Florida Atlantic University Research Report
Visual Cues Provide Keys to Driverless Vehicles

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Florida Atlantic University
Research Report

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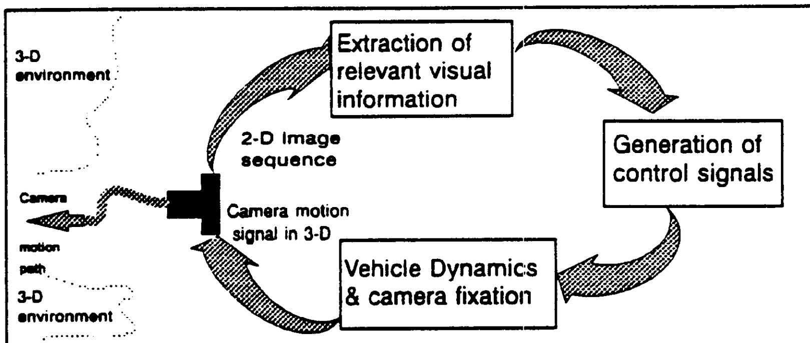
Visual Cues Provide Keys to Driverless Vehicles



2-D Visual-Cues-Based Active Navigation

Daniel Raviv believes that the best way to improve highway safety might just be to take drivers out from behind the wheel.

Raviv, a professor of electrical engineering at FAU, notes that it takes humans 1/5th of a second to respond to an impending collision or similar emergency. But when a computer – guided by a video camera – is at the controls of a vehicle, reaction times are reduced to as little as 1/30th of a second.

As part of the U.S. Department of Transportation's multimillion-dollar Intelligent Vehicle/Highway System program, Raviv and his colleagues at FAU and the National Institute of Standards and Technology (NIST) have developed technology that has been used to control a driverless Army HUMVEE safely at speeds of up to 45 miles per hour.

At the core of this seemingly improbable process, referred to as "active vision," is the study of "relevant visual cues," Raviv explains. "When dealing with a moving observer (for example, a camera), a huge amount of visual information is captured. In these projects, we are extracting relevant visual information from a sequence of images and using it as part of feedback control loops. In other words, we are refining all of the information viewed by the camera into a small set of relevant characteristics that the computer needs to control the motion of the vehicle." (See illustration.)

"We have taken a theoretical approach to understanding the basics of active vision," Raviv continues. "This formal, mathematical development of visual fields provides a quantitative scientific basis for understanding the relationships between optical-flow-based cues in the moving eye and the environment through which it moves." Understanding these collectively, he says, enables researchers to put driverless vehicles on the road.

Two key control concepts developed by the FAU and NIST researchers are the "tangent point" and "visual looming."

Unlike other studies that attempt to find out as much information as possible about the road itself in order to control vehicles, Raviv's research determined that the only road feature necessary for road following is the "tangent point" – the point on the road edge lying on an imaginary line tangent to the road edge that passes through the camera. The camera provides a flowing optical image of the road edge and the center line, supplying the data that the on-board computer requires to steer the vehicle as it moves along the road.

Welcome to Research Report

The Office of Graduate Studies and Research is pleased to send you this inaugural issue of the FAU Research Report, a monthly publication to inform faculty, the University community and the general public about the quality and scope of research activities at the University.

Beyond merely keeping a vehicle on track of course, comes the need to avoid collisions by braking, speeding up and steering. These functions are guided by the concept of "visual looming" – a principle that relates to the ways that animals' instinctive defense mechanisms lead them to behave when threatened.

The theory of visual looming, which was developed by FAU researchers, describes the time-based expansion of objects in the image plane viewed by the camera. In other words, visual looming determines the rate at which an image is being approached by or is approaching the vehicle carrying the camera. Information drawn from these observations is mathematically analyzed by the on-board computer and then translated into responses that enable the vehicle to avoid imminent collisions. Current research on this concept by Raviv and others at FAU is exploring ways to differentiate other vehicles from less relevant background information.

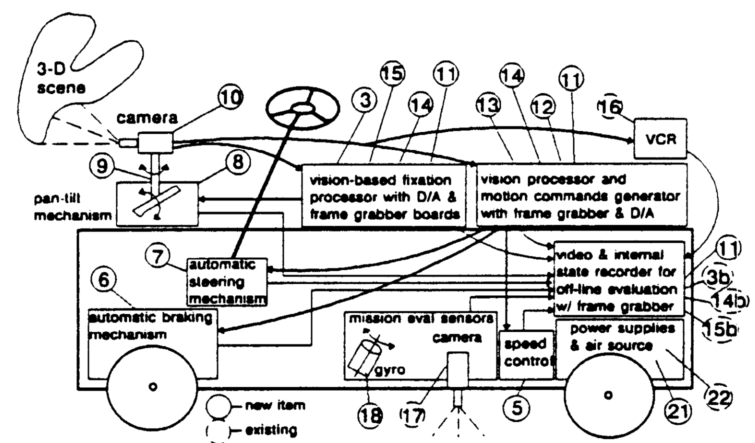
These basic explorations of active vision have been funded by the National Science Foundation under the direction of Dr. Howard Moraff. As the results began to show promise, Department of Transportation funding became available to put the theories into practice.

In addition, Because of Department of Defense interest in developing unmanned ground vehicles, an Army HUMVEE was provided for the FAU/NIST road test. Within four months, Raviv notes proudly, the vehicle – outfitted with the necessary camera, computers and control equipment – successfully drove autonomously on an NIST track in Maryland. Tests took place during the day, at night, and under rainy conditions.

"The machine is a far better driver than human beings from a repeatability point of view," Raviv notes.

In order to continue this research using the facilities of the Robotics Center at FAU, the research team has outfitted an electric golf cart with control mechanisms similar to those used on the Army vehicle (see illustration). The project's next stages involve further work with visual looming and its applications to "platooning" (several vehicles closely following one another, as in a military supply convoy or between major cities on a highway), expanding the camera's view to the back and the sides, and incorporating information from road signs.

The day is not far away, Raviv believes, when "our cars will know where to go without driver intervention."



Proposed Upgrade of the Electric Car

Florida Atlantic University Research Highlights

- The Advanced Marine Systems (AMS) Program in the Ocean Engineering Department, in partnership with the University of South Florida, has received two grants (for $2.5 million and $9.8 million) from the Department of Defense.
- FAU is concluding a cooperative relationship with the South Florida Water Management District. The agreement has provisions for cooperative research activities, a shared research facilities agreement and the delivery of graduate programs to the District.

Florida Atlantic University Research Report is a publication of the Office of Graduate Studies and Research.
Dean John T. Jurewicz welcomes your suggestions and comments at (407) 367-3624.

Sun-Sentinel
PALM BEACH COUNTY
Monday, March 20, 1995 35 cents

Driverless cart paves new way to the future

By KIRK SAVILLE
Staff Writer

BOCA RATON — It's a great golf cart to putt around in. There's no driver.

With a golf cart, a video camera and a computer, a Florida Atlantic University professor is trying to perfect a driverless vehicle.

Eventually, the system might be used to control cars on long trips. With the computers at the wheel, cars could follow more closely, lanes could be made smaller, interstates could carry four times as many cars.

Daniel Raviv, an electrical engineering professor, wants to apply a psychological principle called "looming" to the roadways. In looming, objects appear to grow larger as they move closer. In the same way, objects moving away appear to look smaller.

The golf cart is named "Loomy" after the principle. While Loomy doesn't need a driver, it does have to follow another vehicle.

The video camera, mounted on the front of the cart, is aimed at a target, in this case a white rectangle on the back of the lead vehicle.

A computer knows the size of the target. As the golf cart follows the lead vehicle, the computer constantly compares the relative size of the target with its actual size. If the target becomes too small, the computer knows the cart is falling behind and increases its speed.

If the target appears too large, the computer knows the cart is getting too close to the lead vehicle and slows down the cart.

For turns, the computer com-

PLEASE SEE CAR /6A

FROM PAGE 1A

Road of the future might not have too many drivers

pares whether the target is centered. If it goes off center, the computer turns the car until the target is back in the center of the camera.

Raviv said a good driver can react in about a third of a second. The computer reacts about 10 times faster.

The secret to making the system work is deciding what information is vital to driving. Drivers speeding down the highway see a lot of things, such as trees, clouds and distant buildings, but none of that is necessary to driving.

"Even though the information you get is endless," Raviv said. "You only have two controls, speed and steering."

A compressed air system is used to steer the vehicle. Thomas Kelly, an engineering graduate student, is working the final bugs out of the computer system. He said the cart should be ready to be tested on campus in the next few weeks.

Raviv said the system's first widespread use would be as a warning device. With the computer sounding a signal if the driver came too close to another car, Raviv said such a system could probably be produced for as little as $200.

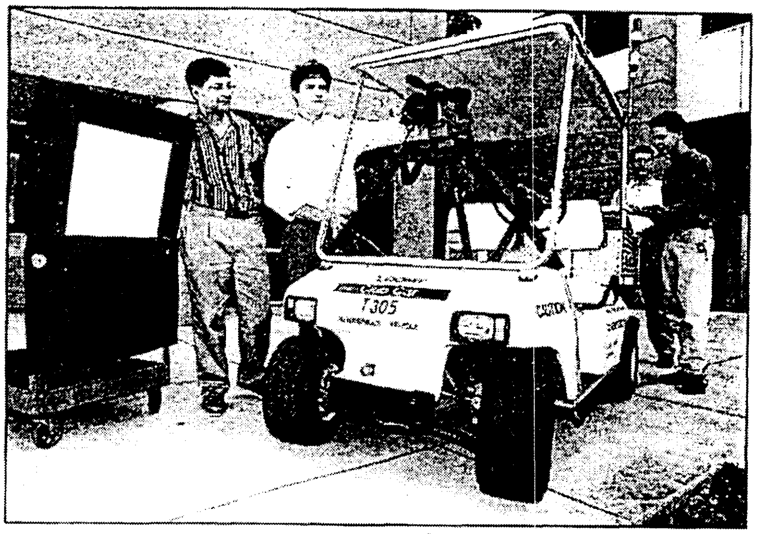
"There's a tremendous interest in this kind of technology among transportation experts," said Tom Schroder, a spokesman for the American Automobile Association of Florida. "We could pack more cars on the roads we have, instead of building expensive new roads. Imagine an interstate packed with cars, all traveling at 65 miles per hour with only two or three feet between them."

Raviv's research is financed by grants from the National Science Foundation, the National Institute of Standards and the federal transportation department. Raviv estimated the golf cart's cost at $5,000 to $6,000.

Raviv has demonstrated a system where a military vehicle has followed another on a closed course at speeds up to 65 mph.

When and to what extent the devices are accepted is less likely to be decided in the laboratory than in the courtroom, Raviv said.

"If you want to build cars like this, you can, but the liability is a problem," Raviv said. "If it gets into an accident, who is liable?"



Staff photo/NICHOLAS R. VON STADEN

FAU professor Daniel Raviv watches as graduate student Thomas Kelly adjusts the video camera on the "Loomy" cart.

Driver optional in computerized cars

By ARDEN MOORE
Staff Writer

"How we really see has always been a mystery to me. My goal has been to build a system that can navigate a vehicle based on vision, not radar."
— research team member Daniel Raviv

The newest feature for motorists in the next decade or so may be smart control.

Imagine safely putting your vehicle on automatic pilot while you nap, read a book or stretch out in the back seat during long road trips.

Within the next few years, an automatic alarm system can be installed in your car to alert you to a pending collision.

Florida Atlantic University professor Daniel Raviv is part of a national team of researchers developing innovative technology for self-guided, computer-controlled vehicles.

Eventually, this smart-car, smart-highway system would allow more vehicles to move faster on highways without danger of colliding.

Sound farfetched? Raviv points to recent test results. His computerized system, relying on a camera as the vehicle's eyes and a computer as the brain, has successfully kept an Army vehicle called a Humvee within its lanes at speeds of up to 60 mph.

A driverless Humvee also has closely followed another at 30 mph without colliding.

Tests were conducted on roads at the National Institute of Standards and Technology in Gaithersburg, Md. The research is paid for by the National Science Foundation and the Federal Highway Administration.

This research represents one segment of a national campaign to develop high-tech highways and smart cars. It falls under the umbrella project called Intelligent Vehicle-Highway Systems being coordinated by the highway administration.

"The trend is definitely toward high technology on our highways," said Tom Schroder, American Automobile Association of Florida spokesman. "Technology can help people save time, save gasoline, prevent accidents

PLEASE SEE SMART CARS /4A

SMART CARS

FROM PAGE 1A

Researchers trying to improve vehicles that drive themselves

and eliminate the need to build new highways and roads."

Also in the testing stages:

■ Intelligent cruise control — If a car ahead of you slows down, the control system would automatically adjust and decrease your car's speed to maintain the same distance between the two.

■ Computerized dashboard maps — Motorists can get step-by-step directions to destinations from a car computer. The computer could also give drivers alternate routes around congestion or accidents. A yearlong study that ended in March involved 2,000 motorists in the Orlando area, and another test is expected to involve 5,000 drivers in the Chicago area next year.

■ Automated toll collections — Motorists in Dallas, parts of Oklahoma and Louisiana are able to drive through toll booth lanes without stopping as a computer camera records the license plate and automatically deducts the charge from the motorist's credit account. The system is expected to be in operation on Florida's Turnpike in south Florida by late 1995.

"To handle the increase in traffic, the only way to go is to provide more intelligent automation," said Maris Juberts, a program manager for automated vehicle control systems for the highway administration. "A computer-controlled system can triple or quadruple the number of cars on highways as well as increase safety for all drivers."

The success of this impending technology depends on public acceptance, researchers say. Raviv's work may face the biggest resistance.

"I think it will be a hard sell, because some drivers may not want to give up the thrill of driving over to computers which do the steering, braking and accelerating," Schroder said.

Public acceptance will come only by a gradual, step-by-step introduction of technology's benefits to motorists, said August Burgett, an official with the National Highway Traffic Safety Administration.

"It will take time and experience for people to feel comfortable with it," he said.

There are also unanswered legal questions: Who would be at fault in an accident involving a car steered by computer?

"A computer-controlled system can triple or quadruple the number of cars on highways as well as increase safety for all drivers."
— Maris Juberts, Federal Highway Administration

"Legal questions — that is still a big issue that we have to tackle," said Richard Bishop, a Federal Highway Administration manager.

Raviv's contribution deals with developing "seeing" computerized cameras that can act — and react — like human eyes. The camera keeps the vehicle in its proper lane by keeping an eye on the center line and the edge of the road. It would operate much like cruise control, giving the driver the ability to regain control easily.

"How we really see has always been a mystery to me," said Raviv, an associate professor of electrical engineering. "My goal has been to build a system that can navigate a vehicle based on vision, not radar."

His research on the automated warning system would alert a driver to an imminent collision or drifting off the road by a beeping sound or flashing light. It could eliminate the "blind spot" for motorists by having seeing sensors around the vehicle. That system could cost about $1,000 per vehicle and be available within three years, Raviv said.

"This computerized vision system's reaction time is 10 times faster than that of a human," Raviv said. "Hopefully, my research can save lives and reduce the number of accidents."

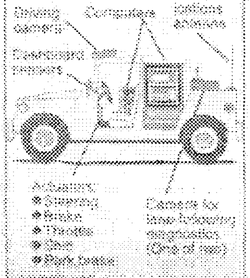
Experts agree that the future puts technology in the driver's seat.

"To have all this technology tied together coast-to-coast will be quite a task," said Don Gordon, AAA project manager in Orlando. "A total automated highway system might be decades away, but people have to realize that steps are being taken today."

Sun-Sentinel
PALM BEACH COUNTY
Monday, September 6, 1993 35 cents

Smart car

A U.S. Army Humvee equipped with a computerized camera system has successfully traveled driverless at speeds of up to 65 mph and followed a vehicle at 30 mph without colliding.



Sun-Sentinel

Sun-Sentinel

SOUTH FLORIDA • MONDAY • AUGUST 26, 1996

Researcher developing computerized eye at FAU

By KIRK SAVILLE
Staff Writer

BOCA RATON — Daniel Raviv is developing a set of eyes for the back of his head.

The Florida Atlantic University professor is working on a sort of computerized eye. The device someday could help the blind avoid obstacles, help control driverless cars or help guide industrial robots.

Pedestrians could even wear it to let them know what was going on behind their backs, Raviv said.

The National Science Foundation gave Raviv a $60,000 grant to develop the device. As far as grants go, $60,000 isn't a lot of money. But Raviv's grant is designed for high-risk research.

"They know the payoffs could be big," Raviv said. "But they know it could fail."

But Raviv doesn't expect to fail. He'll spend the next year designing a computer chip that can make his small artificial eye work. He hopes the device could be produced for as little as $10.

The NSF grant is the highest form of support from the federal government. Grants are judged against competitors from all over the country. "It's very prestigious," said Craig Hartley, dean of the college of engineering at FAU. "It's one of the marks of the quality of the research and the university."

Raviv has long worked on developing a driverless car, and the computerized eye is an offshoot of that research.

PLEASE SEE EYE /4B

EYE

FROM PAGE 1B

Computerized eye arose from research on driverless car

The device relies on measuring how blurry an image is.

To understand how the system would work, imagine a camera focused on an object. As long as you stand the same distance from the object, the image remains sharp.

If you move away from the object, it goes out of focus, and the image becomes blurry.

Raviv's eye would work the same way. "The change in the blur is what we're interested in," he said.

Raviv said the device would be set so the image of an object, such as a car, is blurry when the object is a safe distance away. If the object gets too close, the image would become sharper.

The computer chip would sense when the image became too sharp, meaning the object was getting too close. In a car, for example, the device could either set off a warning alarm or apply the brakes.

Raviv said the key to the research is deciding what information is crucial to avoiding a collision.

"This is something that has puzzled me for many years," Raviv said.

Daniel Raviv, a professor at Florida Atlantic University, is developing a computerized eye that could guide a driverless car or aid the blind. A National Science Foundation grant is helping him in his research.
Staff photo/ NICHOLAS R. VON STADEN

When people are driving along Interstate 95, for example, they receive tremendous amounts of information. Drivers see trees, signs, buildings and other people. But all that information is reduced by the brain to a couple of crucial pieces of information: how close you are to the car in front of you and how fast you're approaching the car.

"Who cares if it's a Mercedes or Lexus, the important thing is how fast you're approaching," Raviv said.

The blur system allows the computer chip to disregard everything but the distance between the camera lens and the object in front.

Raviv sees plenty of uses for his device. In addition to being used to control the speed of a car, the device could be put in the back of the car to warn of a vehicle approaching too fast.

Blind people might also be able to use the system to warn them of obstacles.

"Right now, the most efficient device is the stick," Raviv said.

LOCAL

Sun-Sentinel, Monday, August 26, 1996 Section B

FAU's car would do the driving for you

JACK WHEAT
RESEARCH

Florida Atlantic University researchers are building a car that can drive itself.

Their Army HUMVEE can go it alone at speeds of up to 60 miles per hour, and do so safely at night, in heavy smoke, and in rain, reports Daniel Raviv, FAU professor of electrical engineering. He published an article on the project in the August issue of Transactions on Systems, Man and Cybernetics, a journal of the Institute of Electrical and Electronics Engineers.

A videocamera on the front of the HUMVEE sends images to a computer, which determines how the HUMVEE should respond. It reacts to an impending collision or other emergency six times faster than a human, said Raviv. Human response time is one-fifth of a second. For the com-

MIAMI HERALD 9/19/94

PLEASE SEE **RESEARCH, 5B**

DEVELOPING AN AUTOPILOT AUTO: FAU's Daniel Raviv.

FAU making car that'll drive you

RESEARCH, *FROM* **1B**

puter, it's one-thirtieth of a second.

The computer makes judgments through principles of "visual looming." As objects before the camera grow or shrink, the computer figures how rapidly the changes are occuring and speeds up, slows down or stops accordingly. People drive the same way, but process the information more slowly, Raviv said.

The HUMVEE has been tested at a National Institute of Standards and Technology track in Maryland, Raviv said. Now the researchers are figuring out how to make the car able to weave in and out of traffic.

Before cars with automatic pilot make it onto Interstate 95, he says, something trickier than technical issues must be resolved — who'll be legally liable for where the car goes?

Cars on autopilot likely by 2002

FAU electrical engineering Professor Daniel Raviv is optimistic about automation on the highways.

By DON HORNE
Palm Beach Post Staff Writer

BOCA RATON — Taking a long drive by yourself? How would you like to get on the highway, put your car on autopilot, climb into the back seat and curl up with a good book or even take a snooze?

In as soon as 10 years, you might be able to.

While you rest, computers would steer, keep your car a safe distance behind the next vehicle and stop the car when necessary.

The basic technology for a self-guided car should be ready within two or three years, in the view of Daniel Raviv, a Florida Atlantic University electrical engineering professor who is one of several scientists doing the pioneer research.

Last month, an Army vehicle outfitted by Raviv drove on its own around roads at the National Institute of Standards and Technology in Gaithersburg, Md., guided by a television camera that kept an eye on the edge of the road and the center line and fed the information to a computer. At night and through heavy rain and dense smoke, the multipurpose vehicle, known as a Humvee, stayed within its lane at speeds of up to 45 mph.

Raviv is convinced that the system will work just as well at 65 mph.

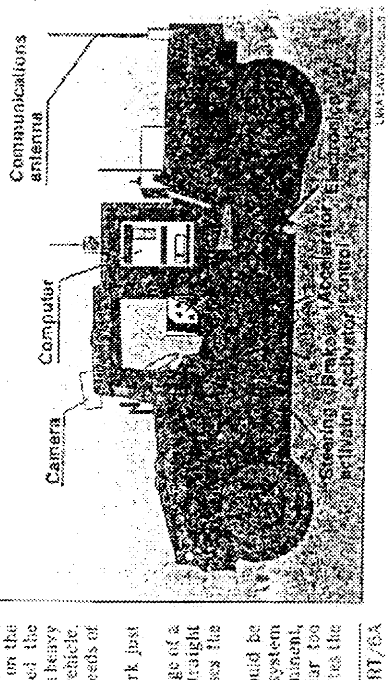
"I don't see any problems," he said. "The edge of a highway is well defined. The camera looks straight ahead, finds the edges of the highway and uses the center line to navigate the vehicle."

Within about five years, Raviv says, it should be possible to buy a car equipped with a warning system that sounds an alarm when a collision is imminent, such as when the car is following another car too closely or starts to go off the road. Raviv estimates the

Please see SMART/6A

SELF-GUIDED HUMVEE

FAU professor Daniel Raviv developed the guidance system used in a recent test by the Army. The Humvee drove itself around a test course through rain and smoke at speeds of up to 45 mph.



'Smart highways' that allow push-button navigation next

SMART/from 1A

system would cost about $1,000.

A totally automated car could be ready almost as soon and would cost about $2,000 more than a conventional car, Raviv said.

But he and other experts in the field believe it will take car manufacturers much longer to install fully automated driving systems in vehicles than it will to install warning systems.

The reason: concern about legal liabilities. If an automated car is in an accident, whose fault would it be — the driver's or the automobile manufacturer's?

Another potential problem is consumer skepticism. Before people are willing to turn control of a vehicle over to a computer, they will have to be convinced that it's safe.

"Even though airplane pilots land by instruments all the time, there's a real reluctance on the part of people to do that," said Mike Sheldrick, a distinguished industry fellow with Intelligent Vehicle-Highway Systems America, a Washington group that is advising the U.S. Department of Transportation on the development of a totally automated highway system.

Sheldrick agrees with Raviv that these obstacles will be overcome.

"We envision that one day you'll hop in your car, say 'work,' and it'll take you there," Sheldrick said last week.

Recognizing the need to make the nation's highway system more efficient, Congress has directed the Federal Highway Administration to develop a prototype automated highway system by 1997. About $660 million is to be spent on research and development, including $123 million in 1992-93.

The basic goal: to improve highway efficiency, enhance safety, conserve energy and protect the environment.

'Smart' highways to be developed

In addition to making "smart" cars, the project calls for developing "smart highways" that would allow motorists to punch a destination into a dashboard computer as they get into their cars. Based on the latest traffic information, the computer would tell them the best way to get there.

A fundamental part of the "smart cars" research is assuring that vehicles don't drift over into the next lane. The task isn't as simple as it may seem, Raviv said.

"Driving down a highway is easy for a human being, but not as easy for a machine," he explained. "A camera has to find which edges are relevant and which aren't. There are many edges — of trees, billboards, signs, many things."

After last month's road tests of the Army vehicle, Raviv returned to the robotics lab at FAU to work on the next phase: keeping a vehicle a safe distance behind another vehicle based on images the computer receives from the camera.

In its application, the concept, called "platooning," envisions packs of closely spaced, driverless cars with the same destination moving along a highway in perfect synchronization.

Raviv, working on a $225,000 Department of Defense contract, expects the platooning stage of his system to be road tested within a year.

Other vision-related research has been done by other researchers in the United States, Europe and Japan. Raviv said he believes his system is unique because of the simplicity of the method by which the computer processes the images of the road edge and objects on the road relayed by the camera.

"It is far simpler than what other people are trying

> 'We envision that one day you'll hop in your car, say "work," and it'll take you there.'
>
> MIKE SHELDRICK
> Intelligent Vehicle-Highway Systems America

"A lot of artificial intelligence approaches are fairly sophisticated, and extracting the information is very tedious and takes a considerable amount of time," Juberts said. "His approach is simple and extracts just the information you need to control the vehicle."

Defense Department pays for research

The Department of Defense is paying for Raviv's research because of the military applications. Entire convoys of supply vehicles might require a single human driver situated in the lead truck, explained Roger Kilmer, deputy manager of the technological institute's Intelligent Machines Program. The rest of the convoy would consist of automated trucks programmed to follow and maintain a specified distance behind the vehicle immediately ahead.

"It's quite easy to achieve," Raviv said of the technology behind so-called smart cars. "The research can be finished in two or three years. Whether you put one in your car depends on how much you value safety."

But consumers are likely to be wary.

"It could prevent a lot of off-road collisions," Sheldrick said. "For example, people who lost control of their cars would stop in front of a tree instead of running into it. But are people really going to want to have their brakes go on automatically?"

Use to be restricted to highways

At first, at least, experts agree, automated vehicles will be used only on highways, because city driving requires more sophisticated judgment calls. Most experts also believe the first generation of automated vehicles will have to have a lane or two set aside for them and will not share the highway with conventional vehicles. That system has drawbacks — a flat tire or other mechanical failure could create a huge traffic jam.

Steven Shladover, a University of California at Berkeley professor who is considered one of the foremost experts on the subject, believes the public's use of automated vehicles initially will be limited to one or two locations, so flaws can be worked out.

"I think we can get something fully automated on the road for the public to use in specific locations in 15 years," said Shladover, deputy director of a $56 million California program called Program on Advanced Technology for the Highway. "It'll probably be 15 or 20 years before they're widespread."

Automated vehicles will be much safer than human-driven vehicles, Raviv said, because a camera's attention doesn't wander, and the computer's reaction to potential danger is almost instantaneous.

"If the computer decides you're going to collide, it'll take action," Raviv said. "A human being responds in a quarter of a second to a sign of danger. A machine is far faster. It can respond in a 50th of a second."

Similar research is being conducted at several other U.S. universities, backed by domestic automakers, and in Japan and Germany.

The technology differs. Some, like Raviv's, use vision-based sensors, others use infrared sensors, ra-

Vetronix's Crash Data Retrieval System

Don J Felicella
ACTAR, Felicella Consulting Engineers, Inc.

Vetronix's Crash Data Retrieval System

Donald J Felicella, ACTAR, Felicella Consulting Engineers, Inc.

INTRODUCTION

General Motors vehicles equipped with air bags that were manufactured between 1990 and 1993 have a unit called a Diagnostic and Energy Reserve Module (DERM). One of the functions of the DERM is that it records a limited amount of data at the time of a deployment event. In 1994 General Motors air bag systems started utilizing a Sensing and Diagnostic Module (SDM). This device was able to compute and store the change in the longitudinal velocity of the vehicle during an impact. The SDM receives data from the vehicle's Powertrain Control Module (PCM) once a second regarding the vehicle's speed, engine speed and percent of throttle. Currently the SDM's do not sense lateral accelerations or forward longitudinal accelerations which may result from a rear impact.

In 1990 Vetronix developed the first Event Data Retrieval Unit (EDRU) to be used internally by General Motors. Vetronix was awarded the exclusive contract from General Motors in 1999 to develop a Crash Data Retrieval (CDR) system for use by both GM and the aftermarket. The CDR system has the availability to download data from the involved vehicle in an easy-to-read graphical and tabular format. The retrievable data includes vehicle's speed, state of warning light indicator, throttle position, engine RPM, brake switch circuit status, time from algorithm enable to deployment command, status of the front passenger's air bag suppression switch, and post crash data.

VETRONIX EQUIPMENT

The CDR unit from Vetronix consists of a CDR Interface Module, various cables, software, and power supply connections. The data can be retrieved by either connecting under the vehicle dashboard into the DLC jack or connecting direct into the air bag control module.

TYPE OF DATA

The data is compiled into two categories or events "near deployment events" and "deployment events." A near deployment event is one which is sever enough to "wake up" the vehicle's sensing algorithm but not enough to cause the air bag(s) to deploy. The typical predictive algorithm must make air bag deployment decisions within 15-50 msec after impact. The SDM can store up to one near deployment event which will be overwritten by an event that has a greater recorded velocity change. A deployment event will contain Pre-Crash and Crash data. The SDM will store up to two different Deployment Events if they occur within five seconds of one another. Once the air bag has been deployed, the data cannot be overwritten or cleared. The SDM must be replaced.

CASE STUDIES

The following are examples of cases involving a vehicle supported by the CDR system in which the data was utilized:

1999 Chevrolet Corvette:

This crash involved a 1999 Chevrolet Corvette which was traveling at a high rate of speed. The driver swerved to avoid other traffic and lost control of the vehicle, rotating approximately 55 degrees, leaving tire surface marks for approximately 177 feet prior to striking the curb and becoming airborne. The vehicle traveled approximately 34 feet prior to striking a tree 1.5 feet higher then takeoff. The driver received fatal injuries. This investigation has been completed by the governing police agency. However, the investigating officer and an accident reconstructionist are currently analyzing the evidence along with calculating the vehicle's speed during this event. Upon completion of such analysis, they will then do a comparison of the calculated speeds and the data from the SDM.

The data from the SDM indicated that the vehicle's throttle went from 100 percent at -5 seconds to 0 percent at -2 seconds during which time the vehicle's speed increased from 106 MPH to 122 MPH respectively and the engine RPM's went from 4736 to 5248. The SDM also revealed that at -2 seconds the brake switch status went to the on position. The last data recorded at -1 seconds was 82 MPH with a RPM reading of 2624.

1999 Chevrolet Camaro Z28:

This case involved a 1999 Chevrolet Camaro Z28. The vehicle was found abandoned and on fire in a remote parking lot. The vehicle also had damage to the right rear fender area from striking some round object. The police made contact with the registered owner of the vehicle who then reported it stolen. During the investigation, it was found that the vehicle was equipped with an anti-theft micro chip key. This is a special key that has a micro chip attached to it which is programed into the vehicle's ignition system. State Fire Marshals determined that the vehicle had intentionally been set ablaze. Even though the vehicle was a total loss due to the fire, the Sensing and Diagnostic Module (SDM) was intact and was removed from the vehicle. The data retrieved from the SDM indicated a "Near Deployment Event" and an "Ignition Cycle" number. The SDM also indicated that the vehicle's Brake Circuit Status was "On" and recorded a speed of zero mph.

An investigation was able to find a "witness" to the crash who confirmed that the vehicle apparently was traveling on a wet roadway at which time the driver loss control and applied the brakes skidding into a tree. The driver then fled the scene.

The data from the SDM supported these facts, the vehicle's speed was recorded as zero mph with the brake circuit status as "On." It also indicated that there was an Ignition Cycle registered by the SDM supporting that a key was used. The ignition lock assembly was examined and found that the Vehicle Anti-Theft System (VATS) wiring which contained the contacts were present and did not show any signs of tampering.

The police investigation found that only two people had keys to the involved vehicle, the owner's mother whose actions were accounted for and the owner, who was on probation and did not possess a valid driver's license. The police confronted the owner with information they were supplied with from the SDM. The owner eventually confessed to the crime.

The data from the SDM helped the local State Attorney's Office in the successful prosecution in this case.

2000 Oldsmobile Alero 2-Door Coupe:

This crash involved a 2000 Oldsmobile Alero 2-Door Coupe which was sideswiped by a motorcycle causing the driver to take evasive action and lose control veering off of the road and then striking a wooden utility pole. The question was "What was the impact speed at the utility pole?" A post crash inspection revealed that there was 1.5 feet or 18 inches of maximum crash damage to the involved vehicle. These measurements were used to manually calculate an impact speed with the pole utilizing three different energy-based equations. A comparison was then made with the data retrieved from the vehicle's Sensing and Diagnostic Module (SDM) and the calculated impact speed.

FORMULA 1: $V = D\sqrt{(395 - .062W) * (1 + \Delta E)}$

Where: V = impact speed in feet per second (fps)
D = maximum crush in feet
W = weight of a vehicle in lbs.

ΔE = increase or decrease in energy absorbed in crushing the vehicle upon impacting a wooden utility pole

Calculated speed: 21.81 fps or 14.88 mph

FORMULA 2: V = BPO + BP1 * CRM

Where: V = Pre impact speed in mph
BPO = Speed at which no crush is expected
BP1 = Slope of speed versus crush
CRM = Maximum crush (inches)

Calculated speed: 13.64 mph

FORMULA 3: EBS = 1.30 * Cmax - 6.0

Where: EBS = Equivalent barrier speed
1.30 = Consent for small front wheel drive vehicles
Cmax = Maximum crush in inches

Calculated speed: 17.4 mph

SDM: Data from the vehicles SDM indicated a speed of 14 mph.

METHOD	SPEED
Formula 1	14.8 mph
Formula 2	13.6 mph
Formula 3	17.4 mph
SDM	14 mph

References

Chidester, A.,et al. "Recording Automotive Crash Event Data" International Symposium on Transportation Recorders, NTSB, Arlington, Va. 1999.

Goebelbeck, J "Crash Data Retrieval Kit Recovers Reconstruction Data from G.M. Black Boxes" Accident Investigation Quarterly, Winter 2000.

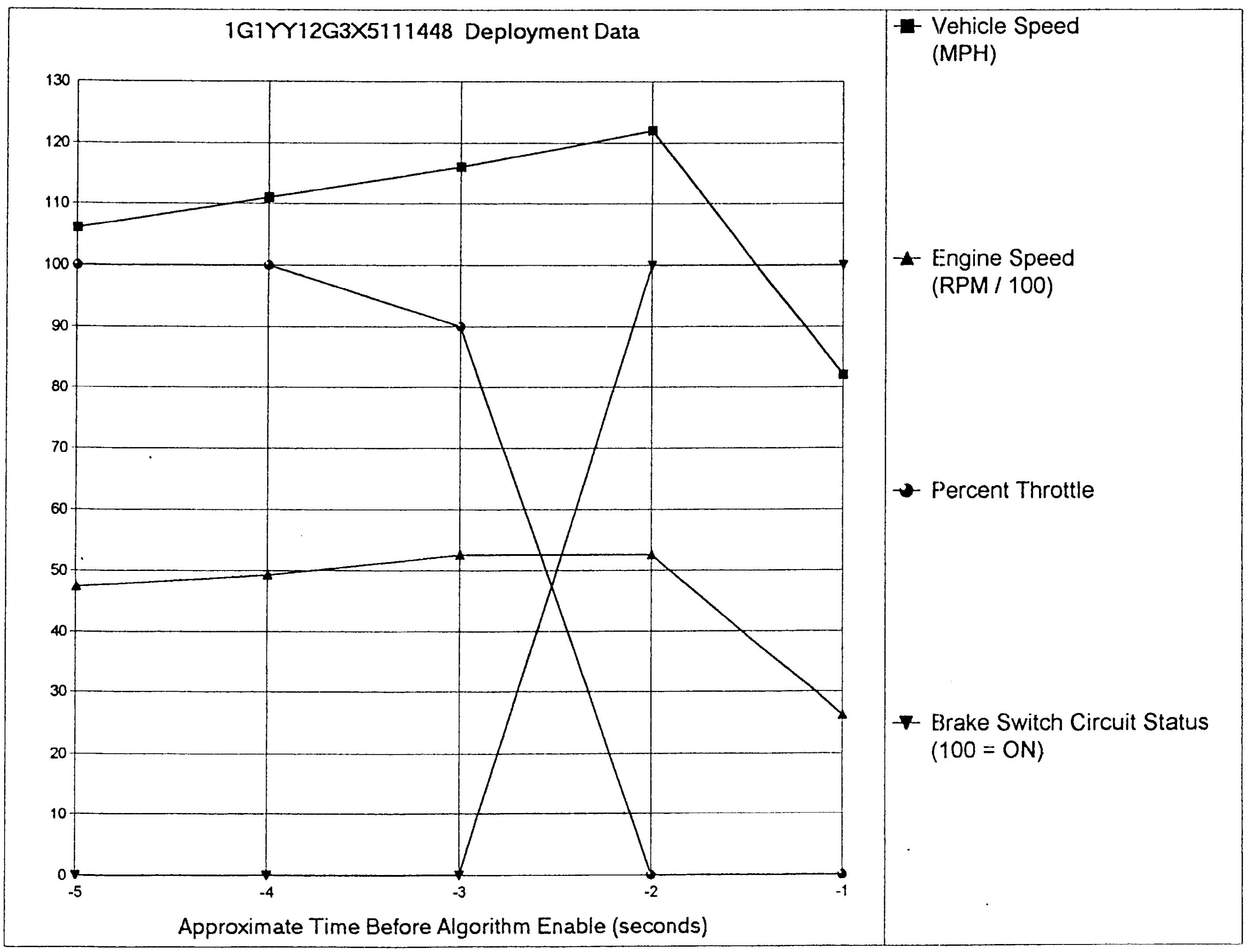
Vetronix "Viewing Data" help files

1999 Chevrolet Corvette

1G1YY12G3X5111448 System Status At Deployment	
SIR Warning Lamp Status	OFF
Passenger Front Air Bag Suppression Switch Circuit Status	ON
Ignition Cycles At Deployment	4463

PRE-CRASH DATA		Electronic Data Validity Check Status = VALID		
Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle	Brake Switch Circuit Status
-5	106	4736	100	OFF
-4	111	4928	100	OFF
-3	116	5248	90	OFF
-2	122	5248	0	ON
-1	82	2624	0	ON

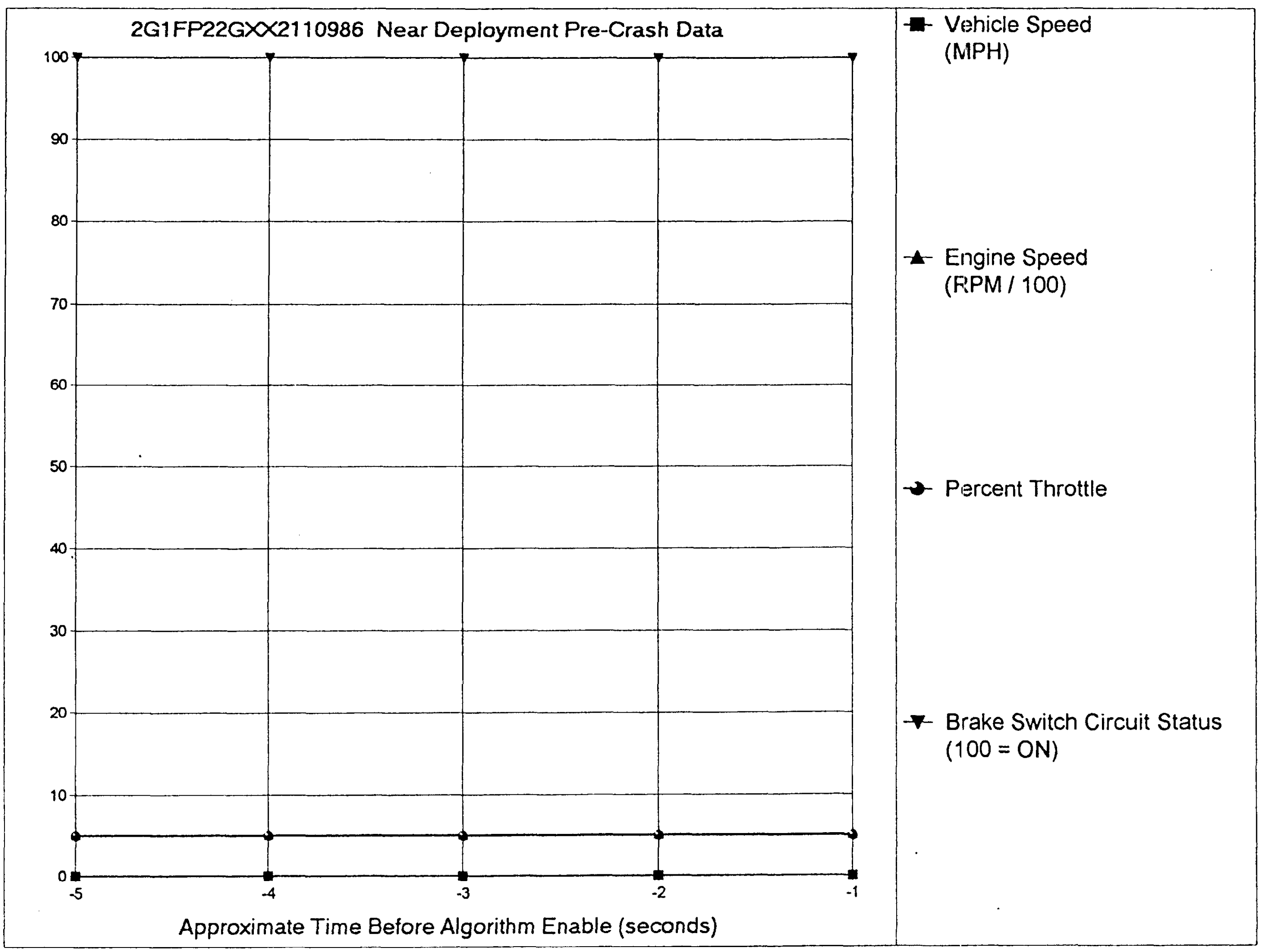
Time Between Deployment and Near Deployment Events (msec)	300



1999 Chevrolet Camaro Z28

2G1FP22GXX2110986 System Status At Near Deployment	
SIR Warning Lamp Status	OFF
Passenger Front Air Bag Suppression Switch Circuit Status	ON
Ignition Cycles At Near Deployment	4835

PRE-CRASH DATA		Electronic Data Validity Check Status = VALID		
Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle	Brake Switch Circuit Status
-5	0	512	5	ON
-4	0	512	5	ON
-3	0	512	5	ON
-2	0	512	5	ON
-1	0	512	5	ON



2000 Oldsmobile Alero 2-Door Coupe

[redacted] System Status At Near Deployment	
SIR Warning Lamp Status	OFF
Passenger Front Air Bag Suppression Switch Circuit Status	ON
Ignition Cycles At Near Deployment	188

PRE-CRASH DATA		Electronic Data Validity Check Status = VALID		
Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle	Brake Switch Circuit Status
-5	30	2624	24	OFF
-4	31	2688	24	OFF
-3	32	2624	16	OFF
-2	24	1280	0	ON
-1	14	640	0	ON