Computer Controlled Cars

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Abstract

This article is originally from approximately 1968, but was probably revised in the 1970s.

There have been a number of proposals for automatic control of cars. Mostly, they have involved simple servo-mechanisms that sense a cable buried in the roadway and some other mechanism for sensing the distance of the car ahead. Such a scheme was studied at RCA at the instigation of Zworykin, but the work was eventually abandoned.

In science fiction, systems in which a single computer controls all the cars in a wide area have been depicted but without telling how the system would actually work.

We are also proposing the computer control of cars. Our system requires a computer in the car equipped with television camera input that uses the same visual input available to the human driver. Essentially, we are proposing an automatic chauffeur. Our goal is a system with the following qualities:

1. The user enters the destination with a keyboard, and the car drives him there. Other commands include: change destination, stop at that rest room or restaurant, go slow, go at emergency speed.

2. The user need not be a driver and need not even accompany the car. This would permit children, old people, and the blind greater personal freedom. It also permits a husband to be driven to work, then send the car home for his wife's use, and permits her to send it back for him at the end of the day. The car can be sent for servicing or to a store where a telephone ordered purchase will be put in it. If there is a suitable telephone system, the car can deliver a user to a place where there is no parking, go away and park, and return when summoned. Thus, the system is to have almost all of the capabilities of a chauffeur.

3. In contrast to a system based on a central computer, the proposed system will be of advantage to the first person who buys one, whether anyone else has it or not. It will require no change in existing roads, but will be able to take orders from traffic control computers when they are installed. When freeway lanes can be dedicated to computer controlled cars they will multiply the capacity of existing freeways by permitting 80 mile per hour bumper-to-bumper traffic with greater safety than we have at present. Since the system is a product and not a public utility, competition among suppliers will be possible.

4. A key goal is to achieve greater safety than we have at present. A fivefold reduction in fatalities is probably required to make the system acceptable. Much better is possible since humans really are rather bad drivers, but complete safety cannot be guaranteed.

Now we shall consider the problems that have to be solved in order to realize the system.

1. *Performance of the computer, cameras, and associated electronics.* Present computers seem to be fast enough and to have enough memory for the job. However, commercial computers of the required performance are too big. We envisage that a computer of about the power of the Digital Equipment PDP-10 will be required. Military versions of similar computers have volumes of one or two cubic feet, but the requirements for memory and secondary storage would be difficult to meet in a reasonable volume at present. However, the development of more compact computers and other electronic circuitry is proceeding at a rate that makes achieving the required compactness not the pacing item. Some

improvements in the performance and compactness of television cameras is also required, but it is not yet clear what these requirements are.

2. *Cost of the computer and other electronics.* At present prices, a computer capable of controlling a car but containable only in a large van would cost \$400,000 to \$800,000. A few thousand dollars worth of other electronics would be required. Ten years should bring the cost down by a factor of ten. Mass production would give another factor of three. This would permit the system to be available as a luxury item. Another five to ten years might be required before computer control would only double the price of the car. These estimates must be regarded as guesses.

3. *Reliability of the computer and other electronics.* We can attempt to compute the required reliability by demanding that present traffic fatalities be reduced to a fifth the present number, i.e. to 10,000 per year, and by allocating only half of these fatalities to unreliability of the electronics. This further depends on the fraction of failures that lead to fatality which can be kept quite low by having the computer check its health and that of the electronics every tenth of a second, giving it programs for dealing with partial failures, and providing a "dead man switch" for stopping the car if the computer fails to reassure it every tenth second. There are many possibilities in this direction and the expenditure of much cleverness is called for. The reader is advised against using his unaided intuition to estimate the results. Nevertheless, present computer failure rates would not be acceptable even if they never led to accident simply because of the inconvenience. We estimate that an improvement of 1000 in mean-time-between-failures is required. Rapid progress is being made in this field, and we expect that ten to fifteen years normal progress of the computer field will give the required result.

4. *Performance of the driving programs.* Developing the required computer programs is the most difficult of the required tasks; it will probably take the longest time; and the amount of time required is very difficult to predict. Work on computer control of vehicles has started at the Stanford University Artificial Intelligence Project. An experimental vehicle has been equipped with a television camera and con-

nected to the computer with a two-*way TV and radio link. A simple program to guide the vehicle to follow a white line like that in a road has been successfully checked out, and programs for determining the course of the road and detecting cars and other obstacles are being developed. However, before computer controlled cars become a reality a much larger scale effort will have to be made.

The nature and extent of this effort are not easy to forsee yet. We are far from having exhausted the possibilities of our present equipment, but eventually the radio link to the computer will have to be replaced by a computer in the vehicle, and television equipment capable of seeing better into shadows in the presence of bright areas will be required. We need to be able to identify many different types of objects on the road such as: persons, vehicles, animals, traffic police, shadows, pieces of paper, cardboard boxes, objects that have dropped from vehicles, traffic signs and other signals, intersections, house numbers, and other information required for navigation. It will have to be equipped with programs to recognize and deal with a variety of emergency conditions. It will surely be possible to make it better at this than humans since its attention won't lapse, it can sense the mechanical condition of the car continuously, and it can look to the side, underneath the car, and behind every second.

The most intricate single problem is the visual pattern recognition.

1. *Testing.* After the required performance is demonstrated and before the system can be trusted without a human driver an extensive testing program is required. To demonstrate that the system is five times safer than a human driver approximately 25,000 automobile years will be required. This might be reduced somewhat by concentrating testing on situations in which humans make most of their fatal mistakes, but we would still need to be sure that situations in which the program made fatal blunders peculiar to the computer system were rare enough. Developments in the mathematical theory of computation may permit getting rid of ordinary programming errors and proving that they are absent, but possible inadequacies in the algorithms themselves can only be obviated by testing.

2. *Public acceptance.* Automobiles without qualified human drivers will require changes in the law. Fortunately, testing such systems with a

driver present to take over if necessary does not. Moreover, computer driven cars will not be able to obey oral instructions from policemen , so a digital system will have to be developed. A general resistance to technological innovation on the part of the literary culture will have to be overcome, but it seems to me that after the test phase the advantages will be clear enough so that this will not be difficult.

3. *Support for research and development.* The development of computer controlled cars will cost hundreds of milliions of dollars. A computer program capable of reliably taking care of all the contingencies that can arise in driving a car will have to be more complex than any ever written, and adequate testing will require a complex organization. Fortunately, The commitment of large amounts of money will be required only after spectacular though unreliable performance will have been demonstrated. So far as I know, the Stanford Artificial Intelligence Project is the only organization now working on computer control of a vehicle using vision. This work is part of a basic research project on artificial intelligence supported by the Department of Defense. Even at the present stage of the work, other projects are needed to secure an adequate diversity of approach. While considerable additional progress will certainly be made with the present support, even a prototype will require more money than is now available.

Fortunately, this problem is within the jurisdiction of the Department of Transportation. The automobile companies and the computer companies also might be expected to help, but their past record of seeing beyond the ends of their noses is not encouraging. Because the programming is the pacing item, more support at this time will hasten the day when computer control of cars is achieved, but the possibilities will be much more obvious in five years with the advances in hardware and programming that are already taking place for other reasons.

Finally, we would like to deal with some arguments that might be raised against supporting research aimed at computer controlled cars:

1. *Cars must be done away with because they produce smog, require too much space, and use up too much natural resources.* We believe the smog devices will eventually be made to work well, or if not, another form of propulsion can be found. Computer controlled cars will require

less space than equivalent present cars because they can go faster and closer together on streets, roads and freeways, because they can park at a distance from a place where they discharge passengers, and because a computer driven car can be shared more easily than a conventional car. If hydrocarbon fuel runs out and is still required for cars, then with nuclear energy, the burning reaction can be driven backwards and fuel synthesized from carbon dioxide and water.

2. *A simpler scheme of automatic control is preferable.* The buried cable and other simple schemes do not increase human freedom and convenience. They only permit us to use the freeways a bit more efficiently. Because of their inability to detect dogs, children, potholes, and objects that have fallen from trucks they may require unrealizable control of access to the highway in order to achieve safety.

3. *Some form of automated mass transportation is obviously better.* The automobile can go point to point in areas of both low and high density. We believe that these advantages should not and will not voluntarily be given up. We favor the development of improved mass transportation, but predict that the automobile will be given up only for something that works better in all ways such as an individual computer controlled flying machine capable of point to point transportation.

1 Inside the Computer Controlled Car - 1996 March

The first cars were horseless carriages and inherited the design features of carriages. Here are some of the features.

- Horses were slow, so aerodynamics could be entirely neglected.
- Light weight was essential, so there were no heaters, and the cars were not usually enclosed.
- Horseless carriages were high which gave them a high probability of rolling.

We can expect the first computer controlled cars to be like present cars in their internal layout. There will be a driver's position on the left front with a full set of manual controls including a steering wheel right in front of the driver. It will be boring and constraining sitting there.

After riders, manufacturers and Government regulators become more confident of the computer control, the steering wheel will be replaced by something much smaller and less intrusive.

The main changes will come from the driver wanting to do something else with his time. He will sit farther back with a display in front of him that can be used for reading, any kind of work done with computer terminals, watching TV and doing whatever else the infotainment industry can persuade us to pay big bucks for.

There will be a large premium on making the ride smoother so that the motion of the car won't interfere with the work and play of the occupants.

There will continue to be as much single occupant travel as today, and there will be advantages in having the car capable of re-arranging the interior to give a single occupant more space to work, play, eat or rest.

Therefore, contrary to the wishes of the energy priests, cars are likely to become larger, not smaller. Some of the present disadvantages of large vehicles will be eased by the ability of a computer controlled car to go off and park itself until summoned.

The NAVLAB automated car project,
http://www.cs.cmu.edu/afs/cs/project/alv/member/www/navlab_home_page.html at Carnegie-Mellon University has the same ultimate goals but is still in a stage amounting to an improved cruise control.

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