Sharing Driving between a Vehicle Driver and a Sensor System using Trust-Factors to Set Control Gains

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Abstract—A system is presented that shares control between a driver and sensors to maneuver a vehicle. The vehicle can be driven by a driver, or by the sensors, or they can share control between them. In some circumstances, sharing control can allow a human driver to drive more efficiently and safely. The gains in the controller are automatically set for the human driver and sensors by calculating a trust-factor for the vehicle driver. The sensors can assist a human driver in driving the vehicle to offset for any detected shortcomings; for example, the driver may not be able to see a vehicle ahead or the human driver may be tired. In emergencies, efficient interaction between the vehicle and a human driver can make all the differences. This research explores that collaboration and interfacing. The proposed methods are validated with initial testing.

Keywords—Vehicle; driver; trust-factor; shared-control

I. INTRODUCTION

Advanced driver-assistance systems automate, adapt and enhance vehicle systems to improve driving and safety. Safety features can avoid collision or accidents. Technology can be used to avoid collisions and / or alert drivers about difficulties and can take over all or some control of a vehicle. Features can include adaptive cruise control and automatic braking or can alert a driver about other cars on the road or about potential danger. They can keep a vehicle in the correct lane or consider and / or reveal objects in a blind spot. In emergencies, efficient interaction between the vehicle and a human driver can make all the difference. This research explores that collaboration and interfacing [1]-[8].

Some driver-assistance systems features are being built in to some modern cars and others can be available as optional add-on packages or as after-market solutions [9]. Driver-assistance systems rely on inputs from sensors such as radar, imaging and vision, in-car networking and Light Detection and Ranging (LiDAR).

Driver-assistance is fast growing [10], [11] with increasing adoption rates and specific standards being developed. For example, IEEE 2020 image quality and communications protocols such as Vehicle Information Application Programming Interface (API) [12].

In addition, vehicle-to-infrastructure and vehicle-to-vehicle systems can be added; for example, Wi-Fi, mobile telephony or data networks [13].

Many systems have been described in the literature for helping human drivers to work in hazardous or remote environments [14]-[22]. Research has explored the way that drivers can cooperate with vehicles [23]-[25]. Controllers have tended to trade stability margin for clarity [26]-[28].

Unstructured environments can make operation more difficult for vehicles [29]-[35]. A wheeled vehicle has been studied in this paper because that remains the most common type [36]-[42].

A simple control input device for testing vehicle control has been a low current joystick. A vehicle then draws a higher current to drive motors. A human driver is usually better at driving than a computer so the systems described here attempt to assist a human driver.

Driving tends to be open-loop. A human driver indicates a desired speed and direction and their vehicle attempts to travel at that speed and on that bearing. Differences between the wheels on the vehicle or different responses to a variety of gradients and surfaces can disturb the path. Drivers need to react to the disturbances and correct the vehicle path.

Unpredictable situations can happen [43] that might affect a vehicle driver and vehicle operation [44]. Collaboration between the sensor systems on board the vehicle and a human driver [45] can help the driver [46].

Kuniaki [47] presented a collaborative system and Macharet [48] presented a sensor system using ultrasonics to show the bearings to targets using triangulation and those ideas were extended in [49], [50].

Methods described here allow intimate collaboration between sensors and a vehicle driver because of merging human driver commands with data from the vehicle sensors. A combined control architecture is explained in [51] and IntelliSys paper and IEEE journal that promotes cooperation between a vehicle and driver. In [52], combined control is described that improves performance and reduces workload by providing feedback from an automated process. Autonomous systems can assist a driver to improve reduce workload and improve safety for vehicles [53], [54]. Satti [55] described combined control employing computer-brain interfaces. A controller is presented in [56] that controls quadcopters and that can avoid collisions and fly the copters in formation.

A human driver and the sensors can provide commands simultaneously and in that case they can be fused using specified ratios [57]. How authority is distributed is significant for efficient co-operation. Numerous interfaces might be employed [58]-[64]

In [65], Carlson *et al* described methods to predict a direction of travel and change the control signals to make a vehicle move in that direction. Experimentation provided the parameters and dynamic-distribution adjusted the distribution of control in real-time. In later work the weights were changed after evaluating the commands from a human operator.

Methods to assist a vehicle driver in complex and changing environments are introduced in this paper. By combining suggestions from sensors and commands from a human driver, both the driver and the sensors cooperate to produce safe movements. The sensor system knows the vehicle status and then directs the vehicle to turn. The vehicle moves in that direction but avoids obstructions along the way.

Section II is a description of the vehicle and sensors used to test the ideas. The new controller is described in Section III and shared control in Section IV. Section V discusses the results and Section VI summarises work. Finally, some future work is suggested in Section VII.

II. VEHICLE AND SENSORS

This research used a Bobcat II Vehicle [22], [26] consisting of: inputs from a driver and sensors, the vehicle base, ultrasonic sensors used to avoid obstacles, and the shared controller. Ultrasonic sensors provided ranges to obstacles ahead of the vehicle. Data from the sensors were processed by a computer that adjusted the speed and direction of the vehicle base.

A. Vehicle

The vehicle base had four wheels; two large driving wheels at the front and two casters at the back. Each driving wheel was attached to a motor and could be driven independently.

The vehicle was steered by changing the current sent to each wheel motor. The vehicle could turn on its center-of-

rotation. If V is vehicle linear velocity, ω is angular velocity and ϕ is direction, then velocity at the center of mass of the vehicle base is

$$V_c = (V, \phi, \omega) \quad (1)$$

The kinematic model is explained in [3].

Independently driving the wheels produce orientation and movement because the driving-wheels of the vehicle were on the same axis.

B. Sensor System

Ultrasonic sensors detected obstacles ahead of the vehicle. The transmitters needed a 3 ms pulse to achieve the highest output. Long pulses held more energy and could detect obstacles at longer ranges. If the speed of sound is assumed to be 330 m/s... then a 3 ms sound pulse is 0.99 m long. Permitting a pulse to exit from its transmitter, rebound back from an obstacle and reappear back at a receiver, suggests 0.5 m is a minimum range for a 3 ms pulse. The work needed ranges that were closer and so various shorter pulse lengths were used.

Obstacles appeared and disappeared when the vehicle travelled about and it was sometimes challenging to lock on to a target. Ultrasonics were noisy and returned some misreads. Misreads were filtered out to improve reliability. Histogrammic In-Motion Mapping was used. Volumes ahead of the vehicle were separated in to a 3 sector grid and stored in an array: far, middle and near. Ultrasonic transducers were fixed so that they overlapped and covered the area ahead. Array elements were incremented by five if they contained an obstacle. Array elements that did not contain an obstacle were decremented by 1. Fig. 1 illustrates beam patterns for two ultrasonic sensors.

Fig. 1. Overlapping beams from two ultrasonic sensors to create an array.

Arrays had a minimum quantity of 0 and maximum of 15. Fig. 2 symbolizes a 3-element histogrammic depiction of a local environment. An obstacle in the 3rd element is making it increase.

Fig. 2. 3-element histogrammic depiction of a local environment. An obstacle in the 3rd element is making it increase.

An obstacle within a grid element caused the element to rapidly increase in value to the highest value. Arbitrary misreads within the other elements increased values briefly, but they were decremented during every system update period. If the obstacle relocated to another element, then that element rapidly increased in value and the previous one reduced in value. Reliable ranges were acquired within 0.5 s.

III. CONTROL

A controller drove the vehicle following commands from a driver and the sensor system automatically avoided obstacles in the vehicle path.

A. Controller

Angular velocity and linear velocity of the vehicle were considered. The vehicle followed a desired direction and linear velocity when the vehicle was at an arbitrary heading angle, as shown in Fig. 3.

The control law to track the target position for the vehicle's linear velocity, V_r was:

$$V_r = V_M \times D / D_{Des} \quad \text{when } |D| < D_{Des} \quad (7)$$

and

$$V_r = V_M \times D / D_{DesSp} \quad \text{when } |D| > D_{DesSp} \quad (8)$$

Where, V_M is the maximum speed of the vehicle, D is a vector from the vehicle joystick, and D_{Des} is the demanded speed. If the vector from the vehicle joystick is greater than the sensor range, the vehicle moves at the desired speed.

Fig. 3. Controller design.

The vehicle's heading changes during traveling. To track the vehicle's heading, the control law for the vehicle's angular velocity, ω_r , is defined as:

$$\omega_r = \omega_M \times \Delta\theta / \theta_D, \quad \text{when } |\Delta\theta| < \theta_D \quad (9)$$

and

$$\omega_r = \omega_M \times \Delta\theta / |\Delta\theta|, \quad \text{when } |\Delta\theta| > \theta_D \quad (10)$$

Where, θ_D is the desired heading, ω_M is the maximum value of the vehicle's angular velocity and the direction of the vehicle is expressed as a vehicle heading error, $\Delta\theta$.

If the vehicle's heading error is greater than a buffer angle, the vehicle turns. If the vehicle's heading error is less than a buffer angle, the control law adjusts angular velocity to track the desired heading.

B. Avoiding Obstacles

The omnidirectional mobility of the vehicle made obstacle avoidance easier. A vector represented speed and direction. A repulsive force was generated if the vehicle drove near to an obstacle and the vehicle steered away from the object (Fig. 4).

The avoidance velocity, V_o was:

$$V_o = a \sum_i [(D_{Ms} - |x_i|) / D_s] (-x_i / |x_i|) \quad (11)$$

Where, D_s was a safe distance, x_i were vectors to represent objects ahead of the vehicle, and a was a constant. Ultrasonic sensors detected the positions of obstacles, x_i .

Fig. 4. A repulsive force was generated if the vehicle drove near to an obstacle and the vehicle steered away from the object.

When both safety and avoidance trust-factors were high, a driver would drive their vehicle smoothly. When avoidance was high, the vehicle was far away from objects in its path and

the driver had complete control of their vehicle. When safety estimates were higher, the speed of the vehicle was limited.

V. RESULTS

Experiments were undertaken to validate the methods.

A. Simulation

Simulation validated the vehicle shared-control. The input from the joystick was fixed to steer to a target destination. Speed was set to 1/2 speed.

An example of a trajectory is represented in Fig. 6. Fig. 6 shows the vehicle's heading and position at numerous instants in time. At the start position, the simulated vehicle was facing right. The direction to a target destination is represented by a dotted line that is the input from the joystick. A sensor on the left of the vehicle detected a wall and guides the vehicle away. The additional solid line indicates the direction of motion; towards Point A from the Start. As the vehicle moves towards Point A, the ultrasonic sensor on the right of the vehicle detects a wall below the vehicle and turns the vehicle left to avoid it. Once in free space V_o , reduces to zero and the vehicle turns and moves towards the target destination, guided by the joystick. At Point C the sensor on the left of the vehicle detects a gap and V_oC grows so that the vehicle steers right to avoid the gap edge.

At Point D and through the gap, the vehicle is safe. No obstacles are detected ahead of the vehicle. The vehicle can turn and move towards the target.

The simulated vehicle did not collide with any obstacles and safely approached the target destination.

Values for the Trust-factors were:

Start	0.4
A	0.6
B	1.0
C	0.7
D	1.0

Fig. 6. Simulation experimentation and testing.

The Confidence value for avoiding obstacles was significant when objects were detected, so driver confidence was decreased when objects were detected. The vehicle reduced speed. The sensors partially controlled the vehicle until it was in open space and safe. The shared and combined control meant that the vehicle obeyed joystick commands to move towards a destination while avoiding obstacles.

The commands to the vehicle motors were an amalgamation of a simulated input from a sensor system and simulated joystick input (13). Controller gains for the sensor system and driver produced speed and steering commands for the simulated vehicle. The simulated vehicle did not crash.

B. Experimenting with a Vehicle

Volunteer drivers at Portsmouth maneuvered the vehicle past obstacles to drive to a target destination. Drivers controlled the vehicles using joysticks.

Trajectories were recorded using a camera and a typical vehicle and Fig. 7 shows a typical path. The vehicle could easily turn and was able to spin on its axis if required, before driving in a selected direction to maintain a desired heading. That allowed drivers to concentrate on steering. They did not have to concentrate on avoiding obstacles.

The ultrasonic sensors helped drivers to control their vehicles using shared and combined control. The vehicle did not collide and safely reached the target destination.

Recorded values of Trust-factor for the experiment were:

Start	0.0
A	0.07
B	0.69
C	0.69
D	0.71

Fig. 7. Recorded trajectory of vehicle experiment.

Control of the vehicle was a combination of inputs from the driver's joystick and from the sensors (13). Control gains for both the driver and the sensors dictated the speed of the two motors and therefore the direction that the vehicle moved in.

Driver Confidence reduced when obstacles needed to be avoided and the vehicle did not collide with anything.

If a driver slowed the vehicle then it became safer and so that driver had a higher authority. Shared-control allowed the vehicle to move away from objects while following instructions from a driver's joystick.

VI. DISCUSSION AND CONCLUSIONS

Shared-control was implemented on a vehicle. A driver was in control of the vehicle unless sensors needed to assist, for example, to avoid an object.

The work did not deal with objects above or below the volume that could be detected by the ultrasonics in the way that they were set up on the vehicle.

The mix of the input from sensors and driver were calculated using Trust-factors. They were established using evidence from the sensors such as: range from the vehicle to an object; how long the vehicle operator has been driving, etc.

Human drivers controlled the vehicle more safely when assisted by the sensors. Experimental results showed that the shared-control method was safe.

An optimal mix of human versus autonomous control exists for different vehicle drivers in various conditions, for example, whether a driver is tired. The most favorable mix changed with human experience and skill.

VII. FUTURE WORK

The static ultrasonic sensor array is limiting ongoing work and a scanning device has been created at Chailey Heritage (by Martin Langner). Future research will use that device as it is smaller, covers a bigger volume and range and position can be detected more accurately. Different AI methods are being investigated but they are tending to be more complicated.

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