviewing a photograph taken after a crash. In this case, the tire-roadway contact points are the target locations to be identified by the photogrammetry tool. For another example, sometimes it is desirable to measure the length of a skid mark so that the pre-crash speed of a vehicle can be estimated. In this case, points along the skid mark will be the target points to be identified with a photogrammetry tool.

For different utilization scenarios of a photogrammetry tool, the respective levels of accuracy requirements can be quite different. When a major accident is thoroughly investigated because of serious injuries or fatalities involved, it is often required to obtain as detailed and accurate documented information and scene measurements as possible. This is particularly true if the evidence and associated analysis need to be used for litigation support. On the other hand, if the analysis of scene data extraction is used to provide supplementary information due to the incomplete documentation at the time of on-site measurements, then the requirements will be much relaxed. The tool developed under this project is generally intended for the latter.

4.2 Preliminary Version of Photogrammetry Application

In a previous project [3], a preliminary version of the photogrammetry application was developed in the Java programming language platform. [1] The particular advantage of this platform is its motto of "write once, run anywhere". It can be run on any operating system without future changes and maintenance. Furthermore, not only can it be deployed as a desktop application on any platform, it can also be deployed onto any web page as a Java Applet or as a Java Webstart Application.

To use this application, a photograph taken from the incident scene must be loaded as a digital format. Such digital formats can be obtained directly from a digital camera itself, or scanned from a physical photograph into any of the supported digital formats. The digital formats supported include:

JPEG: (Joint Photographic Experts Group) www.jpeg.org
GIF: Compuserve GIF
PNG: Portable Network Graphics

The jpeg and gif formats are the most widely used in terms of storing highly compressed lossy (jpeg) and lossless (gif) photographs. Should other formats be used, they can be easily converted to these formats with any convenient graphics program such as Windows Paint, Photoshop, or ACDSee.

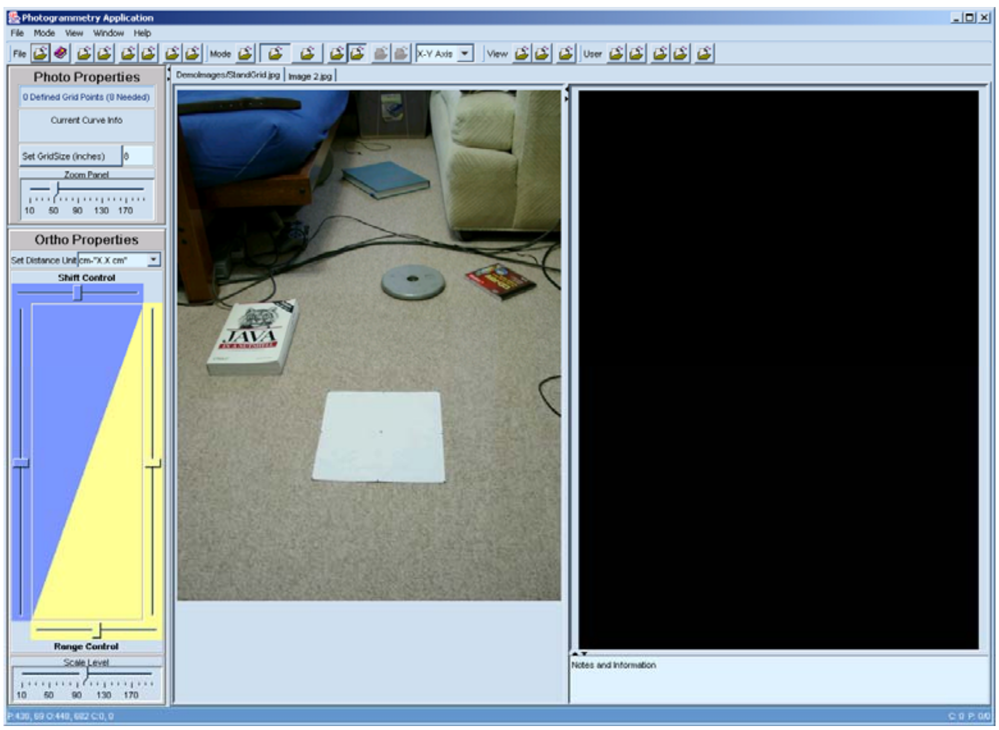

Figure 7 Basic Screenshot of Photogrammetry Application

Figure 7 shows the main display or interface for the developed application. The application itself has an intuitive and easy to use Graphical User Interface (GUI). There are two main views of the loaded image:

- Photo View: Shows the original loaded digital image. Located in the center of the GUI.
- Orthographic View: Shows the result of the photogrammetric techniques; where all the measurements are shown. Located on the right of the GUI.

In addition to the Photo View and the Orthographic View windows, the application also contains various tool bars, drop-down menus on the left side and top side of the displays. For example, the two-color (colors seen in application but not visible on report pages) rectangular window on the left of the GUI is used for scaling and zooming adjustments of the Photo View and the Orthographic View.

In using the application, any of the interested point in the photograph can be selected or defined by directly clicking onto the photograph in the Photo View, resulting in a numbered point. The result of defining a point will produce a corresponding point in the Orthographic View. Multiple points can be defined to outline more complex objects. See Figure 8.

The projection from the Photo View to the Orthographic View yields the real-world distances between any two of the defined points, which is shown in the right-side window of GUI. To extract measurements from photographs of accident scenes, the simple technique of defining the distances between two points and the length of any straight edged object does not suffice. Usually the projection and measurement of curves are also needed. The developed application supports this required functionality.

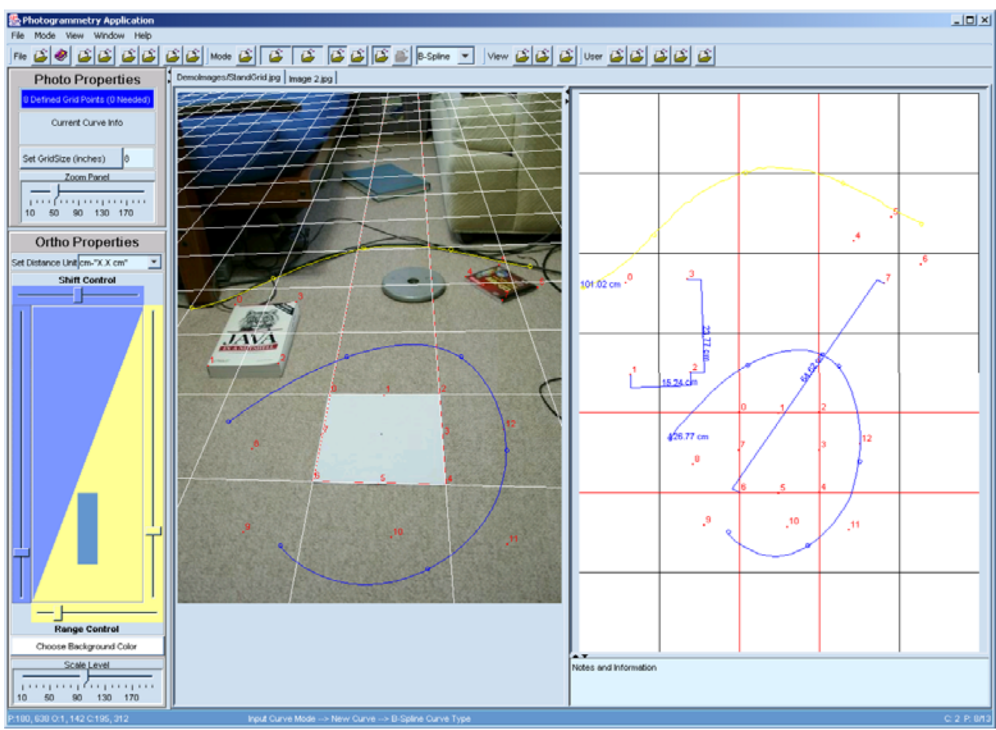

Figure 8 Screenshot with Multiple Defined Points on the Photo View and Corresponding Orthographic View

4.3 Revised and Enhanced Version of Photogrammetry Application

The application software developed in this current project is a continuation of previous work described in the previous section. The objectives of the software developments for this project include modifications in several areas:

(1) Functionality Enhancements

- Adding options for aerial survey photographs
- Providing object naming and editing options
- Providing curve-fitting options
- Allowing output diagram download
- Including output-diagram merging, if photograph scenery allows

(2) Calculation Procedure Revisions

- Adding the option of grid generation in photos without template
- Refining grid generation methods and techniques
- Enhancing calculation and error-checking procedures
- Adding measurement unit selection

(3) User Interface Improvements

- Revising function selection menus and windows
- Enhancing display options and color selection

4.3.1 Revised Screen Display and User Interface

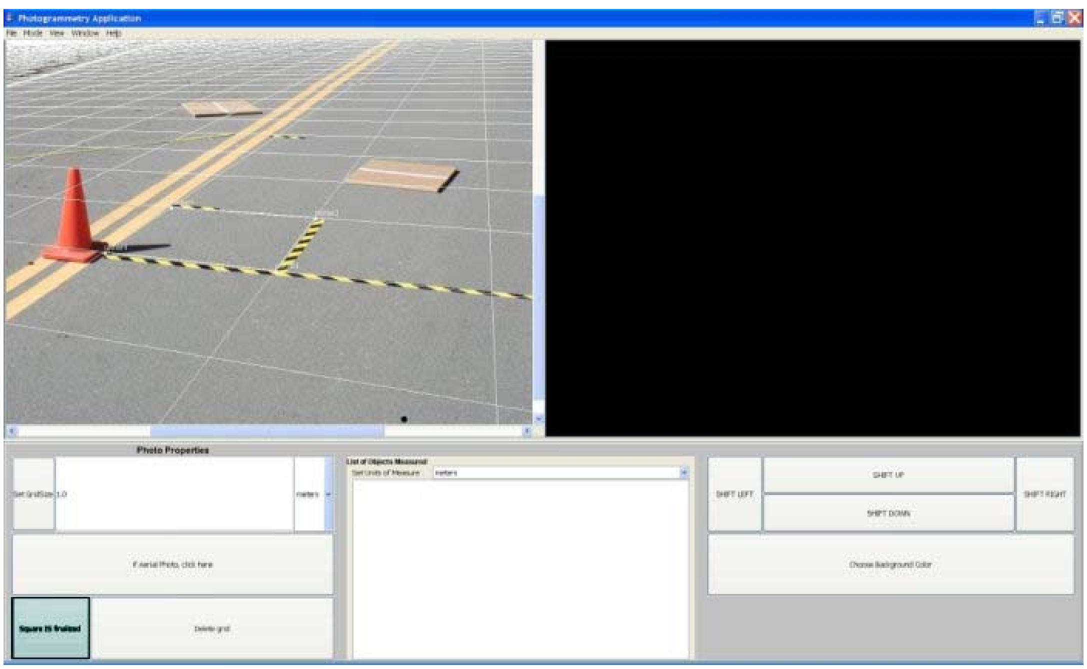

Figure 9 Basic Screenshot of Revised Photogrammetry Application

Figure 9 shows the main display or interface for the developed application. The application itself has an intuitive and easy to use Graphical User Interface (GUI). There are two main graphical elements of the loaded image:

- Photo View: Shows the original loaded digital image, located in the upper left portion of the GUI.

- Orthogonal View: Shows the result of the photogrammetric techniques; where the conversion of measurements from the photograph to an orthographic view are shown. Located in the upper right of the GUI.

In addition to the Photo View and the Orthographic View windows, the application also contains various tool bars, drop-down menus on the left side and top side of the displays.

An image is first loaded through the Open Image command under the File menu located in the top menu bar. Images can be exported through the Export Image. Export image will save an image along with any additional elements made by the user to the Photo View of the GUI.

The Mode menu located in the top menu bar has options for selecting different input modes. The modes that can be chosen are: Edit ref square, Input points, and Input curves. Edit ref square mode is the default mode when an image is first loaded. This allows a user to draw a reference square and make changes to the reference square. Input points mode allows the user to draw points on the image and also to draw lines between points. Input curves mode allows the user to draw curves between multiple points (or lines between 2 points).

In using the application, any point in the photograph can be selected or defined by directly clicking onto the photograph in the Photo View, resulting in a pop up box asking the user to name the point. The result of defining a point will produce a corresponding point in the Orthographic View.

The projection from the Photo View to the Orthographic View yields the real-world distances between any two or more the defined points, which is shown in measurements panel in the middle of the bottom portion of the GUI. The linear Spline curve mode can be used to find the total distance between a series of points.

In the lower left portion of the GUI, there is an input to set the size of the grid. This can be used to set the length of the side of the reference square. There is a text box to enter the number of units (should be a positive real number) and a drop down box to select the type of unit (ie. meter).

4.3.2 Aerial Photo Option

Below the grid size input, there is an Aerial photo button. This button can be used if the photograph is taken from an overhead aerial view where the expected grid overlay is already orthographic to the image. When this button is clicked, a pop up menu appears that asks for the scale (e.g. how many meters in an inch?), the unit of measurement, and how many pixels per inch. These inputs are then used to generate a grid overlay on the image.

4.3.3 Gird Adjustment Options

Below the Aerial photo button, there is a button that is labeled "Square NOT finalized" or "Square IS finalized" depending on the state of the grid overlay. If the reference square is drawn, but the grid has not been drawn yet, then clicking on "Square NOT finalized" will draw the grid overlay and cause the text of the button to become "Square IS finalized". Clicking the button again will cause the grid overlay to disappear and change the text of the button to "Square NOT finalized". The reference square can be adjusted when the text of the button reads "Square NOT finalized".

The Delete grid button is used to delete the grid overlay, reference square, and all other measurements. This button should be used when the user wants to start over with a new reference square or just to get a fresh start.

The lower right portion of the GUI has control buttons to shift the orthographic view up, down, left, and right. This can be used to shift the orthographic view when portions of the orthographic view do not appear in the Orthographic panel.

A method to draw a more accurate grid was implemented by allowing the user to set a measurement as a reference for the grid. By right clicking a measurement in the measurement panel, the user can select a measurement to be used as a reference. This allows the user to draw a reference square without knowing the measurements of it. If the user knows the length of another measurement on the image, then the user can input the length of that measurement and the size of the grid will automatically be calculated based on the user input.

4.3.4 Reference Square

The photogrammetry technique requires certain control points to be defined in the photograph. These control points are known as reference points or real-world locations. For our application we require 4 standardized control points (the four corners of a reference square). An example of a reference square is given in Figure 10. Once a reference square is drawn, the program can automatically extrapolate geometric information from the reference square to overlay a grid on top of the reference square. See Figure 11.

Figure 10 Example of A Reference Square

The overlay grid lies on the same plane as the reference square. In other words, the reference square should be drawn on top of the plane of interest. For example, in Figures 10 and 11 the reference square is drawn on the surface of the road.

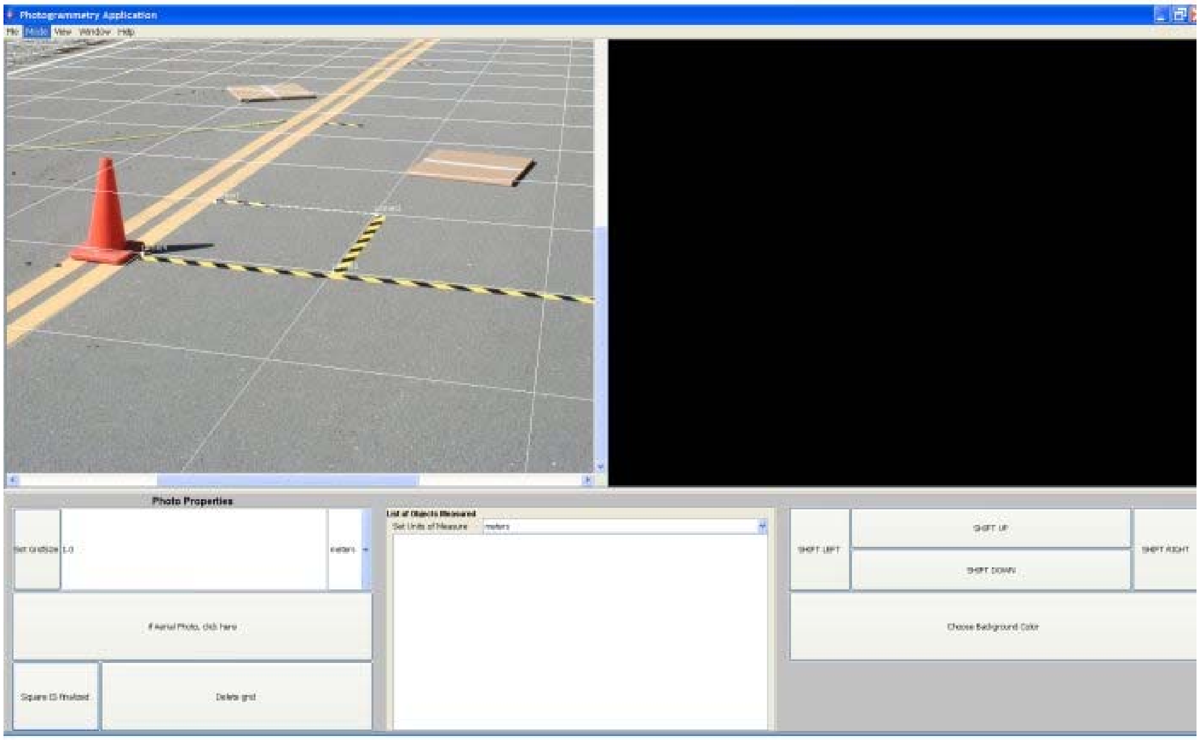

Figure 11 Image Panel after Grid Generation

4.4 Accuracy of Photogrammetry Application

The accuracy of the photogrammetric measurements relies on the accuracy of the drawing of the reference square. If the reference square is accurately drawn, then the accuracy of the application can be reasonably high. Test cases using a 3 foot reference square showed the photogrammetric measurements throughout the test image to be within 10% of the actual measurements. If the reference square is carefully drawn, usually the error is less then 5%. Photogrammetric measurements tend to be more accurate the closer they are to the reference square. The error tends to increase as the measurement moves away from the reference square because each pixel of error translates to a larger error.

Figures 12 and 13 show the measurement of a tape measure that is laid out close to the reference square. The reference square is 3 feet in length and the tape measure is laid out 10 feet. The application calculates the length to be 10.07 feet.

Figure 12 Measurement of a Tape Measure

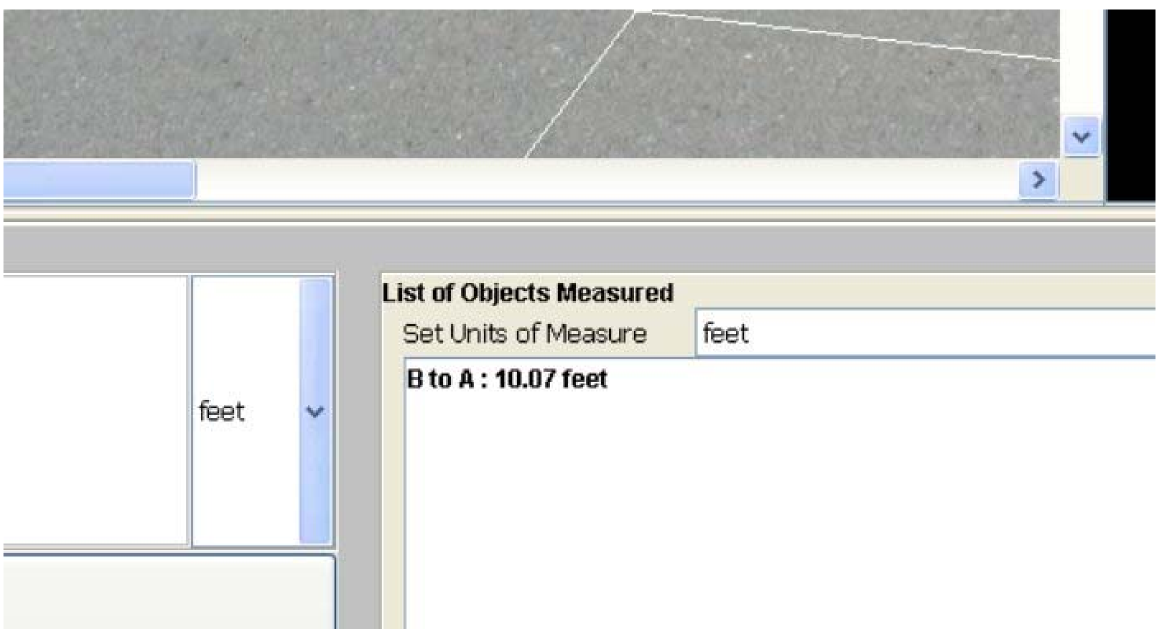

Figure 13 Application Calculating Tape Length

4.5 Future Extensions

In its current state, this software application is functional and can accomplish the essential functions in documenting roadway incidents. However, further improvements can be made to enhance the application software. Future developments may be pursued in these areas:

- An improved photogrammetry technique using mathematical principles derived from linear algebra instead of geometry, such as by a technique illustrated in Appendix B. [13-15]
- Improved GUI functionality to allow more user options and greater flexibility

5. SUMMARY AND CONCLUSIONS

In recent years, developments in computing and wireless technological fields have advanced considerably. Many devices and associated software are now readily available off the shelf. Selective use of such products will enable the implementation of driver-assistance systems for law-enforcement applications. In this project, we evaluated the applicability of GPS, Project 54, and Photogrammetry tools to assist law enforcement officers in handling and documenting crashes.

5.1 Scope of Technology Survey and Experimentation

During the course of the project, the research team carried out a broad survey and assessed the availability and suitability of individual devices and packaged systems for law enforcement applications. After initial evaluation, a collaborative relationship was established with the University of New Hampshire CATlab, where Project54™ was developed. This cooperative effort allowed us immediate access to the mature and already deployed technology set that appears to be an ideal candidate to be considered for CHP and state agency vehicle fleets.

The research team also collaborated with the city of Carlsbad Police Department, where a Public Safety Technology Problem was implemented with great success. Considerable resources were dedicated to implement infrastructure and vehicle renovations to provide officers with mobile office capability.

In addition, the research team deployed a Project 54 system at the Police Department of the University of California at Berkeley on an experimental vehicle on one UCB-PD cruiser. Experiments and user surveys were carried out to explore technical and institutional issues in using a driver-assistance system for law enforcement functions. Furthermore, work was also conducted to evaluate the use of vehicle-mounted GPS device for the purpose of vehicle location identification and incident reporting.

In this project, we also developed and enhanced a computer software application using photogrammetric techniques to facilitate the measurement of the aforementioned incident scenes. This software will allow the user to take photographs taken at the crash sites and extract supplementary measurements in the convenience of the office, mitigating the shortcomings of time-limited on-site documentations.

5.2 Summary of Findings

The evaluation of Project 54 provides tremendous insight into the keys to successful implementation of vehicular-based assistance for law-enforcement officers:

(1) Flexibility and diversity of user interfaces, which allows the users to activate on-board devices under various field operating conditions.
(2) Short learning curves with user-friendliness design.
(3) Non-proprietary open architecture, which allows the flexible choice of modular components and sub-systems.

Based on the feedback from the Carlsbad Police Department, their successful Public Safety Technology program can be contributed to:

(1) The system-wide implementation of Information Technology Architecture, and working closely with software vendor.
(2) Selecting the appropriate and user-friendly systems, such as Project 54.
(3) Multiplicity of functions giving officers mobile office capabilities.
(4) Favorable cost-benefit returns for Agency investment.

The results of GPS data experimentation at UCB-PD can be summarized as follows:

(1) Low-cost GPS devices are readily available with decent resolutions and performance specifications for the purpose of incident reporting.
(2) GPS Data recording in the Berkeley neighborhood, a suburban region with scattered tall buildings and occasional narrow streets, was consistent and reliable for its intended usage.
(3) Mapping and navigation was an application preferred by officers.

5.3 Recommendations

The recommendations as a result of the work described in this project can be summarized as follows:

(1) Close collaboration and frequent interaction between the developers and the users are essential for successful implementation of technology programs.
(2) Positive feedback from officers is achievable and apparent benefits for local jurisdictions can be expected, as evidenced in the New Hampshire Project54 Project and the City of Carlsbad Public Safety Program.
(3) Sufficient flexibility must be built into the user interfaces so that users can adopt a level of utilization according to his/her personal preferences.
(4) There may be significant institutional issues involved in the deployment of technology systems. Early participation and coordination by all interested parties is desirable.
(5) Extensive user training and extended phase-in periods could minimize the obstacles and mitigate the side effects.

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Appendix A: Experimental Vehicle Instrumentation

A.1 Computer Installation

The Project54 system embedded computer is installed in the right side of the trunk of the vehicle (Figure A.1). The made and model of the computer is, Advantech, PCM 9371.

Figure A1 Equipment Mounted inside the Trunk

A.2 Power supply Installation

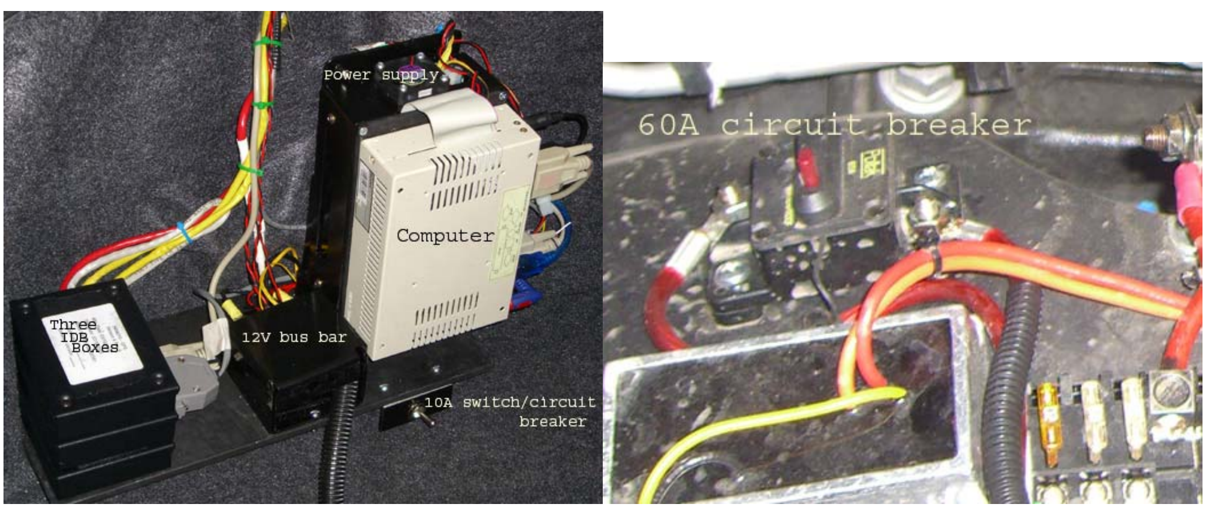

Figure A2 Power Supply and Ignition-Switch Controlled Circuit Breakers

The system is powered by DC to DC (OPUS Solution, Inc. Model: DCA.080.512) time delay power supply (Figure A2) directly from the car battery through 10A circuit breaker and 60A circuit breaker. The 10A switch/circuit breaker (Figure A2) is located by the computer and the breaker is used to turn on 30A relay which provides power to 12V bus bar. The 60A circuit breaker (Figure A2) is located in the engine compartment. However, the power supply is ON only when ignition signal is received by ignition signal (Figure A3) input of power supply. The power supply will be turned off approximately one minute after the ignition is turned off.

A.3 Interface Boxes (IDB Boxes)

There are five IDB (Intelligent Transportation systems Data Bus) boxes installed in the trunk. Radio and Light Bar IDE boxes are located near the radio and light bar control (Figure A5). Computer, Microphone and GPS IDE boxes are located by the computer (Figure A2). All IDB boxes are connected in series by network cable. For proper termination, the GPS box must be last unit in the network.

<u>Computer IDB</u> box is directly connected to the computer serial port and powered by 12V bus bar as shown in Figure A3.

<u>Microphone IDB</u> box is daisy chained to computer IDE box with network cable. The parallel port of the Microphone IDE box is used for executing voice command function. The execution is done by connecting the two wires of the parallel port when push to talk button is pressed (Figure A8). Since Ford Police car is not equipped with the cruise control option, one of the cruise control buttons can be used as push to talk button. However, the buttons on the cruise control do not make contact two conductors, instead they send different voltage levels between 0 to 5V when pushing a button. For Example, zero volt when pressing OFF button and five volt when pressing ON button. A cable connection is required in order to link between a button on the steering wheel and Microphone IDE box. Therefore, a simple circuit is necessary to trigger Microphone IDE box to listen voice command. The circuit between the Microphone IDE box and the OFF button on the steering wheel makes contact to the two wires from Microphone IDB parallel port by turning on relay (Figure A3). An inverting chip 4069 is used to turn on the relay when OFF button cruise control is pressed.

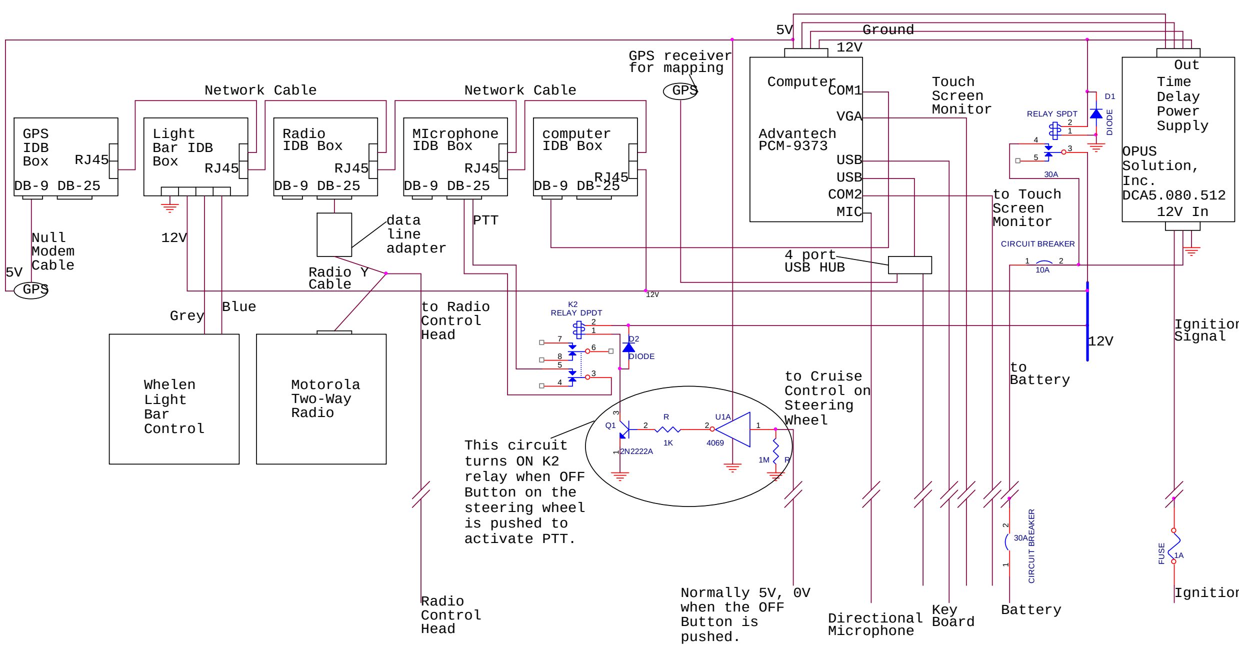

Figure A3 Electrical Wiring Diagram

Radio IDB box is connected to the other end of Microphone IDE by network cable. DB25 data port of Radio IDE box is connected to the Motorola radio and Radio control Head using "Y" cable. The Data Line Adapter is needed between "Y" cable and DB25 data port of Radio IDE box for conversion between RS-485 to RS-232. RS-485 is the standard serial communication protocol used on the Motorola radio external bus while the Radio IDE uses the RS-232 protocol on the DB25 port, see the diagram below (Figure A4).

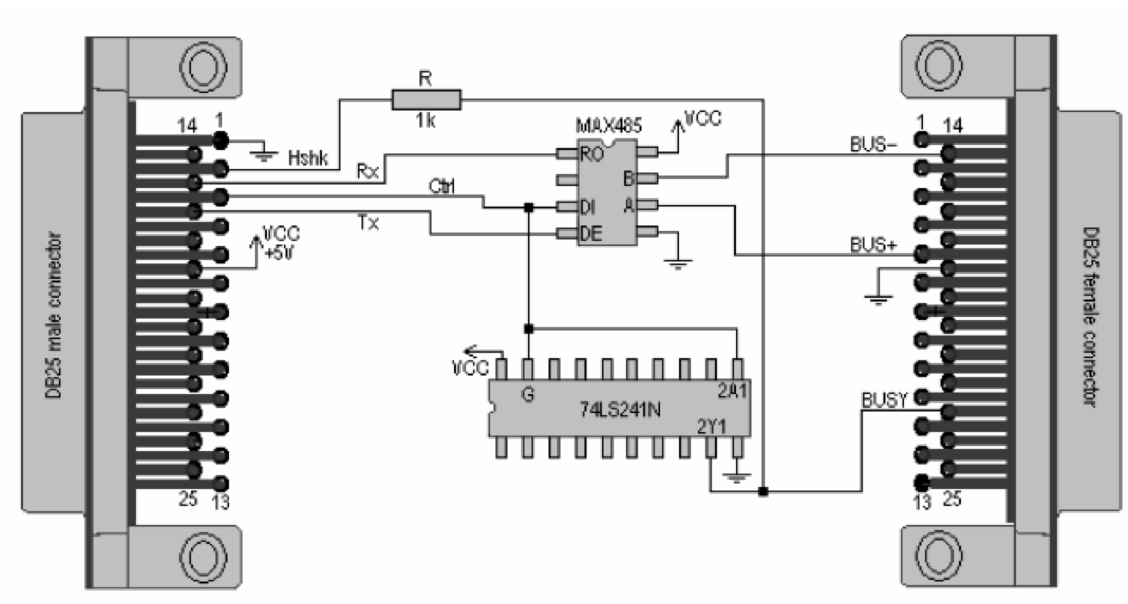

Figure A4 DB25 Port Connection

Light Bar IDB box is connected at the other end of Radio IDE network cable. Two wires (Grey and Blue) are used the connection between Light Bar IDE box and Whelen Light Bar control (Figure A5) for controlling light bar.

Figure A5 Whelen Light Bar Control

GPS IDB box is the last box in network connection as mentioned above. The GPS receiver is connected to the DB9 serial port of the GPS IDE box. The GPS unit is powered by computer power supply as it is needed five volts to power. The GPS antenna is located at the top of trunk cover (Figure A6).

Figure A6 GPS Mounting Location

A.4 Directional Microphone Installation

The directional microphone is installed behind the driver side sun visor. The use of a microphone allows an officer to commands via speech to the system. Microphone is directly connected to the system through MIC input of computer. Twelve volts power (12V from bus bar) is needed to power the directional microphone. The make and model of the microphone is Andrea, Auto Array AD-350 (Figure A7).

Figure A7 Microphone Mounting Location inside Windshield

A.5 Monitor and Keyboard Installation

The touch screen monitor is located by the right side of steering wheel between the driver and the passenger seat. One of the Serial ports is used for communication between computer and touch screen monitor. Also, twelve volt from bus bar in the trunk is needed to power the monitor. Make and model is Gvision, J1PS-DA-4266 (Figure A8).

Keyboard is installed right in front of the monitor and USB connection is used for the Keyboard. Make and model is Ikey, SL-86-911 USB.

Figure A8 Monitor and Keyboard Mounting next to Driver Seat

Appendix B: ***Camera Model for Spatial Projection in Photogrammetry***

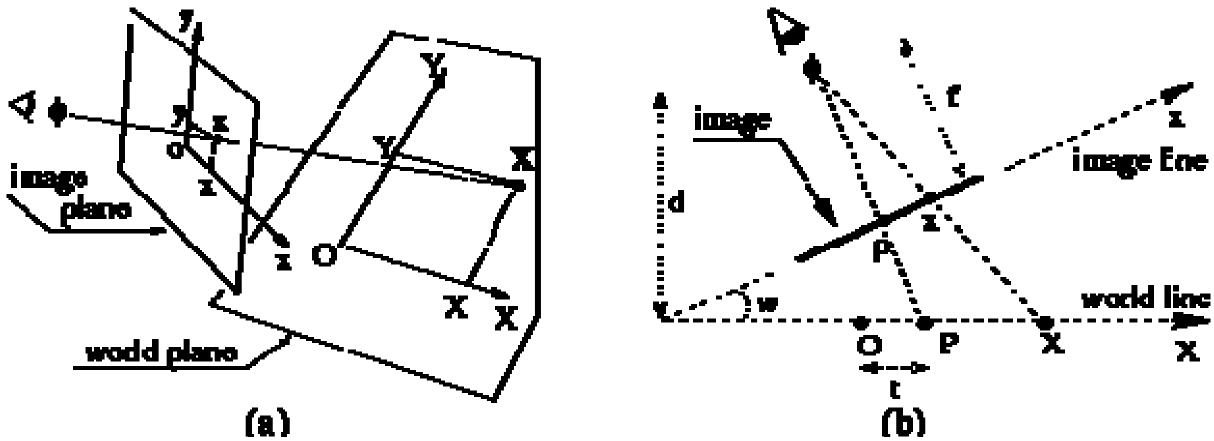

Figure B1**:** (a) Plane Camera Model: a point *X* on the world plane is imaged as *x*. Euclidean coordinates *X-Y* and *x-y* are used for the world and image planes, respectively. Φ is the camera centre. (b) One-dimensional Camera Model: The camera centre is a distance ***f*** (the focal length) from the image line. The ray at the principal point ***p*** is perpendicular to the image line, and intersects the world line at ***P***, with world ordinate ***t***. ***w*** is the angle between the world and image lines.

Figure B1a shows the imaging process. The notation used is that points on the world plane are represented by upper case vectors, ***X***, and their corresponding images are represented by lower case vectors ***x***. Under perspective projection corresponding points are related by [13, 14]:

$$\boldsymbol{X}=\boldsymbol{Hx}$$

where ***H*** is a 3X3 homogeneous matrix, and ``=" is equality up to scale. The world and image points are represented by homogeneous 3-vectors as $\boldsymbol{X} = (X,Y, W)^T$ and $\boldsymbol{x} = (x,y,1)^T$. The scale of the matrix does not affect the equation, so only the eight degrees of freedom corresponding to the ratio of the matrix elements are significant.

The camera model is completely specified once the matrix is determined. The matrix can be computed from the relative positioning of the two planes and camera centre. However, it can also be computed directly from image to world point correspondences.