

A New Approach to Automated Highway Systems: Puppet Master

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Abstract—In this research, a novel system is designed in scope of automated highways. The aim of this system is to provide safe, secure and fast transportation on highways. This system uses both road sensors and GNSS (Global Navigation Satellite System). Since no human interaction is allowed in this system, the driver mistakes are reduced to zero. Based on the road sensors and the GNSS, the system is able to adjust the speeds and the following distances between vehicles. The messaging system is also designed for this puppet master architecture, which allows vehicles to communicate with the central components of the system.

Index Terms—Automated highway, intelligent transportation systems

I. INTRODUCTION

After it is estimated that 90% of the traffic accidents are caused by human factors [1], the researchers are mostly focused on a system that does not need human interference. Studies have been made so far dealt with autonomy of a single car. Considering only a single car brings up safety problems. In 1993, Varaiya made a research about automated transportation system and stressed on control problems [2]. In 1997, Thorpe et al. made a demonstration of a system that uses autonomous cars and proved that the system is technically feasible [3]. After one year, in 1998, McMillin and Sanford made a wide research about intelligent transportation systems and automated highways [1]. Those were the first approaches for the autonomy of a system, but it was not designed for a single car. However, there were a number of studies that were focused on autonomous vehicles [4]-[6]. The cars have been developed so far, used sensor systems to observe the environment [5], [7], [8]. Whereas, previously studied, using sensors to determine the environment is a successful, but not sufficient enough for an autonomous car to move safely [9]. Another algorithm that has been developed to have the autonomous car followed the other car which is also, at one point, dependent on human driving [10]. Problem with this algorithm is, if the followed car fails, depending on current condition, it might be unable for the other car to react on time. Even though an efficient method has been developed for a single car to observe the environment and react dynamically, the effects of human drivers have

never been eliminated [11]. The effect of human drivers is much more different than the effect of other autonomous cars. While controlled by a centralized system, the autonomy of the autonomous car is somehow restricted. The controller separates the shared data in terms of location and sends the agents in a certain region. By sharing the location, the vehicles are able to make adjustments to their velocity, acceleration or direction accordingly. They are also able to communicate with each other to negotiate their priority. This human-like behavior will lead the vehicles to predict others' behaviors and avoid a possible accident. As a result of intelligent agent-like approach, we can observe that imposing emotions on autonomous cars reduces the risk of accidents [6]. In this centralized system, each car is driven by the centralized system and they are unable to interfere with the human. Since every single car is given orders by only one decision mechanism, the cars will not collide.

The organization of the paper is as follows. In Section 2, we present the related work and comparison of the related work with our system. Section 3 describes the structure of the system. Section 4 introduces the messaging interface. Section 5 includes an example for the messaging phase. Section 6 clarifies the localization process of the vehicles. Section 7 concludes the paper.

II. RELATED WORK

As described in the previous section, there are number of studies on autonomous vehicles and autonomous vehicle systems. In this section, we are going to list the studies and compare those studies with our work. Thorpe's system used in his demonstration used central system similar to ours [1]. However, the system uses video cameras and has a speed limit of 88kmh. The cars move as clusters through the highway, taking the leader car as reference to follow. Drawbacks of the system also investigated in the paper. The main drawback is, the system is dependent on one car. In our system, all cars are autonomous, yet controlled by a central system continuously. When one car fails, central controller can handle it because it controls the other cars. When central controller fails, the cars will halt safely since they are also autonomous. The car-like robot developed in year 2003 is also an autonomous vehicle [12]. The vehicle uses landmark to navigate and has a speed limit 30kmh. Main object for this robot is to move among pedestrians,

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therefore it is more reflexive but less robust. The technique used in this system is not applicable to real motor vehicles for this reason. Autopia is another system that has been developed in year 2009 [13]. The system uses GPS, which has drawbacks against GNSS. Also, the system is only tested on empty roads, whereas our system is applicable to highway traffic. CyberC3 is the system which is the most similar to our system with respect to the usage of central control [14]. However, the system is fully centralized, which is a drawback compared to our system. Once the central controller fails, autonomous vehicles will not be able to stop safely. The system works with three logical layers and takes road lines as references. Progress among three layers brings up delay issues and road lines are not always proper (they may be stale). In the next section, we are going to describe the structure of our novel system.

III. STRUCTURE OF THE SYSTEM

For each highway, the system as a whole is based on a central controller. Each central controller is responsible for a single highway. However, there are also local controllers which are responsible for certain regions of the highway. Local controllers act as puppet masters and steer the cars on the highway. Central controllers and local controllers work in a hierarchical order. Notice that the vehicles themselves are always in touch with other vehicles. If the system fails or the exception occurs, they can stop immediately. In order to steer the cars, consider that there is a control system integrated in each car.

A. Central Controllers (CC)

Main duty of the CC is to manage a database where the information about cars are kept (details are given in Section 2). The controller also stores the information contains which car is assigned to which local controller (LC). Thus, each LC has an attribute CONTROLLER_ID. When the cars are introduced to the system, the CC assigns each car an integer, CAR_ID, and sends the information when it is required by any LC. The CC is able to communicate with autonomous cars through LCs. The data are sent from LCs to CCs. The CCs can be utilized to avoid future possible traffic jams. Since the CC contains all the data from the LCs, it is able to report the traffic density through LCs to each autonomous car.

B. Local Controllers (LC)

The LC is responsible for a certain region of highway. The LCs act as a puppet master where the cars are puppets and the steer systems are the strings. When a new car enters the highway, related LC requires the CAR_ID of the car and keeps track of the car using its CAR_ID. The LC checks the location of each car, the distance between cars and adjusts cars' velocities accordingly. In other words, the LCs pull the wires and let the cars reach the destination as fast as they can. In an emergency situation, each LC is responsible to arrange positions of cars in their territory.

IV. THE MESSAGING PROCESS

The vehicles need to be continuously in communication with controllers. This communication is an essential part of the system for various reasons. As an example, the system needs to keep track of the number of vehicles on a highway, so that it will not waste its messaging capacity by gathering information about vehicles those already left the highway. The cars need to send messages to controllers about their distance to other cars. This is crucial during high speed travelling. Thus, we developed a messaging interface. Note that, because of space limitations, we omit the common fields for all messages e.g. *message id*, *sender id*, *receiver id*.

A. Introduction Messages

When a new LC is built, it should be given an ID by the CC. The new LC sends a message to the CC, reporting its location and region that it is responsible of. The Controller's introduction message is formed as NEWCONTROLLER [*<controllerLocation>*, *<territoryCoordinates>*] where *<controllerLocation>* includes north (N) and east (E) coordinates, which specifies a point on the map. The *<territoryCoordinates>* is a vector contains four corners of a rectangle. Using these coordinates, the CC creates a new area of territory, determined by TERRITORY_ID and registers the new LC to the database with the following attributes; CONTROLLER_ID, LOCATION, TERRITORY_ID. Thus, newcomer LC is responsible for area which is denoted by TERRITORY_ID. After registering the new LC, the CC responds with a message reporting that new LC is successfully done; NEWCONTROLLER [*controllerID*, *<neighboursID>*]. Thus, the LC is now has the information of its own ID. Also, the *<neighboursID>* contains the IDs of the other LCs. A car introduction message is a message when a new car is introduced to the system. The information about the car is sent directly to the CC. The message is formed as; NEWCAR [*length*, *width*, *weight*, *maximumVelocity*]. Thus, the CC is able to create a new registry and assign a new ID to the new car using the following attributes; CAR_ID, WIDTH, WEIGHT, MAX_VELOCITY, CREATED_ON, ASSIGNED_TO where CAR_ID is an integer and automatically incremented, WIDTH, WEIGHT and MAX_VELOCITY are numeric values determines weight, height and maximum velocity of the car, CREATED_ON is an attribute which keeps the date and the time that the car is introduced to the system. ASSIGNED_TO shows the ID of the LC (CONTROLLER_ID) that controls the car with CAR_ID. When the car changes territory, via territory change message (see Section 4.3), the value of attribute ASSIGNED_TO is changed to the new LC. After receiving the message, the CC responds with a message reporting that new car entry is successfully done; NEWCAR [*carID*]. Thus, the new car is aware of its ID that is kept in the database. When the car is introduced to the system successfully, they are able to be controlled and driven by the system.

B. Initial Messages

Initial messages are sent between the car and the LC. The car, which is already registered, enters the highway

and requires to be driven. The corresponding LC, which is responsible for the territory, sends a response to the message sent by the car. The initial message broadcasted by each car, is captured by the relative LC, and is formed as;

INIT_CAR_TO_LC[locationOfSource, locationOfDestination, requiredPriority, gasLevel]. Then, the LC reports that the car requires to be driven. The LC sends a message to the CC that contains information about the car. The initial message sent from each LC to the CC is formed as;

INIT_LC_TO_CC[carID,<locationOfSource>, <locationOfDestination>]. The initial message sent from LC to each car is formed as;

INIT_LC_TO_CAR[<currentLocation>, <routeToFollow>, givenPriority, estimatedDistance] where <locationOfSource>, <locationOfDestination> and <currentLocation> are vectors, which keep north (N) and east (E) coordinates. The requiredPriority is an integer value (each car's priority is 0, by default, meaning "no priority required") that is used to require the right of way. This property is used when there is an emergency situation (e.g. an ambulance carrying an injured person). The system decides the required priority. Then, the message is responded by the givenPriority. The gasLevel is a value between 0.00 and 1.00, showing the gas level of the car. The controller responds to this message by the estimatedDistance considering the possible velocity and the gas consumption of the car. The routeToFollow is a set of checkpoints which the car is going to pass. After the initial messaging, the cars should always be aware of other cars via sensors and the messages received from the LC.

C. Territory Change Messages

When a car moves out of the territory of its current corresponding LC, the LC first informs its neighboring LC that a car is going to enter its territory. That is, transferring a puppet into another master. The message is formed as;

TERR_LC_TO_LC[carID, <routeToFollow>, givenPriority]. After informing the neighboring LC, it informs the car that a new LC will be responsible for it. The message is formed as;

TERR_LC_TO_CAR[controllerID]. The controllerID is the ID of the neighboring LC. Thus, the car will not be sending messages to the previous LC.

V. AN EXAMPLE MESSAGING CASE

Consider that two cars A(lice) and B(ob) are going from X to Z. There is a huge distance between X and Z, say 200km, so that only one controller cannot handle it. So, we add an imaginary point between X and Z and call it Y. There are two local controllers between X and Z, besides a central controller. Local Controller 1 (LC1) is responsible from the region between X and Y, and Local Controller 2 (LC2) is responsible from the region between Y and Z. Also consider that Alice's driver has just bought gas for her car, and Bob has half-full gas in his tank. First, Alice enters the highway, when Alice is on

the point Y, Bob enters the highway. The messaging case is given as below. Before the messaging starts, let us clear that X, Y and Z are considered as vectors with north and east coordinates.

Below is a sample communication case for the system. For avoiding ambiguity, we will write down the source and the destination for the given example:

A enters the highway

A → BROADCAST: INIT_CAR_TO_LC [X, Z, 0, 1.00]
"I am going from X to Z, I don't need priority and my tank is full"

LC₁→CC: INIT_LC_TO_CC [A, X, Z]
"I am controlling car A whose destination is from X to Z"

LC₁→A: INIT_LC_TO_CAR [X, <X,Y,Z>, 0, 200]
"You are in X. You will follow the route X, Y, Z. You aren't given any priority. Distance is 200km."

A reaches the point Y

LC₁→LC₂: TERR_LC_TO_LC [A, <X,Y,Z>, 0]
"The car whose ID is A is moving out of my territory. Its route is X, Y, Z. No priority"

LC₁→A: TERR_LC_TO_CAR [LC₂]
"Your new local controller's ID is LC₂"

B enters the highway

B → BROADCAST: INIT_CAR_TO_LC [X, Z, 0, 0.5]
"I am going from X to Z, I don't need priority and my tank is half full"

LC₁→CC: INIT_LC_TO_CC [B, X, Z]
"I am controlling car B whose destination is from X to Z"

LC₁→B: INIT_LC_TO_CAR [X, Y, 0, 200]
"You are in X. Your next checkpoint is Y. You don't have any priority. Distance is 200km."

LC₁→C: INIT_LC_TO_CAR [X, <X,Y,Z>, 0, 200]
"You are in X. You will follow the route X, Y, Z. You aren't given any priority. Distance is 200km."

VI. LOCALIZATION PROCESS

The locations of the cars are determined by using two pieces of information. The first piece of information is provided by the LCs using the GNSS method [15], the second piece is provided by the cars via sensors, using an algorithm called trilateration and proven to be NP-Hard in noisy environments, by Evrendilek and Akcan [16]. This algorithm is used, since the weather conditions vary and performance of sensors may decrease accordingly. The cars and the LCs share the location information simultaneously to determine a reliable way to manage the cars. The LCs keep track of the cars that they are responsible for and since the messaging processing may not be fast enough to provide the real-time reactions, the

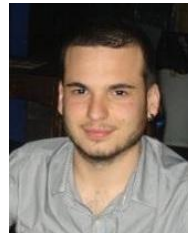
system includes two main decisions to run safely. The first main decision is taken by the cars. Since the cars are developed as intelligent vehicles, they are able to take decisions using the environmental variables. By cooperating them, they also avoid decisions that can lead to accidents. The second main decision is taken by the LCs. Since the LCs possess their whole territory, they are able to make more proper predictions than the cars. They have the ability to assign roles to the cars, or give directions in case of exceptions (e.g. a traffic jam). The sensors that are placed on the side of the highway with equal distances also help the cars and the LCs to determine the location information.

VII. SUMMARY

We have developed a system that reduces human mistakes to zero. The system is both safe and fast. It is safe since there are control mechanisms, work as a puppet master, besides the self-control of intelligent vehicles. The material that is used to build the system is not costly with respect to the services it provides. One can sleep or rest while the car moves on the highways. A really considerable advantage of the system is that we don't need to do any modifications to the highways. When there is sufficient number of sensors, it is possible to locate and control each vehicle that travels.

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