A Multi-modal Architecture for Intelligent Decision Making in Cars

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Abstract. This paper describes a software architecture named "Gatos" engineered for intelligent decision making. The architecture is built on a distributed multi-agent system cougaar. Gatos provides a solution for sensor fusion. We propose using multiple sensors to monitor driver status, driving performance, and the driving environment in order to address bad driving behavior. Our approach for a Driving Monitor is based on both monitoring and regulating driver behavior. The system is designed to intervene and to interact with the driver in real time (if possible) to regulate their behavior and promote safe driving. A prototype is implemented using a driving simulator, but infrastructure buildup and new in-vehicle technologies make this a feasible solution for vehicles on the road.

Keywords: software agents distributed computing, multi-agent, parallel computing, driving simulator, driving behavior, driver status, driver monitoring.

1 Introduction

We are investigating how different aspects of driver state, traffic and driving environment affect driving behaviors. To address this, we are running numerous studies using driving simulators [1-5], paying particular attention to how drivers interact with and react to different types of speech based in-vehicle systems. One of the goals of these studies is to identify how to interact with a driver in real time without having a negative impact on driving performance. If a driver is found to be in a state not consistent with safe driving, it then might be necessary to intervene and influence the driver to move into a state that is consistent with safe driving performance. A driver's state can be measured in various ways. Sensors such as EEG are useful for identifying novelty, complexity, and unexpectedness, as well as emotional excitement and anxiety[6]. Unfortunately EEG is awkward to use in a vehicle because the sensors have to be attached to the scalp. Autonomic activity, including heart rate, blood pressure, blood pulse volume, respiration, temperature, pupil dilation, skin conductivity, and more recently, muscle tension (electromyography (EMG)) is relatively easy to measure. Certain measures of autonomic activity have proven reliable at distinguishing basic emotions. Heart rate increases most during fear, followed by anger, sadness, happiness, surprise, and

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finally disgust, which shows almost no change in heart rate[7-9]. Heart rate also increases during excitement, and mental concentration. Decreases in heart rate indicate relaxation and can be induced by attentive visual and audio observation, as well as the processing of pleasant stimuli [6]. Blood pressure increases during stress and decreases during relaxation.

Combined measures of multiple autonomic signals show promise as components of an emotion recognition system. Many autonomic signals can also be measured in reasonably non-obstructive ways (e.g., through user contact with mice and keyboards; [10]). In the same manner our approach to monitor driver state is based on non-intrusive sensors that can be placed in a car, in the steering wheel, in the seat, in the seatbelt, in the rearview mirror and on the dashboard. The Driving Monitor does not base assessment of driving behavior on the driver state alone, the system also uses sensory input from two other sources 1) the system also gathers driver behavior information such as speed, lane position and distance to other road users and objects and 2) information from the driving environment such as road layout, traffic and weather.

The Driving Monitor can be implemented in a driving simulator. This is our first choice since it gives the possibility to work within a closed and ideal world assumption. All information ranging from driving behavior to traffic and weather is available to the system. The system can also be implemented in a vehicle. This, however, reduces the number of input sources radically. Instead of having full access, we have to rely on information available via CAN bus, other attached sensors such as cameras, GPS and maps for road layout, and third party sources for traffic and weather information. The 'real world' version of the Driving Monitor is hence limited when compared to the simulator version.

The Driving Monitor relies on creating an aura around the car and the drivers. This aura indicates the active safety area of the car., see Figure 1.

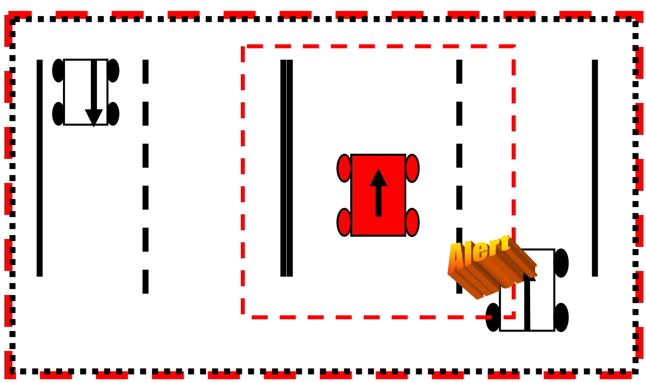

Fig. 1. Overview of Driving Monitor

The subject vehicle is surrounded by a dotted rectangle red in the illustration above (Figure 1) (this could be a sphere instead). This rectangle denotes the active area, and all activity is monitored within this area. The driver state and driving behavior are monitored by sensors within the car, and the driving environment is tracked and monitored using a combination of sensors in the car and the instrumented infrastructure. The active area observed by the Driving Monitor can change dynamically based on driver actions or driving performance to give flexibility in the amount of data used. For instance:

1. When the driver is reversing the active area is shifted to be behind the car and driver.
2. When the driver is making right or left turns (or changing lanes) the active area shifts to the left or to the right accordingly.
3. When the driver is driving slowly the active area shrinks.
4. When the driver is speeding the active area grows as a greater distance needs to be considered for safe driving.

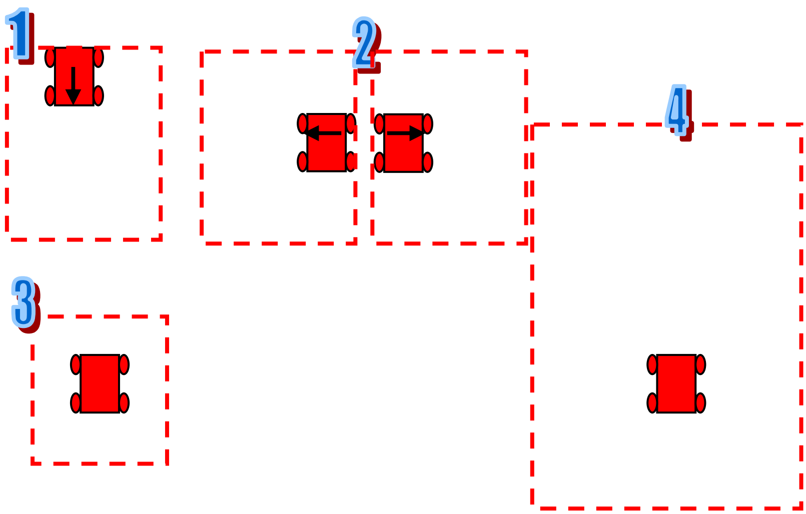

Fig. 2. Some configurations of the active are for the Driving Monitor

The interactions initiated by the Driving Monitor should, among other things, be affected by the location of the alerts. Identified threats located in the drivers blind spots should most likely be presented to the driver differently than threats in the driver's field of vision, be it in front or behind the driver.

2 Gatos

The task that Gatos is presented with is to build software that can combine input from many different sensors, working at different speeds, and making intelligent decisions to help maintain safe driving. Agent oriented solutions, and especially fine grained distributed agent systems are well suited for tasks like this. With a hierarchy of agents, there is one agent per sensor, and that agent is responsible for monitoring its inputs sending its data to the agent that is at the next level of hierarchy. The receiving agent takes this and input from many other sensors. It combines the inputs, makes calculations and finally delivers a regular stream of decisions regarding driver state, driver behavior, driving environment or a combination thereof. This agent's decision making capabilities are scriptable making it possible to update the agent's decision base and reasoning base at run time.

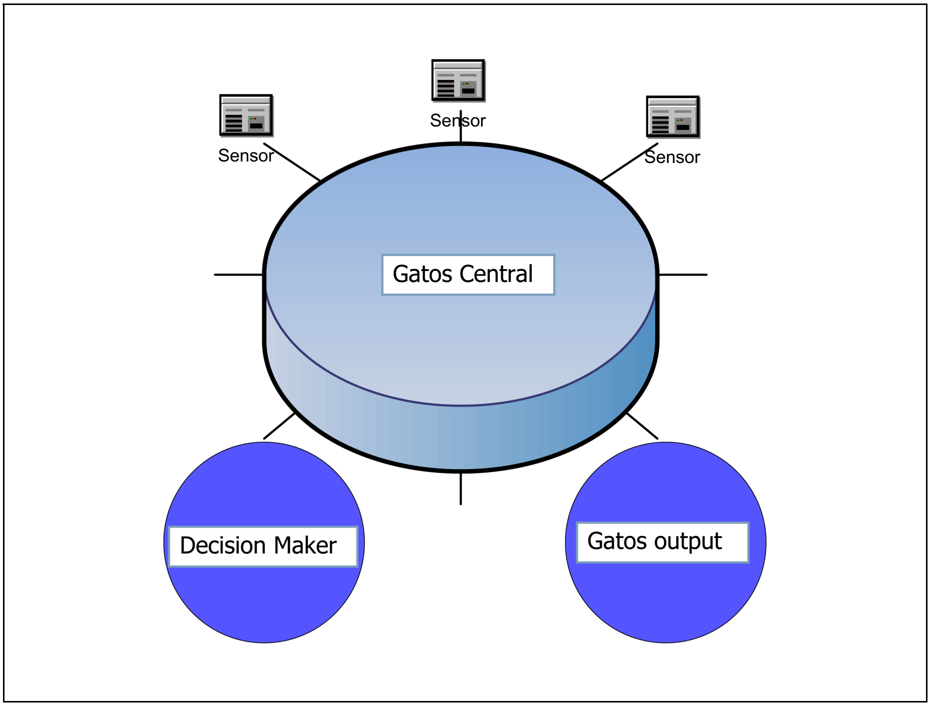

Fig. 3. Overall Gatos Structure

2.1 Distributed Architecture

From the outset it was decided to use a distributed architecture so that devices could be added dynamically and if devices left the system during runtime through failure the system would continue to function albeit with reduced capability.

2.2 Cougaar

Cougaar was chosen as the backbone over other agent systems due to its flexibility and ability to function as a true distributed system.

Cougaar also had many other properties that made it an excellent choice for the backbone of Gatos. Chief among these is that it's a true agent platform where the granularity of agents is defined by the application built on Cougaar and not by Cougaar itself [11, 12]. It is also general purpose giving us flexibility in how to use it in Gatos. The range of communication protocols supported by Cougaar made integration with the driving simulator easy.

2.3 Properties of Gatos

Gatos is an agent based prototype application; it serves as an architecture that integrates sensors and learning subsystem which makes a final decision about driver status based on presentation of complex information to the driver.

Gatos is designed to be a distributed system providing:

- Fault tolerance
- Dynamic discovery of new devices, applications and resources
- Reliability
- Graceful degradation
- Redundancy

Gatos is built on top of cougaar which forms the backbone of the system.

2.4 Inner Working of Gatos

All components within Gatos are Cougaar agents that can be removed at runtime without adversely affecting the execution of the overall system. The most interesting and crucial agents within Gatos are the decision maker and the Gatos monitor

2.4.1 Gatos Decision Maker

The decision maker is the intelligence of the system. This subsystem receives inputs from all other information gathering agents. This information is gathered, logged and passed to the decision maker. At regular intervals the decision maker component tries to ascertain the level of urgency or otherwise of the state of system. At the end of each decision interval a decision is made. All decisions, along with reasons for the decision are sent to the Gatos output agent and Log agent where they are filtered and logged before being finally output to the appropriate device.

Gatos decision maker makes inferences on several streams of data and based on pre-defined heuristics decisions are made as to the standard of driving at regular intervals.

Inside the decision maker we have experimented with different learning approaches to improve the decision making process. Using reinforcement learning algorithms has the added advantage that bad driving patterns can be detected without the need to explicitly define rules beforehand.

The decision maker relies on pre-defined rules using physiological data [8] to determine the emotional state of the driver. The corresponding corrective spoken/audio output [2-4] is then selected for the driver personality in question. This spoken output has a different pitch and different choice of phrasing for different personality types to perform the same corrective action.

2.4.2 Gatos Monitor

The Gatos monitor agent is the hub of Gatos system; it receives information from CanBus/Driving simulator and outputs to the central decision maker and log agent.

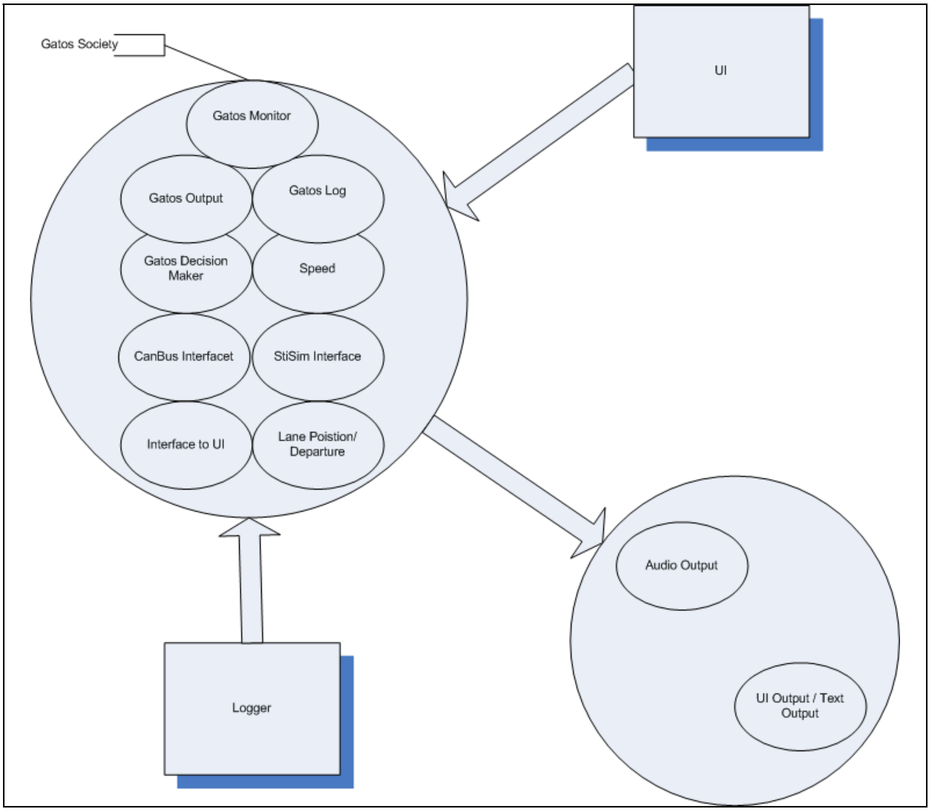

Fig. 4. Inner workings of Gatos

3 Gatos and the Driving Simulator

Gatos was interfaced with a driving simulator. Information from the simulator and a set of physiological sensors fed data to the Gatos monitor. A simulator was chosen so that the Gatos system could be prototyped quickly before interfacing into real car. In this way, ideas could be tested and prototyped before being implemented in the 'real world' scenario.

4 Conclusion and Discussion

The Gatos prototype worked well in simulation. However, there was a steep learning curve in working with Cougaar. Further refinements to the system need to be made before interfacing with a real car; in particular stress testing the parallel capability of Gatos, so that monitoring of the driver could be improved.

With regard to driver safety Gatos allows for an interdisciplinary approach to the study of driver monitoring. The system gives experimenters an approach to monitor driver behavior using multiple sensors to monitor driver status, driving performance, and the driving environment to address bad and dangerous driving behavior.

The other key aspect of Gatos is intervention on part of the decision making agent. This further opens up the field of study of driver reaction to instruction. The automotive industry has long been interested in driver workload and how to best measure and calculate driver workload [13]. Looking at drivers' reaction to interactions (different voices and different ways of presenting the same content) is a relatively new field [1, 4, 5]. There are still many aspects of how linguistic and paralinguistic properties of speech based systems in cars affect drivers.

For the other two domains of information, driver behavior and driving environment, there are both commercial and research approaches that use sensors to convey information to the shop, the driver or other drivers. Information about driving behavior is currently logged in "black boxes", and there is an ongoing debate on who owns the data and for what it should be used. Most automobile makers are investigating the area of communicating cars, where cars communicates with both instrumented infrastructure such as street signs, road markings and road signs, and with other vehicles, such as BMW's initiative of having cars convey information of road hazards to cars close by [14].

The prototype being based on data derived from a simulator means that assumptions have been made. It is at best an approximation of how a car and driver might function in the real world. However, it does allow for experimentation of scenarios that are difficult or dangerous to do in the real world. With this prototype we now have an experimental setup that allows us to continue to investigate how driver status, driving behavior and driving environment interacts to influence driver performance.

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