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PATH – Partners for Advanced Transit and Highways – is a collaboration between the California Department of Transportation (Caltrans), the University of California, other public and private academic institutions, and private industry.

PATH's mission: applying advanced technology to increase highway capacity and safety, and to reduce traffic congestion, air pollution and energy consumption.

CALIFORNIA PATH

CarLink Success Prompts New Program

Susan Shaheen, PATH

Commuter-based carsharing programs, where members share a fleet of vehicles that provide a link between home, public transit, and workplace, give commuters the benefits of both a private car and public transportation. Although driving one's own car offers nearly unlimited flexibility at both ends of a commute, the monumental congestion endemic to today's highways exacts a heavy toll in wasted time, stressed drivers, and polluted air. Commuting by train is practical for people who live or work near transit stations, but most rail commuters have to face the problems of getting to and from the station, and parking at it. Transit feeder shuttles—buses that run from a transit station to neighborhoods or workplaces—are increasingly popular, but are limited both in the areas they serve and the times they operate. Most are subsidized in large part by transit agencies, i.e., by taxes. Carsharing programs, with their greater temporal and geographic flexibility, can be an excellent complement to shuttles; moreover, they have the potential to become commercially viable on their own.

Sharing a car for commuting and other trips can reduce a driver's stress, save money and reduce pollution

The CarLink commuter-based carsharing program was field-tested in Northern California from January to November 1999. The ten-month public-private partnership was implemented and researched by two teams at the Institute of Transportation Studies at UC Davis. Project partners included Caltrans, PATH, American Honda Motor Company, the Bay Area Rapid Transit District (BART), and UC's Lawrence Livermore National Laboratory (LLNL). The German-based smart carsharing technology company INVERS and Teletrac (US) provided the advanced carsharing and vehicle tracking technologies. The program featured short-term rental vehicles, linked by advanced communication and reservation technologies to facilitate shared-vehicle access at transit and employment centers. Fifty-four people from San Francisco, Oakland, and East Bay communities enrolled, and shared twelve natural-gas powered Honda Civics. The cars were based from premium park-ing spaces at the Dublin-Pleasanton BART station, about thirty miles southeast of the UC Berkeley campus, and from LLNL, about fifteen miles (24 km) east of the BART station.

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The CarLink Model

The CarLink model implemented during the field test included three separate user structures, as follows:

- **Homebased Users** drove a CarLink vehicle between their homes in the nearby suburbs and the BART station on workdays, keeping the car at home overnight and on weekends, and paying a fee of $200 per month.

- Workbased Commuters took BART to the Dublin/Pleasanton station, picked up a CarLink vehicle, and drove it to and from work at LLNL. The fee was $60/month per car, shared by carpooling.

- Workbased Day Users at LLNL used CarLink vehicles for business trips or personal errands during the day. The fee was $1.50 per hour and $0.10 per mile for personal trips.

All user fees included fuel, insurance, and maintenance costs. Roadside assistance and an emergency taxi service were also provided. CarLink implementation staff supported the program by cleaning and occasionally refueling the vehicles, as well as by maintaining e-mail and phone contact with users.

Figure 1. Arrivals and departures per hour at the BART Dublin/Pleasanton station (August 1999). Most Homebased Users parked CarLink vehicles at BART in the morning before the majority of Workbased Commuters arrived. In the evening, the opposite occurred. However, there was less flexibility in the evening, as many members from both groups arrived at the station at approximately 5 PM.

Time	Homeside	Workside	Time	Homeside	Workside
12:00 AM	1	0	12:00 PM	0	5
1:00 AM	0	0	1:00 PM	10	2
2:00 AM	0	0	2:00 PM	7	6
3:00 AM	0	0	3:00 PM	5	9
4:00 AM	2	1	4:00 PM	21	7
5:00 AM	1	0	5:00 PM	[illegible]	42
6:00 AM	[illegible]	0	6:00 PM	17	[illegible]
7:00 AM	[illegible]	38	7:00 PM	3	26
8:00 AM	15	50	8:00 PM	1	21
9:00 AM	7	41	9:00 PM	1	11
10:00 AM	1	12	10:00 PM	0	6
11:00 AM	2	8	11:00 PM	0	1

Parking—An Incentive

BART parking lots fill up quite early in the morning, and it is not uncommon for a Bay Area driver, faced with a full BART parking lot, to drive all the way to work rather than lose time hunting for a parking space near the station. Homebased users who commuted via BART before CarLink no longer had to arrive at BART by 7:00 AM or earlier to get a parking place.

CarLink I Technology

Various smart technologies were used to keep track of the cars, to make them available and secure, and to make record keeping convenient both for billing and for research purposes. Commuters got the car keys at the BART station by using a magnetically encoded card to open an electronic key box, which could be monitored from the CarLink office. LLNL employees made Day Use reservations via a web page. Drivers logged travel data on message display terminals in the cars, which were also equipped with radio-frequency based tracking units to inform the CarLink system of their whereabouts. These "smart" systems operated independently. Researchers have concluded that the program's effectiveness would be significantly enhanced by an integrated central management system that included scheduling and reservations, billing, vehicle location and messaging, and smart card vehicle access technology.

CarLink I Research Results

Researchers explored field test participants' attitudes throughout the study, using questionnaires, household interviews, and focus groups. Although the sample was not statistically significant (fifty-four people), valuable lessons can be drawn from the survey and interview results. Findings include operational understanding, participant profiles, behavioral findings, cost and revenue data, and directions for future research. A full discussion of the evaluation can be found in *CarLink—A Smart Carsharing System Field Test Report* (Shaheen et al.

2000), available through ITS-Davis or PATH, or on the Web at www.path.berkeley.edu/PATH/Publications/PDF/PRR/2001/PRR-2001-3.pdf

Key study findings include:

- User Demographics. Participants were predominantly male (67%), married (69%), homeowners (81%), with incomes above $50,000 (81%), and were between 41 and 64 years of age (59%). These numbers are not surprising, given the location of the program in the San Francisco Bay Area suburbs and that most participants worked for LLNL.

- Commute Stress Reduced. Even though many CarLink users' commutes took longer (ten minutes longer on average), they found them less stressful. Many considered the opportunity to read, relax, or work while traveling on BART a significant advantage.

- Personal Vehicle Use Reduced. CarLink drivers used their personal vehicles less while in the program.

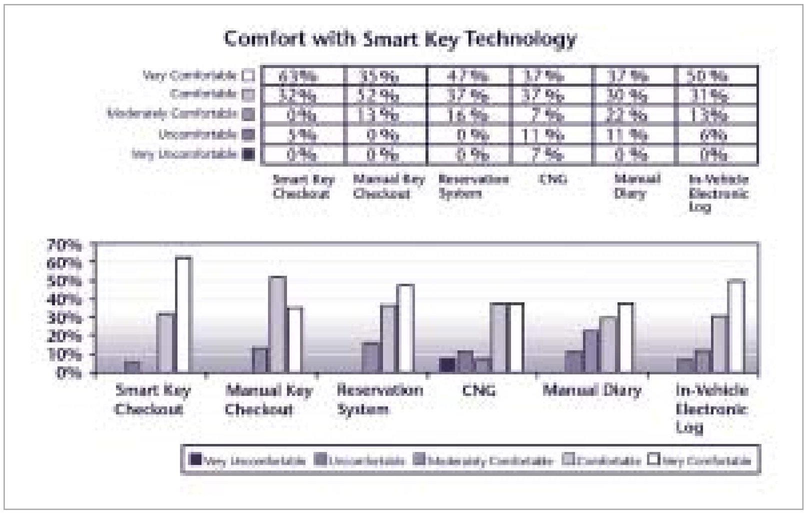
- Vehicle Miles Traveled Reduced. The combination of CarLink, BART, and carpooling resulted in a net commute reduction of approximately twenty vehicle miles (32 km) per day for each Workbased Commuter and Homebased User. This reduction was mainly because Workbased Commuters were more likely to have driven than to have taken BART before the test.

- Transit Use Increased. The participant group made at least twenty new BART trips each day. Furthermore, Workbased Commuters made more recreational trips on BART, as they became more familiar with the system and had easier access to it.

- Vehicle Mileage. The vehicles were each driven 1,000 miles (1600 km) per month on average.

- Smooth Vehicle Transfers. Vehicle transfer worked smoothly throughout the field test. Although on several occasions participants reported that a vehicle was unavailable when they arrived at BART, in all cases but one a car arrived at BART within five to fifteen minutes (in the one case, the participant caught a ride with a fellow user after waiting fifteen minutes).

Figure 2. User comfort with CarLink smart technologies. Overall, respondents preferred automated systems to manual methods (e.g., key lock box and travel diaries). Of all CarLink advanced technologies, only CNG refueling made some respondents "very uncomfortable." None of the smart technologies made more than six percent of respondents feel "uncomfortable."



	Smart Key Checkout	Manual Key Checkout	Reservation System	CNG	Manual Diary	In-Vehicle Electronic Log
Very Comfortable	63%	35 %	47 %	37 %	37 %	50 %
Comfortable	32%	52 %	37 %	37 %	30 %	31%
Moderately Comfortable	0%	13 %	16 %	7 %	22 %	13%
Uncomfortable	5%	0 %	0 %	11 %	11 %	6%
Very Uncomfortable	0%	0 %	0 %	7 %	0 %	0%

- Smart Technologies Preferred. Participants felt comfortable with the smart technologies used for vehicle access and tracking. When low-tech versions were offered (e.g., manual key boxes at LLNL vs. "smart" key boxes at BART, and paper travel diaries vs. display terminals), they strongly preferred the smart alternatives (see Figure 2).

- Homebased Users Would Sell Car. Several Homebased Users said that if CarLink became permanent they would sell one of their personal cars, which would greatly reduce their transportation costs.

- Workbased Users Hesitant. Workbased Commuters, however, said they would be hesitant about selling a private vehicle until transit services improved and CarLink supplied more lot locations and vehicle variety (e.g., minivans and pickup trucks).

- Ridesharing Technology Requested. Many Workbased Commuters had to adjust their schedules, at least occasionally, at the request of their carpooling partners. While some users had cell phones, and all had e-mail, they said a better system (i.e., one featuring some form of handheld device) was needed to facilitate user communication.

- Most Would Return to Solo Driving. Most Workbased Commuters interviewed said that they would return to solo driving after CarLink ended,

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Photodiode-Array Based Detection of Vehicles on the Highway

Harry H. Cheng, Benjamin D. Shaw, UC Davis; Joe Palen, Caltrans New Technology and Research Program; Bin Lin, Xudong Hu, Jason Park, Bo Chen, UC Davis

What travelers most want from a transportation system is a minimum of travel time and a maximum of reliability (i.e., reduced travel time variance and reduced risk). Since all travelers must implicitly or explicitly assess their various travel options before embarking on any trip, this information is definitely of high value. And since trip travel time is the parameter people are most concerned with, it is most important for the transportation service providers to measure and minimize it. Giving travelers an accurate and comprehensive assessment of their transportation system's short-term future state will be a major benefit of intelligent transportation systems (ITS). Travel time is a good indicator of other direct constraints on ITS efficiency: cost, risk, and attentive workload (Palen 1997).

Figure 1. Test site with detection system mounted above the highway. Field tests were conducted with actual traffic.

We have developed a new photodiode-array based system capable of measuring vehicles' speed and length that has several advantages over other systems currently in use. It is easier to install, more accurate, and requires much less computation, and computational hardware, than other systems. Not only does our system produce local speed, vehicle volume, and vehicle classifications, but it also allows highly deterministic reidentification of vehicles between sites, even under high flow conditions. The system's ability to identify and classify vehicles at one detector station, and reidentify them at another station farther down the road, means that point-to-point travel time, incident detection, and origin/destination data can easily be determined.

In current practice, traffic conditions are most commonly measured by inductive loops or video image processing (Coifman 1998, MacCarley 1997). An advantage of our system over loop detectors is its relative ease of installation and maintenance. Since the loops have to be buried beneath the pavement, installation requires heavy equipment, closing lanes, and rerouting traffic. Because our system is mounted above the road, once installed it can be maintained without disrupting the flow of traffic. More importantly, loop detectors cannot be relied upon to produce accurate speed (and therefore length) measurements because the inductive properties of the loop and loop detectors vary (Tyburski 1989). Video can be used to directly measure the length of vehicles; however, real-time video image processing is computationally intensive. And because our system uses an active lighting source, it can work more effectively in twilight than video. Validation of any traffic model requires, either implicitly or explicitly, traffic origin and destination (O/D) data, which in turn requires vehicle identification and reidentification (Kang and Ritchie 1998, Coifman 1998). Our system can directly determine O/D data non-intrusively, without violating the public's privacy, unlike license plate recognition systems.

One system that bears some similarity to the system we have developed is the Automatic Vehicle Dimension Measurement System (AVDMS) developed by the University of Victoria (Halvorson 1995). The AVDMS uses laser time-of-flight data to classify vehicles based on length, width, or height, and is based on the Schwartz Electro-Optics Autosense III sensor (Olson 1994). There are some significant functional differences between our system and Schwartz's. For example, the Schwartz detector determines the range (or distance) from the detector to the objects being detected; our detector does not. The Schwartz detector's laser reflects off the vehicle to determine the size, shape, and "presence" of the vehicle; our detector's laser reflects off the pavement, and the temporal obstruction of the reflection determines the size, shape, and "presence" of a vehicle. Schwartz's system has a rotating mirror system, whereas our system has no moving parts. The detection system is described in detail in Cheng et al. 1999.

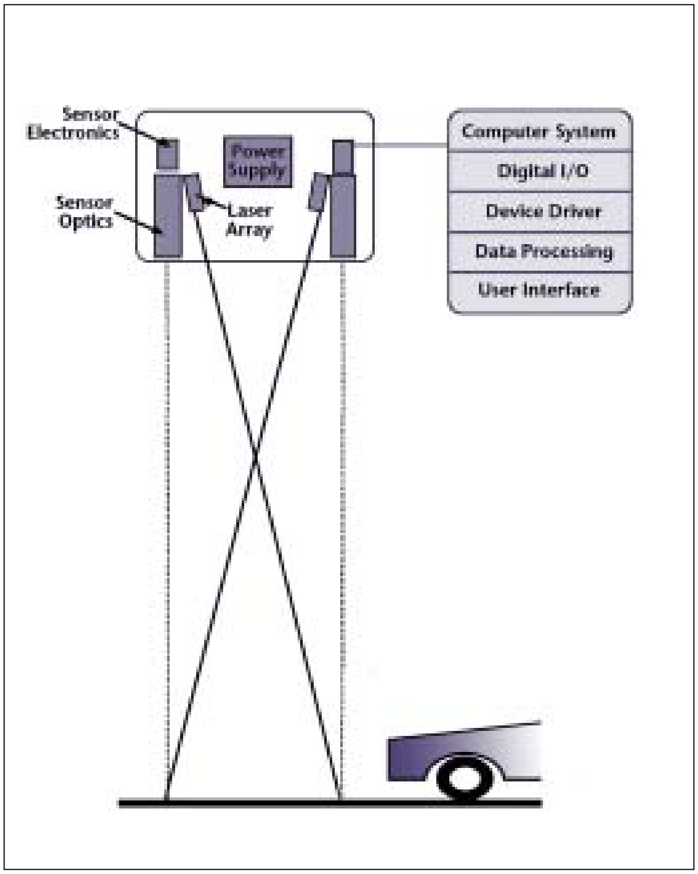

Figure 2. System overview (not to scale)

Principle of the Detection System

In our laser-based detection system, vehicle length is used as the primary identifying feature and is measured using two laser-based detector units. The system operates in the following manner, as shown in Figure 2. The basic detector unit consists of a laser and a spatially offset photodetector positioned above the plane of detection. The laser is a pulsed infrared diode laser that utilizes line-generating optics, which project to a flat surface where objects are to be detected. The detector consists of imaging optics and a linear photodiode array. The offset photodiode array receives the laser light that is reflected back from the region of detection. The signal from the photodiode is amplified and sent to a computer for processing. Vehicle presence is detected based on the absence of reflected laser light. Two of these units are integrated and placed a known distance apart, allowing an object's velocity and the time spent under each detector to be measured. This provides the object's length and top-down outline profile.

The detector is mounted at a distance of about 6.4m (21 ft, the height of a typical highway overpass) above the highway. The distance between each component of a laser/sensor pair is 30.5 cm (1 ft). The offset between the two sensor pairs is 10 cm (4 in). The sensors are mounted in a fixed vertical position, pointing downward, and are focused on the ground, forming two detection zones. The lasers are pointed towards the detection zones and are mounted at an adjustable angle, allowing the system to be mounted at different heights. The detection zones (i.e., the laser lines) stretch across the width of the lane and are each about 13 mm (0.5 in) wide in the direction of traffic flow. Because of the angle at which the beam is reflected, and the distance between the laser and the sensor, objects passing between the pavement and the sensor that are taller than a given height (the critical height) reflect the laser beam away from the sensor, and hence "block" the beam. For objects lower than this height, the beam is still visible to the sensor. (See Figure 3.) In our current prototype the critical height, also called the minimum detectable object height, is about 46 cm (18 in). This is lower than the bumper height of most common vehicles. The critical height could be reduced in future versions of the system.

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When a vehicle moves into a detection zone, it blocks the laser from being received by the sensor. When the first beam is blocked the time is recorded. When the second beam is blocked, a second time is recorded. These times give the speed of the front of the car. In a similar manner, when each of the beams is no longer blocked, the times are recorded and the speed of the rear of the vehicle can be calculated. The time that each detector is blocked is also recorded and is used to calculate the vehicle length, assuming constant vehicle acceleration. The assumption of constant acceleration is valid for free-flow traffic conditions, where there is negligible acceleration, and for conditions where the vehicle is accelerating or decelerating uniformly during the time it is in the detection zone.

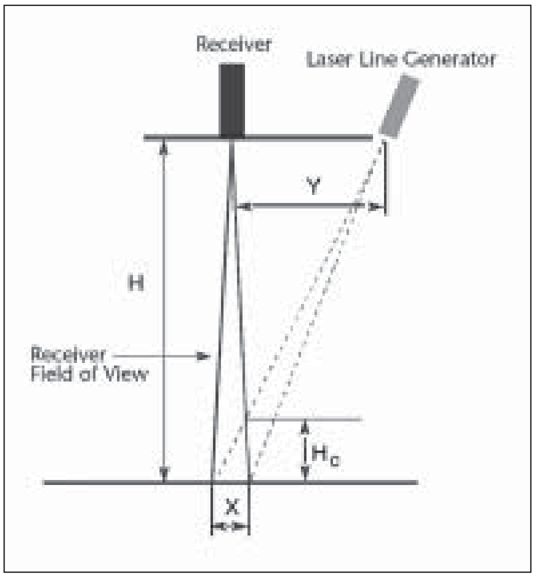

Figure 3. Critical object height

Lasers and Optics

Two off-the-shelf integrated ML20A15-L2 diode laser systems from Power Technology Inc., are used as the laser sources. This laser system can be pulsed at a maximum rate of up to 10 kHz. Its high performance and small size make it a good candidate for use in the field deployable prototype system. A wavelength of 905nm for the laser was chosen for a number of reasons. Infrared light has good transmittance through fog, giving the system good performance under a wide range of weather conditions. Furthermore, the intensity of sunlight around the wavelength of the laser is a local minimum, giving the system better rejection of noise due to sunlight. An infrared laser was also thought to be more appropriate for outdoor use because it is invisible to the human eye, and would therefore cause no distraction to passing motorists. In the field-deployable prototype it is also necessary that the laser be eye-safe. Calculations indicate that the laser power intensity of our detection system is below the minimum national laser safety standard by a large margin (Cheng et al. 1999).

The sensor optics consist of an imaging lens system and a telescopic lens system. Because the laser line is much longer than it is wide, use of the imaging lens alone would result in a much wider strip of pavement being visible to the sensor than is desired. The telescopic lens system, mounted in front of the imaging lens system, is used to match the dimensions of the laser line image with those of the sensor array. It is designed to restrict the field-of-view of the imaging lens along the width of the laser line, but not alter the field-of-view along the length of the line. The imaging lens system focuses the reflected laser light onto the active area of the sensor array. A bandpass filter that is matched with the wavelength of the laser is used to reduce the level of ambient light received by the sensor. Figure 4 shows configuration of the laser detection system. The size of the system is measured as 25x18x5 inches (58x46x13cm).

System Electronics

The system only needs to distinguish whether a vehicle is present beneath the detection system. A sensor electronic system has been developed to detect the weak reflected signals using low-cost commercial components. The electronic system outputs digital signals directly. This design significantly simplifies signal processing in the software, therefore reducing the requirements of the computer system. The implementation of this method is based on the high signal-to-noise ratio of the circuitry. Figure 5 is a block diagram of the system hardware.

A 25-element avalanche photodiode (APD) array is used as the sensor in our detection system. The sensor converts the reflected laser light into a current signal. Low-cost, high-speed amplifier chips with suitable bandwidth were chosen to meet the high demand of our detection system for signal amplification. A TTL logic circuit, which is triggered by laser pulses to generate digital output, is used to

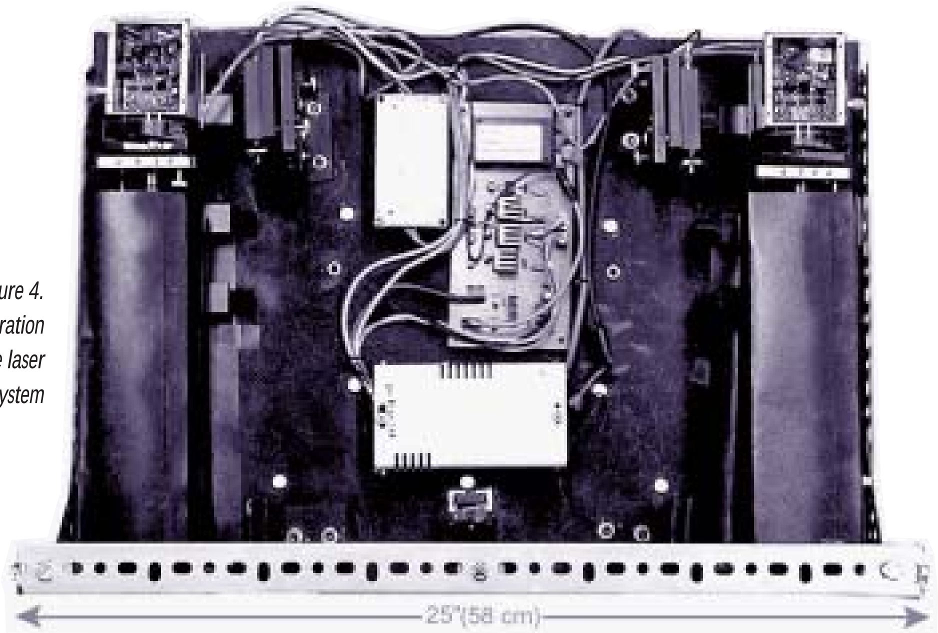

Figure 4. Configuration of the laser detection system

replace a sample-and-hold amplifier for signal peak detection. This method improves the time response of the system.

Real-Time Data Acquisition and Processing System

Since the sensor circuit outputs are digital signals, an A/D converter is not needed. A general-purpose low-cost digital I/O board (PCI-DIO-96 from National Instruments) is used as an interface between the sensor circuitry and the computer system. This digital I/O has 96 channels of configurable input/output, so it is suitable for our system when all 48 channels are required. Real-time data acquisition software is used to collect, process and display signals from the hardware of the detection system. All tasks, such as determining vehicle presence, calculating vehicle parameters, displaying results, and storing data to the disk or sending data to the remote machine, have to be done at the same time. However, the data has to be read from the output of the sensor electronic circuit in accurate time intervals. In order to reduce the cost of the system, we have developed software on RTLinux, a real-time Linux system. Because the kernel of RTLinux is small and fast, the data reading task, which has the highest priority in the program, can be scheduled periodically at a frequency higher than 10 kHz.

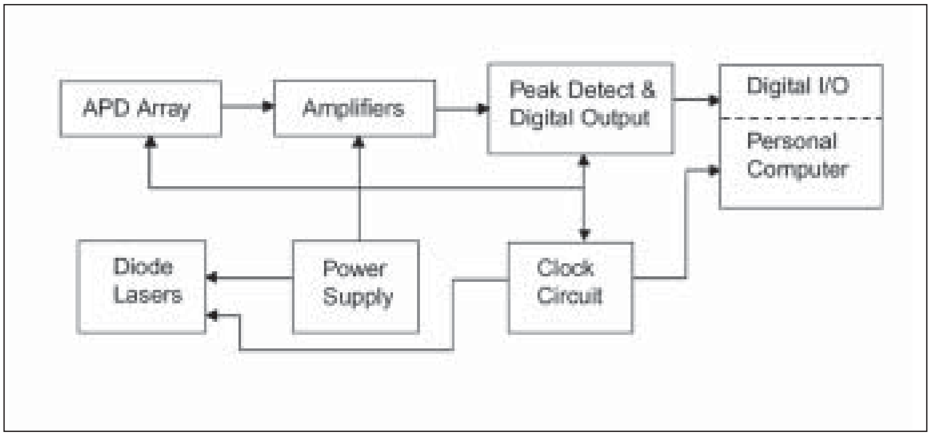

Figure 5. Block diagram of electronics hardware

Field Test Results

In the current phase, only four of twenty-four elements of each photodiode array were used for testing. The more elements are used, the higher resolution in the width of vehicles can be obtained. The front and rear speeds, length and acceleration were obtained in the tests. The sampling rate of data acquisition is 10 kHz.

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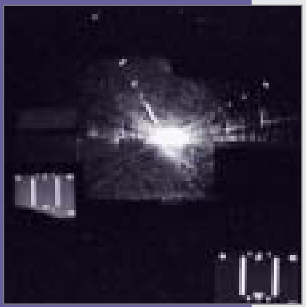


PATH Cars Popular Attractions at SmartCruise Demo 2000

Japan Demo 2000

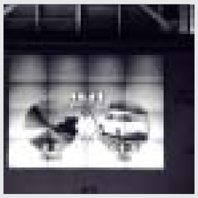
STEVEN SHLADOVER, PATH

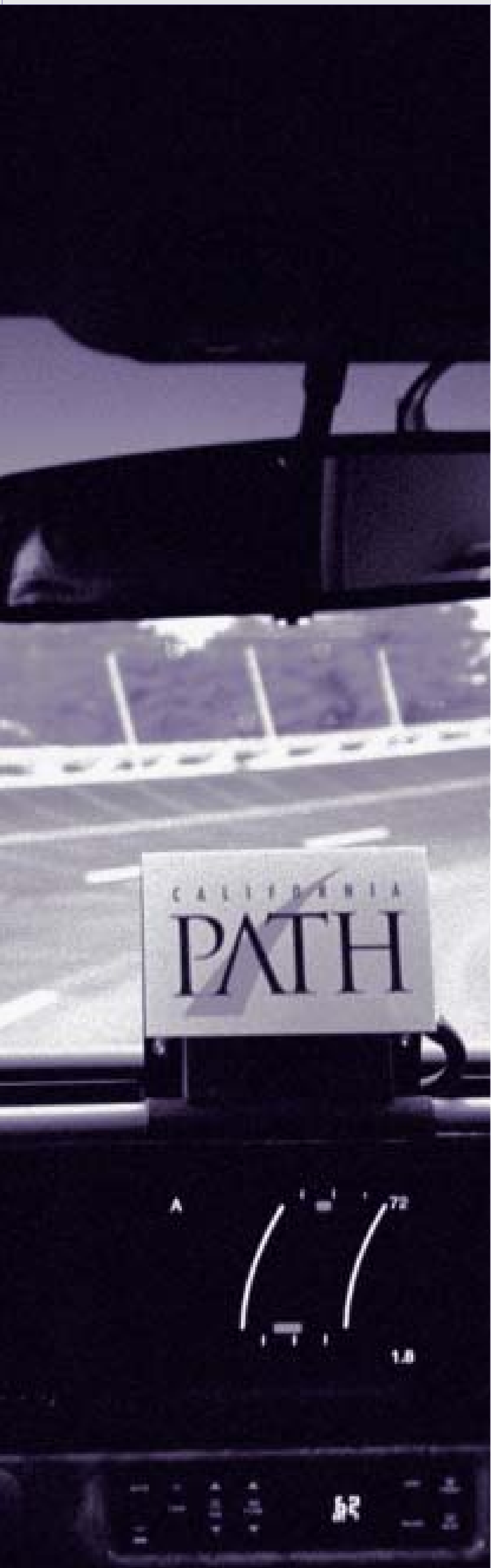
PATH continued its unprecedented and uninterrupted streak of participation in all major international demonstrations of Advanced Vehicle Control and Safety Systems (AVCSS) by participating in Demo 2000 under the sponsorship of Japan's Ministry of Construction. This sequence began with Demo '97 in San Diego and has continued through Demo '98 in Rijnwoude, Netherlands; Demo '99 at the Transportation Research Center, Ohio; and now Demo 2000 in Tsukuba City, Japan. We were one of only three non-Japanese vehicle demonstration teams at this most recent demonstration (the others being DaimlerChrysler and Hyundai).

PATH researchers showed how we could use magnetic markers buried in the pavement to support two of the seven "user services" specified for Japan's "Smart Cruise Systems," preventing vehicles from wandering from their lanes and preventing them from entering curves too fast. In practical terms, the demonstration showed how a driver could be provided with a guidance display to help steer the vehicle accurately, even with zero visibility in a fog-filled tunnel, as well as lane departure warning, lane departure prevention (by corrective automatic steering action) and completely automatic steering control. PATH also demonstrated a new feature that lets the driver switch automatic steering on and off using a button on the steering wheel. This capability is based on recent innovative PATH research on transitioning between automatic and manual driving control.

The six-kilometer-long test track of the Ministry of Construction's Public Works Research Institute (PWRI) was equipped with magnetic markers using knowledge gained from much prior PATH research. However, the Japanese implementation of magnetic marker technology differed from PATH's implementations in the United States in a number of important ways:

Markers were installed at 2-meter separations rather than 1.2 meters. Three rows of markers per lane were used, rather than one. Magnetic fields of the markers were five times stronger. And, there was no binary coding of roadway geometry information.





These differences posed significant development challenges for the PATH team, who had very limited time available to make the necessary accommodations.

Our participation in Demo 2000 succeeded because of the intense, dedicated work of PATH staff researchers Han-Shue Tan, Bénédicte Bougler, and David Nelson, who spent many long, hard weeks working at the PWRI test facility, an ocean away from home, while Paul Kretz provided critical support from home base in Richmond. Because the tight project schedule left almost no time to test our vehicles (two of the Buick LeSabres from Demo '97) before they had to be shipped to Japan, Han-Shue and Bénédicte spent nearly all of October and November in Tsukuba City making necessary changes to the hardware and software, so that the cars would work in cooperation with the different Japanese infrastructure elements, and performing the necessary "proving tests." This was especially challenging because of limited time available on the test track (since the same facilities were shared by sixteen other vehicle development teams), frequent changes in operating conditions, and a significant language barrier. Outstanding support and cooperation from the Demo's hosts and organizers made it possible to overcome these challenges and bring off a very successful demonstration.

They tested the vehicles under a wide range of conditions, including much higher speeds than used in the public demonstration and at different marker spacings (by ignoring some of the markers on some test runs). They also showed that we could integrate a new magnetic sensor system, developed by the demonstration hosts, with the rest of our vehicle systems.

Demo 2000 attracted a large number of visitors for rides in the test vehicles, including a substantial number of international participants. We were very pleased that our PATH cars worked perfectly on every demonstration ride, and became increasingly popular attractions from day to day, as word of mouth about their outstanding performance spread among the visitors. We were also pleased to see that so many elements of an important international demonstration were built on a key enabling technology (permanent magnetic markers installed in the pavement) that we invented and refined here at PATH. ■

CarLink Success Prompts New Program

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although some would try to carpool more frequently than they had previously.

CarLink II Pilot Program

The field test's key finding was participants' willingness to sell a vehicle and increase their use of transit or carpooling if the program were ongoing. Accordingly, Caltrans, American Honda, PATH, and UC Davis, have entered into the CarLink II pilot program, which will investigate the economic potential of commuter-based carsharing and test an integrated new carsharing system. CarLink II will further test commuter-based carsharing's market potential in two main ways. First, it will evaluate user demand and satisfaction, building upon the findings of the CarLink I field test. Second, researchers will assess CarLink II's economic potential based on the deployment. For more information on CarLink II, please visit: www.gocarlink.com. CarLink II includes a continuation strategy for evolution of the program to an ongoing carsharing organization. Because many CarLink I participants were willing to continue in the program, a more permanent approach was considered critical by the CarLink II project partners.

To broaden the program's economic base, Carlink II focuses on providing commuter feeder and Workbased Day Use services to many companies in its service area rather than a single employer. Multiple employer/employee participation in turn requires the development of integrated carsharing technologies to coordinate vehicle tracking, data collection, and reservations. "Smart keys" will enable instant vehicle access and eliminate the need for multiple key boxes at transit stations and work locations. The potential of these technologies to enhance service capabilities and reduce program costs is central to the CarLink II program and evaluation. The CarLink fleet will increase from twelve to twenty-seven vehicles, all 2001 Ultra Low Emission Vehicle (ULEV) Honda Civics. Using more vehicles will enable researchers to evaluate carsharing's market niche potential with greater statistical significance. CarLink II's service area is the Palo Alto/Stanford region; the cars are based at the California Avenue Caltrain station and at the Stanford Research Park. Caltrain is a commuter rail system that runs from San Francisco to San José and the southern suburbs for approximately 75 miles (120 km). The notable congestion and growth of the South Bay also renders it a prime location for exploring commercial viability.

The CarLink II user model also has three distinct categories of users sharing the cars: Homebased Users, Workbased Commuters, and Workbased Day Users. All CarLink user fees include fuel, insurance, maintenance, cleaning, roadside assistance, and an emergency taxi service. CarLink staff maintains e-mail and phone contact with users.

Over the past decade carsharing has become common in Europe, where approximately 200 carshar-ing organizations in 450 cities claim a membership of almost 200,000 participants.

Its use is increasing in North America: besides CarLink, programs are underway in Portland, Oregon; Seattle and Olympia, Washington; Boston, Massachusetts; San Francisco (www.sfcarshare.org) and Riverside, California; Boulder, Colorado; Rutledge, Missouri; and Traverse City, Michigan. Others are planned for Chicago, Illinois; Corvallis, Oregon; Fort Collins and Aspen, Colorado; Los Angeles, California; and Washington, DC.

Carsharing is an idea whose time may well have come. But for carsharing to expand successfully in the US, programs must be able to thrive with minimal outside support. CarLink II is the next step in determining carsharing's economic viability.

Related Research Papers and Reports

Shaheen, S. 2001. Commuter-based carsharing: market niche potential. TRB Paper Number: 01-3055. 80th Annual Transportation Research Board Meeting, Washington, DC.

Shaheen, S., and R. Uyeki. 2000. CarLink economics: an empirically-based scenario analysis. Proceedings, Seventh World Congress on Intelligent Transportation Systems, Turin, Italy, November 2000, pp. 1-8.

Shaheen, S., J. Wright, D. Dick, and L. Novick. 2000. CarLink: a smart carsharing system field test report. University of California, Berkeley: Institute of Transportation Studies, California PATH Program. UCB-ITS-PRR-2000-10, May 2000. Available online at www.PATH.berkeley.edu.

Shaheen, S., J. Wright, D. Dick, and L. Novick. 2000. CarLink: a smart carsharing system field test report. Institute of Transportation Studies, University of California, Davis: UCD-ITS-RR-00-4.

Shaheen, S. 1999. Dynamics in behavioral adaptation to a transportation innovation: a case study of CarLink: a smart carsharing system. Institute of Transportation Studies, University of California, Davis: UCD-ITS-RR-99-16.

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Shaheen, S., D. Sperling, and C. Wagner 1998. "Carsharing in Europe and North America: past, present, and future," *Transportation Quarterly*. Summer 1998, pp. 35-52. ■

CarLink II will further test commuter-based carsharing's market potential

Carsharing is common in Europe, in 450 cities — with nearly 200,000 participants

Photodiode-Array Based Detection of Vehicles on the Highway

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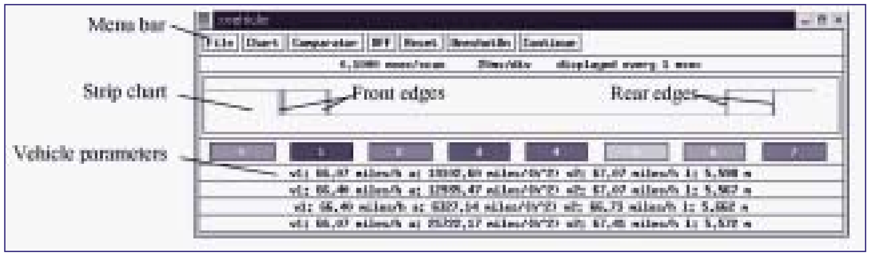

Figure 6. Test results for a car

Figures 6 and 7 demonstrate the typical signals and measurements of highway test for a passenger car and a van. Images of the vehicles are also placed in these figures for comparison.

The user interface window is shown on top of each figure. This window contains a menu bar, a status window and a strip chart. The menu bar is used to control the system, i.e., to start or stop data acquisition and to set parameters of the system. The signals from the sensor electronic circuitry are displayed dynamically in the strip chart, which scrolls from left to right. The signal is at a high level when a vehicle is not present, and changes to a low level when a vehicle blocks the laser. This transition occurs over a time that is much shorter than the sampling interval. Since all the signals are displayed at the same position, only one signal line can be seen on the chart when there is no vehicle or a vehicle blocks the laser lines. We can distinguish signals from different sensor elements when they change from low to high level, or inversely, at different times. The front speed (v1), rear speed (v2), acceleration (a), and length (l) of the vehicle are displayed on the lower part of the window. Each row in the lower window corresponds to one pair of sensor elements. Currently we only display four pairs of sensor elements. The first row of numbers in Figure 6, corresponding to the first pair of sensor elements, shows the front speed=66.07 mph, acceleration=19102.6 mile/hour^2 (note that 1 m/s^2=8053 mile/hour^2), rear speed=67.07 mph, and length=5.598 meters.

As the strip chart on the top of Figure 6 shows, different parts of the vehicles' curved front bumpers hit the laser lines (which are straight) at different times. On the other hand, rear bumpers are essentially flat, and the transition edges for the rear bumpers (in the right side of strip chart) transit-up at almost the same time. These results show that the signals for the new field prototype system are clear and the transition is fast enough for measurement. The system is consistent in measuring vehicle lengths and speeds. A vehicle traveling at a representative speed of 65 mph will cross the two laser lines in about 17.5 ms. As a result, the error caused by the sampling interval is less than 1.14%. Misalignment of the laser lines on the road might also cause some errors, though such errors can be accounted through system adjustment and calibration.

Conclusions

Test results have shown that the principle of the detection system is technically sound and that the algorithms implemented in the software work. This simple method of detecting vehicle presence based on the absence of reflected laser beam can work reliably in real traffic environments. With well-designed sensor optics and electronics, the system can achieve the high resolution and sensitivity nec-

Figure 7. Test results for a van

essary to distinguish the presence of a vehicle with high accuracy. Real-time data acquisition software is used to gather and process the data from system hardware. Data such as the speed, acceleration, and length of a detected vehicle can be calculated and displayed on a screen simultaneously. These data can be saved with a time stamp to a disk in real time, or can be transmitted to a host machine for further processing to obtain travel time information. Such data can prove very useful both for intelligent transportation system research and implementation.

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Acknowledgments

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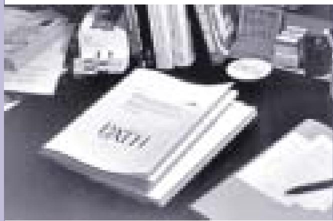
The recently published PATH research report describing the project, Development and testing of field-deployable real-time laser-based non-intrusive detection system for measurement of true travel time on the highway. (PATH Research Report UCB-ITS-2001-6) is available online at http://www.path.berkeley.edu/PATH/Publications/reports.htm#2001 ■



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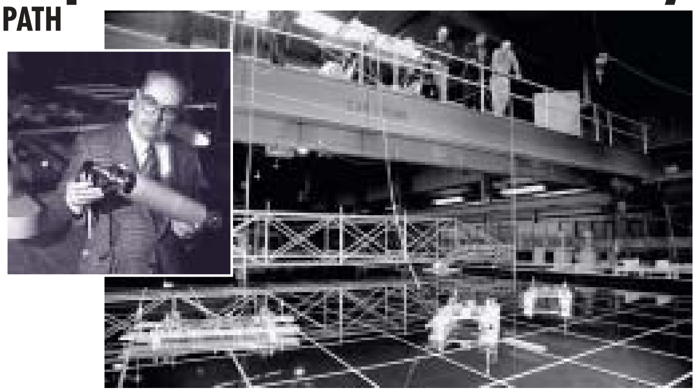

PATH's Mobile Offshore Base (MOB) experiment for the US Navy Office of Naval Research is now poised for testing of the three two-meter long, 150:1 scale modules under fully automatic control. (In concept, three to five full-scale MOB modular barges would link together at sea to form a mile-long (1.6 km) floating runway.) The graduate student researchers working on the project, Anouck Girard and Stephen Spry, along with exchange students Perry Huang, Harald Nyberg, Egil Hansen, and Mogens Mathiesen have made great progress in readying thruster indicators, new umbilical cables, well-tuned sensors, modifications to the test tank, and a complex software control system.

Because of the computationally intensive nature of the controllers, a set of three Pentium III computers will be used to run the control algorithms. We will be testing a variety of control schemes. The coordinated PID (Proportional Integral Derivative) controller, a linear controller, uses standard PID control techniques to control the relative position of the MOB modules with respect to one another. The sliding mode controller, a nonlinear controller with proven stability and robustness properties, uses a variant of sliding mode control called dynamic surface control. It controls the modules to both an absolute position and to a relative position with respect to the other modules. We also hope to test a model predictive controller (MPC) developed by an outside firm, Scientific Systems Company, Inc.

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