Automated Highways And The Free Agent Demonstration

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1 Abstract

In August of 1997, The US National Automated Highway System Consortium (NAHSC) presented a proof of technical feasibility demonstration of automated driving. The 97 Demo took place on car-pool lanes on I-15 in San Diego, California. Members of the Consortium demonstrated many different functions, including:

Vision-based road following
Lane departure warning
Magnetic nail following
Radar reflective strip following
Radar-based headway maintenance
Ladar-based headway maintenance
Partial automation and evolutionary systems
Close vehicle following (platooning)
Cooperative maneuvering
Obstacle detection and avoidance
Mixed automated and manual driving
Mixed automated cars and buses
Semi-automated maintenance operations

Carnegie Mellon University (CMU) led the effort to build the Free Agent Demonstration (FAD). The FAD involved two fully-automated cars, one partially-automated car, and two fully-automated city buses. The scenario demonstrated speed and headway control, lane following, lane changing, obstacle detection, and cooperative obstacle avoidance maneuvers.

This paper describes the demonstration itself, the technology that made the demonstration possible, and the current efforts to turn the demonstration system into a practical prototype.

2 Introduction

In August of 1997, the National Automated Highway Systems Consortium (NAHSC) organized a public demonstration of automated cars, trucks, and busses. This demo was requested by the US Congress in the 1991 ISTEA legislation. The legislation read in part: "The Secretary of Transportation shall develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed … The goal of this program is to have the first fully automated roadway or an automated test track in operation by 1997." Unfortunately, Congress didn't fund research on AHS until 1995. But the US Department of Transportation (USDOT) still requested the demo in 1997.

This paper reviews the motivation for AHS, and a variety of interesting technologies. It goes into more detail on two of the demonstration Scenarios: Platooning, led by the University of California at Berkeley PATH program, and Free Agents, led by CMU.

3 Motivations

The most important motivation for building automated vehicles and highways is improved safety. In the US alone, accidents cost 40,000 lives, and 150 billion dollars, every year. The number of fatalities peaked in the 1960s. Since then, a combination of safer cars (e.g., designed crumple zones), safer roads (the Interstate highway system), and policies (mandatory seat belt use, tougher drunk driving laws) has eliminated many of the mechanical causes of accidents and made collisions more survivable. At this point, the dominant cause of accidents is human error: in 90% of all accidents, the driver is at least partly to blame. The next step, to make further significant safety improvements, requires eliminating driver error, either by offering driver assistance or by automating the vehicles.

Congestion is also an increasing problem. Vehicle miles traveled have steadily increased in the US at 4% per year, much faster than the rate of growth of highway miles. The Interstate Highway System is now complete. Adding new lanes in congested urban areas can cost as much as $100 million per lane-mile. Automation is an attractive solution to many congestion problems. On today’s roads, with manual driving, the maximum capacity is about 2000 vehicles per lane per hour. If traffic were evenly spaced, this would translate, at 100 kph, to an average spacing of 50 meters per vehicle. But traffic is not evenly spaced; there is bunching and

Figure 1: Westrack automated pavement test vehicle

gapping, and lane changing and weaving. Automated vehicles, communicating with each other and with the infrastructure, should be able to maintain much closer and more even spacing, and to double or triple roadway capacity.

The two motivations, of improved safety and improved traffic flow, are neither directly competing nor directly complementary. Different research groups have developed different technologies and different architectures, partly in response to different emphases on the two main motivations.

4 Alternative Technologies

The NAHSC is not the first group to invent automated driving, nor the only currently active group working on the problem. Serious research efforts began in the late 1950s at the GM Research Center. Their Firebird 2 followed a buried cable. Interestingly, one of the junior engineers on the Firebird 2, Bill Spreitzer, just retired after the 97 demo from his position as head of GM efforts worldwide on intelligent vehicles. The Firebird 2 was brought out of retirement and restored to running order to be shown at the 97 demo.

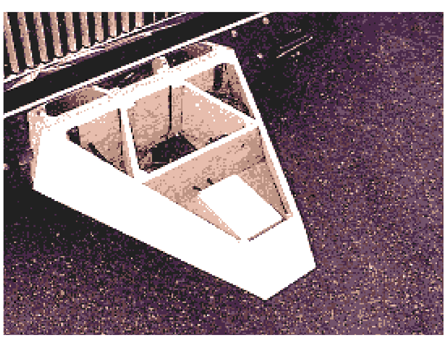

Figure 2: Westrack pickup coil

4.1 Westrack

Some of the most practical current efforts focus on special-purpose roadways dedicated to automated vehicles. Westrack, at the Nevada Automotive Testing Center, is a pavement test site. They have 26 different types of asphalt pavement along a 2.9 km oval test track. In order to do load testing of the pavement, they have four semi-tractors, each pulling triple trailers around the oval. Since driving in circles is boring, fatiguing, and dangerous for humans, they decided to automate the trucks. The centerpiece of their work is automated steering based on following a buried cable. They put an audio-frequency signal on the cable and sense its lateral position with pickup coils mounted under the front bumper of the trucks. That signal is used for steering control.

The Westrack trucks have logged over 800,000 km of automated driving. The designers took great care to ensure system safety: there are dual pickup coils on the front of the vehicle, dual wires operating at different frequencies, dual windings on the steering motor, triply redundant shaft encoders, and redundant controllers with no computers in the critical loop. There are still some shortcomings in the system, though. Since there is no preview information in the steering system, the trucks overshoot the entrance and exit of each corner. Where there was a small error in laying the original cables, the vehicles tracked the cable and oscillated on each lap until they wore grooves in the pavement. Eventually, vehicle control became difficult, and that section of track had to be repaved and the cable had to be replaced. Finally, since asphalt is flexible, the passage of the trucks "milked" the cable through the conduit with each lap, eventually pulling out the 10" service loop and snapping the cable.

Overall, the system has performed its design task admirably, but it may not be suitable for mass deployment.

4.2 O-Bahn

Several systems around the world use mechanical guideways. The O-bahn system uses concrete rails on both sides of the road. Buses are equipped with horizontal rollers near the front wheels. These buses can run normally on city streets. Then they enter the O-bahn through a centering system, similar to a car wash.

The horizontal rollers run along the concrete rails and directly control the steering.

The O-bahn installation in Essen, Germany allows buses to drive through the very narrow streets at the old city center. The O-Bahn in Adelaide, Australia provides a narrow busway elevated over an ecologically sensitive wetland.

As with Westrack, O-Bahns do a remarkably effective job at providing a service, but are probably not easily extensible to mass use. In particular, they work well for situations where there is one entrance, one exit, and a fleet of well-maintained vehicles that are not likely to break down and block traffic.

4.3 FSS

The Ohio State University showed their Frequency Selective Strip (FSS) technology at Demo 97. The FSS is lane marking tape with an aluminum foil layer in the middle. The foil has slots punched in it, spaced to provide a strong return from an automotive radar at a particular shallow angle. This way the same sensor used to see other vehicles on the roadway can also be used to see the road position, at a distance of several meters in front of the vehicle. The system shown in August 97 used a 10 GHz radar and a strip placed down the center of the lane. Current work is designing a strip for the 77GHz frequency that is now the standard for automotive radars, and is designing strips that are visible from a range of azimuth angles, so they can be placed as lane markers.

4.4 Vision

Besides the CMU group, many other groups around the world are also working on road-following using vision, including: Professor Dickmanns at the Military University of Munich[1], Daimler Benz[2], BMW,[3] and several of the Japanese auto companies.[4] Two of those, a Honda system and a Toyota system, were shown as part of the 97 Demo.

5 97 Demonstration

The 1997 AHS Demo included seven demonstration scenarios, designed to showcase different technologies and different functions:

Platoons, with closely-spaced vehicles following buried magnets (coordinated by UC Berkeley PATH program) [5]

Free agents, with cars and busses using vision and radar (CMU)

Evolutionary, showing how this technology can be introduced incrementally for driver assistance (Toyota)[6]

Control transition, using both vision and buried magnets (Honda) [7]

Alternative technology, using a radar-reflective strip for lateral control (Ohio State) [8]

Infrastructure diagnostic, checking the accuracy of the magnets (Lockheed Martin) [9]

Heavy trucking, using radars for smart cruise control and driver warning (Eaton Vorad)

Of these seven demos, the Platoon and Free Agent demos were the largest and the most distinctive, and are therefore the best examples to explain.

5.1 Platoon Demo

The Platoon demo used two interesting technical approaches: lateral control by magnetic nail following, and longitudinal control in tightly spaced groups of vehicles, or platoons.

Magnetic nails are permanent magnets. The markers were installed every 1.4 m by surveying the location, drilling a hole, placing the magnets, then sealing them with epoxy. Each vehicle had three magnetometers mounted beneath the front and rear bumpers. As they drove over each magnet, they sensed its location, and servoed the steering to follow the markers. The magnets can be installed either North Pole up or South Pole up. This creates a simple binary code which can be used to signal upcoming curves or intersections.

The motivation for platoons is that packing vehicles very closely can add to safety. In the unlikely event that a computer-controlled vehicle has an abrupt failure in its velocity regulation, there may be a collision with a leading or trailing

Figure 3: Platoon Demo

vehicle. But since the space is so small, any collision will happen quickly, before a large relative velocity can build up. Generally, platoons run at inter-vehicle spacing of a few meters down to one meter.

In order to provide the tight control needed to maintain these spacings, platoons need good vehicle range sensing, an accurate dynamic model, high performance actuators, and good inter-vehicle communications to provide control preview information from leading vehicles. For the 97 demo, UC Berkeley used a specially-modified Delco radar, identical Buick LeSabres with modified and instrumented transmissions, and digital radios provided by Hughes for communicating the state of the lead vehicle to the rest of the platoon at 50 Hz.

The platoon demo ran a string of eight vehicles, with 6.5 meter inter-vehicle spacing. They engaged automated control from a stop, and ran completely automatically up to highway speeds and back to a stop. During the run, the second vehicle requested a lane change. The platoon automatically separated to provide maneuvering room, the second vehicle changed into the right lane, and the platoon reformed. After the second vehicle dropped back to the end, it changed back into the left lane, and rejoined the platoon.

5.2 Free Agent Demo

The Free Agent demo included five vehicles: two fully-automated Pontiac Bonneville sedans, a partially automated Oldsmobile Silhouette minivan, and two fully automated New Flyer city busses. The vehicles are named Navlab 6 and 7 (the Bonnevilles), 8 (minivan), and 9 and 10 (busses). Each of the vehicles in the scenario demonstrated slightly different functions. As an example, the following is the trace of a run on one of the sedans.

The Navlab 7 enters the AHS lane following a bus, a sedan, and another bus, and trailed by the minivan. All vehicles start under manual control. As the vehicles pick up speed to 50 mph, the lead vehicles drift off the road under manual control, to demonstrate the lane departure warning system. The warning system beeps, the drivers

Figure 4: Navlabs 6 through 10, from front to back

note they are drifting off the road, and they steer safely back onto the roadway. Once the vehicles are all safely back in their lanes, the Navlab 7 driver engages auto control by pressing the cruise control engage switch. A gentle voice says "automatic control on", a confirming display appears on the interface screen and on the HUD, and the driver takes his hands off the wheel and his feet off the pedals.

In a real AHS system in an urban environment, there could be a Traffic Management Center sending speed commands to the vehicles. The demo did not include a real TMC, so the vehicles simulated receiving a command to increase speed. The computer communicates with the cruise control, and the car increases speed to 55 mph automatically, passing the lead busses and car.

The minivan, driving manually, approaches from the rear at 65 mph. The minivan driver receives a warning that he is closing quickly on the vehicle ahead, triggered by his forward-looking radar. On Navlab 7, the rear looking ladar detects the approaching van. The human interface announces "high speed vehicle approaching". Navlab 7 checks its vision system to see if there is a lane to the right, checks its side looking sensors to confirm that the lane is clear, and checks its rear looking sensor for vehicles approaching in the right lane. If it is not clear of the busses, Navlab 7 holds its position. Once it is safe to change lanes, the voice and displays indicate "changing to right lane", and the vehicle smoothly changes lanes, allowing the minivan to pass.

Later, the second sedan pulls in behind the Navlab 7. The two vehicles communicate by digital radio to establish that they are both automated. The trailing sedan tracks Navlab 7 by radar, and maintains a comfortable 1.5 second gap using the throttle and brake actuators. Navlab 7 detects an obstacle in its lane, in this case an orange plastic construction barrel. Inside the vehicle, the interface indicates "obstacle detected - swerving to left", and the Navlab moves to the side. Since the radar has high angular accuracy, the vehicle only moves over far enough to clear the obstacle. It also communicates the location of the obstacle to the trailing sedan and busses, which automatically and safely change lanes even before their own sensors have spotted the obstacle.

The trailing sedan passes Navlab 7, and pulls back into the right lane. The driver of Navlab 7 wishes to re-pass the other sedan, without disengaging automated control. He presses the *"change lanes left" button, presses the "increase speed" cruise control button, and the Navlab 7 changes lanes, speeds up, and passes the other sedan. Similarly, he requests a slowdown and a return to the right lane, and, once the spacing is clear, the Navlab 7 changes back.*

Eventually, the Navlab 7 detects obstacles completely blocking its lane. For this part of the scenario, a simulation is set up indicating that there is traffic in the left lane, so it is impossible to change lanes. Navlab 7 brakes to a safe halt, and through a combination of radio communication and radar sensing, the trailing sedan also comes to a halt, followed by the busses.

5.3 Underlying Technology

Much of the underlying technology in the Free Agent Demo is new, built specifically for the Demo. Other components have been adapted from previous work. To as great an extent as possible, all systems on the three passenger cars and the two busses are identical. Components include the following:

RALPH: The vision system on all 5 vehicles is the RALPH system, built by Pomerleau[10]. This system uses a forward-looking video camera, mounted behind the rear view mirror of the cars and on the inside of the bus windshield, to image the road. The image is re-sampled to produce an overhead view of the road. The overhead view is processed to find the road curvature, by looking for the swept arc that maximizes the sharpness of edges along the swept line segment. This effectively finds the curve that most closely follows all visible road features. This was especially important for the 1997 Demo, since highways in California use raised dots instead of painted lines, so vision systems that rely on continuity of lines may have difficulty with this course. RALPH uses the raised dots, but also uses pavement joints and the edge of the shoulder and other parallel linear features, in order to find and track the road. This system is now commercially available through Assistware Technology Inc.

Radar: Headway maintenance (keeping a consistent gap from the lead vehicle) relies on a radar. Our partner Delco electronics supplied a 77GHz mechanically scanned radar with software for detecting and tracking targets within a 12 degree field of view, out to a range of 150 meters. It is important to measure both target range and bearing; commercially available automotive radars usually have no measurement of bearing, and therefore cannot properly track targets on curved roads. We have integrated the radar output with RALPH to register detected targets with detected road position. This lets our vehicles classify targets as to whether they are in the current lane, in an adjacent lane, or off the road. The sensors used on the busses are commercially available radars from Eaton Vorad that report range but not bearing.

Side-looking sensors: Each vehicle is equipped with four side-looking short-range radars from Eaton Vorad for detecting objects adjacent to the vehicles.

Rear-looking sensors: The rear-looking sensors are scanning ladars from Riegel. They have a field of view of approximately 20 degrees.

Lane changing: The logic requesting a lane change is based on desired speed, speed of preceding vehicles, and locations of vehicles in adjacent lanes. For the demonstration, the scenario was constructed so lane changes were easily executed when expected. In the more general case, deciding on a lane is an example of "tactical driving", the subject of a recent thesis by Rahul Sukthankar[11], a member of our group. His SAPIENT simulated vehicles do careful analyses of upcoming exits, velocities as well as positions of surrounding vehicles, and other factors, all combined in a distributed behaviorist framework.

Actuators: The car brake and steering actuators were custom provided by our partners at General Motors. The bus air brake and steering actuators were custom built by K2T, Inc. For all vehicles, the throttle actuation is through the existing cruise control. The Free Agent philosophy is to have large enough separations between vehicles that high-bandwidth throttle and brake servos are not needed. Using the existing cruise controls shows that low-bandwidth speed control is sufficient. As an added benefit, it reduces cost, provides commonality of interface between buses and cars, and increases safety by using tested commercial components.

Safety circuit: There are several safety checks in the system, to maximize safety on the demo vehicles. First, at the lowest level, any actuator can be overridden by the human safety driver. The steering motors and amplifiers are deliberately torque-limited to be easily overpowered by a person. The driver can similarly drive the throttle or brakes, and the computer controls have no way to backdrive the pedals. As a last hardware check, an independent safety board can at any time cut power to all actuators. The safety board continually monitors computer heartbeat, lateral acceleration, and state of emergency kill switches. In addition, the vehicle driving behaviors in the Free Agent philosophy are designed to keep safe space around vehicles, and to provide opportunity for defensive driving.

6 Comparison

At each major design point, CMU and Berkeley made different choices:

	PATH	CMU
Obstacles	Exclude	Sense
Driver role	Exclude	Cruise control
Grouping	Platoons	Free agents
Lanes	Dedicated	Mixed traffic
Deployment	Revolutionary	Evolutionary

6.1 Choices

For obstacle handling, CMU chose to give the vehicles forward-looking obstacle detection sensors. PATH did not demonstrate obstacle detection in this demo, and instead emphasized obstacle prevention through inspection of vehicle loads and construction of barriers.

For the role of the driver, in the PATH platoons spacing is so tight that the slow reflexes of a person would lead to unacceptable danger, so the human is locked out of control. When a driver wants to take control, he must request control, and wait until the vehicle has been moved out of the platoon and out of the dedicated lane. In the Free Agent scenario, the automated system is treated like a cruise control, that can be engaged, disengaged, and overridden by the driver.

The grouping strategy used by PATH, the platoon, generates high traffic density. The platoon strings are so long that they block merge lanes for significant distances, so any merging requires coordination to make sure vehicles enter only in the gaps between platoons. This probably relegates platoons to dedicated lanes, on which only automated vehicles can drive. The Free Agents usually run as individual vehicles, but can communicate to share information on emergency braking or obstacle avoidance.

PATH demonstrated a scenario in a dedicated lane. CMU demonstrated driver assist, mixed manual and automated traffic, and finally full automation with communicating vehicles[12].

A dedicated lane system requires a revolution in transportation. The free agents are designed to run in mixed traffic, and to be deployed one vehicle at a time. The dedicated lanes are an easier engineering problem in some ways; but building new lanes is a larger societal challenge.

6.2 Discussion

These different approaches to AHS are appropriate. First, it makes more sense for the NAHSC to explore alternatives rather than to build duplicate systems. But more fundamentally, the different demo systems emphasize the different goals of AHS, and perhaps the different geographic imperatives of the two developers. Berkeley is located in the crowded San Francisco Bay area. Traffic congestion is a major problem. Many freeways are at least three lanes wide in each direction. That encourages them to work on designs that dedicate a lane to automated vehicles, and pack as many vehicles as possible into that lane. For those circumstances, platoons are a reasonable alternative to consider. And for the relatively few miles of urban freeway, infrastructure investments such as placing magnets or building barriers to separate a lane may make sense.

CMU, in contrast, is in the rural western end of Pennsylvania. Few miles of expressways are congested and the only 3-lane wide roads are for climbing lanes on hills, near some interchanges, and for a very few miles of the newest freeway. In those circumstances, safety is more of a market force than congestion. Since accidents occur on rural roads as well as interstates, and since there are 4 million miles of road (vs. 100,000 miles of limited access roads), it is infeasible to consider major infrastructure investments for safety upgrades. This leads to a solution where vehicles are sensor-rich and independent, and where the computing and sensing can be used for driver safety assistance even when the vehicles are driven manually on rural roads.

So which system is better, the Platoons or the Free Agents? Perhaps there is no one right answer; each system has its niche in which it may be more appropriate. A useful deployment strategy may embrace Free Agent technology sooner, at least for driver warning and assist, and later selectively deploy platooned systems in dedicated lanes, after market penetration justifies that lane usage.

7 Conclusion and the Future

The 97 AHS Demo was designed to be an intermediate checkpoint on the way to building a prototype AHS. According to the original schedule, the next two years of the AHS program were supposed to be spent building three separate approaches to AHS, followed by a downselect, followed by designing and building a final prototype and conducting tests up to the year 2002.

The NAHSC program was on schedule and within budget, and the AHS Demo was widely regarded as an outstanding success. But politics and funding priorities change. The current emphasis in the US Department of Transportation is on nearer-term results, and particularly on safety and driver warning devices. The new program, to kick off in 1998, is called the Intelligent Vehicle Initiative. Much of the work on full automation will be reduced or postponed. Increased emphasis will be placed on vehicle-centered technology, and on human factors and driver interfaces.

These new priorities are useful and will generate interesting research questions. But in the longer term, driver warnings will only achieve limited results. The imperative remains for increasing automation, both for congestion relief and for increased safety.

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Core members of the NAHSC are: Bechtel, Caltrans, CMU, Delco, General Motors, Hughes, Lockheed Martin, Parsons Brinkerhoff, the USDOT, and the University of California. Other groups providing demonstrations were Ohio State, Honda, Toyota, and Eaton Vorad.

Figure 3 is courtesy of California PATH Publications.

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9 References

[1] Dickmanns E. D. "Vehicles Capable of Dynamic Vision," in 15th International Conference on Artificial Intelligence, Nagoya, Japan, August 1997.

[2] Zomotor, Z, and Franke, U., "Sensor Fusion for Improved Vision Based Lane Recognition and Object Tracking with Range Finders" in Proceedings of IEEE Conference on Intelligent Transportation Systems, Boston MA, November 1997.

[3] Lerner G. and Steinkohl, F. (1997) "Driver Assistance: Concepts and Systems" Traffic Technology International, Oct/Nov. 1997

[4] Proceeding of 1996 Intelligent Vehicles Symposium, Sept. 19-20 1996, Tokyo Japan.

[5] Zhang, Wei-Bin, "National Automated Highway System Demonstration: A Platoon System" in Proceedings of IEEE Conference on Intelligent Transportation Systems, Boston MA, November 1997.

[6] Andrews, Scott, "Steps to Deployment: An Outline of Toyota's U.S. AHS Program" in Proceedings of IEEE Conference on Intelligent Transportation Systems, Boston MA, November 1997.

[7] Shladover, Steve and Empey, Dan, "Characteristics of the Honda-PATH AHS Team Vehicles for the 1997 AHS Feasibility Demonstration" in Proceedings of IEEE Conference on Intelligent Transportation Systems, Boston MA, November 1997.

[8] Ozguner, Umit, et. al. "The OSU Demo '97 Vehicle" in Proceedings of IEEE Conference on

Intelligent Transportation Systems, Boston MA, November 1997.

[9] McKenzie, Patrick, "Infrastructure Diagnostic Vehicle" in Proceedings of IEEE Conference on Intelligent Transportation Systems, Boston MA, November 1997.

[10] Pomerleau, D. and Jochem, T. (1996) Rapidly Adapting Machine Vision for Automated Vehicle Steering. IEEE Expert, Vol. 11, No. 2

[11] Sukthankar, Rahul. "Situational Awareness for Driving in Traffic", PhD thesis, Carnegie Mellon University, January 1997.

[12] Bayouth, M., and Thorpe, C. "An AHS Concept Based on an Autonomous Vehicle Architecture", in Proceedings of 3rd Annual World Congress on Intelligent Transportation Systems, 1996.

A. Appendix: Overall Demo Statistics

The 97 Demo was a very large public undertaking, perhaps the largest public participation demonstration of robotics and automated vehicles.

Attendees	
Total	3500
Public	1000
Press	100
VIP	1400
Industry	1000
I-15 Demo	
Total vehicle	26
Total automated	21
Automated types	1 truck, 2 busses, 18 cars
Automated makes	Freightliner, New Flyer, Buick, Oldsmobile, Pontiac, Toyota, Honda
Demo runs	20 each
Trial runs	8 each
Total automated vehicle runs	588
Total automated miles during demo	4468
Dress rehearsal runs	22 each
Automated miles during dress rehearsal	3511

Mini demo on short track	
Total vehicles	5
Total automated runs	144
Mini-demo total miles	180
Passengers	
I-15 during demo runs	1350
I-15 during demo trials	500
I-15 during dress rehearsals	1000
Minidemos	1400
Total passengers	4250