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Mathematical Model for UGV TransparencyUsing Laser Range Finder

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ABSTRACT

For extending human capabilities to perform tasks remotely, unmanned vehicles and robots are used,this scenario is called Teleoperation. In teleoperation, human executes tasks in a remote environment. There are many applications of vehicle teleoperation in hazardous environment, military, underwater, and space exploration. Operating a vehicle or a system remotely requires supplyingthe operator in real-time with an accurate data about the operation environment. This operation is subjected to data transmission time-delay, sensors fusion and stability problems.This paper proposes a mathematical model for the time-delay compensation algorithm to achieve transparency in teleoperation using Laser scanner data. The proposed model for compensation depends on predicting the vehicle position in the future time and the environment of operation is available for the operator with respect to this predicted position. Using this algorithm in compensating time-delay in data transmission achieving transparency. Simulation and real experiments are shown to validate the proposed model.

Key Words: Teleoperation, environment construction, time-delay.

1. INTRODUCTION

In the early researches several experiments are interested to overcome the effects of time-delay in teleoperation (Sheridan and Ferrell, 1963; Ferrell, 1965). In teleoperation systems, several complications appears since the communication medium introduces distortion, losses and delays that hinder the performance and stability of the system particularly in the high-delay and low-bandwidth systems. And as a result of these past researches, the main goals of teleoperation are to achieve Stability and Telepresence.

Autonomy are classified into 3 levels which are: ***Teleoperation*** level, ***Semi-autonomous*** level (Supervisory), and ***Autonomous*** level. Teleoperation is considered a low level control and it is considered as the hardest level for the operator as he/she directly controls and drives the vehicle from the control station. The first type of teleoperation is the direct remote control; whereno sensor feedback is needed as there is a direct visual contact with the vehicle. Indirect visual feedback teleoperation; where the operator controls (drives) the vehicle or the robot from a control station depending on the sensor data mounted on the robot. Supervisory control, in this level there is a shared control between the operator and the vehicle as the operator sends key way-points along which the vehicle moves independently. Autonomous level is a high level teleoperation with no operator interference, the operator only determines a goal points and the vehicle autonomously moves to this goal.

In the case of Autonomous vehicle, the vehicle collects the sensor data and executes the orders according to the assigned task and operation. On the other hand, in lower level teleoperation, indirect visual feedback, the sensors data is firstly sent to the Ground Control Station (GCS) and then fused together to a usable form. Since the GCS and the vehicle are located at different locations, and due to slow communication channel, there are non-neglected time-delay and consequently the data arrives to the GCS is out-of-date and not accurate which affects the efficiency of the teleoperation process. So, the operator should wait to get the actual results in the remote environment before making new action.

2. TELEOPOERATION PROBLEMS

Any real wireless communications system introduces bidirectional latency between the vehicle and the control unit. From past researches, it is known that time-delay is one of the main factors that makes teleoperation difficult.Time-delay is ranging from milliseconds to several minutes, depending on the distance, medium and the communication channel used. This latency imposes a tradeoff between system stability and performance due to sensors problems, such as:

(a) Time lag, in video transfer and control commands.
(b) Loss of situational awareness, as control inputs and vehicle reaction are not synchronized.
(c) Limited field of view of many sensors such as cameras.

To solve this problem, this time-delay should be compensated and its effect is eliminated. Also, Sensor fusion and synchronization is a challenge.

This paper proposes a mathematical model for time-delay compensation in the teleoperation system for Unmanned Ground Vehicle (UGV) to achieve transparency.

3. ENVIRONMENT CONSTRUCTION EXPERIMENT

In this experiment, Laser Range finder is mounted on the vehicle at height $\mathrm{H} = 200\ \mathrm{mm}$as it provides a 270^{o}horizontal field of view with distance up to$70\ \mathrm{m}$ for determining the environment, roads, and obstacles around the vehicle and also the vehiclerelative position estimation. Moreover, GPS/ INS is used to provide an accurate positioning for the vehicle location and orientation. Laser Range finder data are accurate, small size and gives cloud of data points.

These laser points are plotted using Mat-Lab code, about 1100 laser point from the Lidar, with angle range $[-45^{\mathrm{o}}, 225^{\mathrm{o}}]$ and angular resolution 0.25^{o}. Also, vehicle control ECUs are connected via CAN bus. RS-422 and RS-232 protocols are used for sharing information between different sensors and computers.

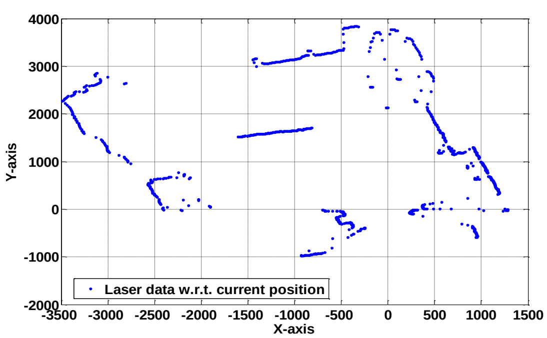


Fig. (1) Laser range finder data points

Fig. (2) Sensors mounted on the vehicle

4. VEHICLE FUTURE POSITION PREDICTION

In this work, it is necessary to determine the vehicle position in the future time to compensate latency in teleoperation process. Many methods are used for determining the vehicle position in future time (after time Δt). The time-delay Δt is calculated in a previous experiments and it was found about

$50\ msec$ [1]. One of the methods, for predicting the vehicle position in the future time, is the model predictive control (MPC)[1], [2].

In this work we are going to use another method for predicting the vehicle position in the future. The predicted vehicle in the future will appear to the operator monitors in the control unit after timeslightly more than $\Delta t = 50\ msec$after the following actions has taken place:

i. Thedata from the sensors about the teleoperation environment around the vehicle is sent to the control station.
ii. Theoperator sends the control commandsand is acted upon by the vehicle.

The teleoperated vehicle appears in the control unit is a virtual vehicleand so it won't make any system distortion to appear to operator monitors in any position. We render the vehicle at its predicted position at the time in the future when the operator sends commands to the vehicle, and the time acted upon by the vehicle. In this technique, it is more useful to predict the vehicle slightly beyond the command arrival time (more than Δt) to produce a display of a vehicle slightly more into the future and so some of the prediction error has not happened yet at this time and real vehicle can correct these prediction errors before it occurs. In the simulation display the virtual vehicle is considered as the leading one and the real vehicle is obliged to follow.And, in this case the path followed by the leader is transferred to the real vehicle as command input [3]. The following figure explains the prediction point of view.

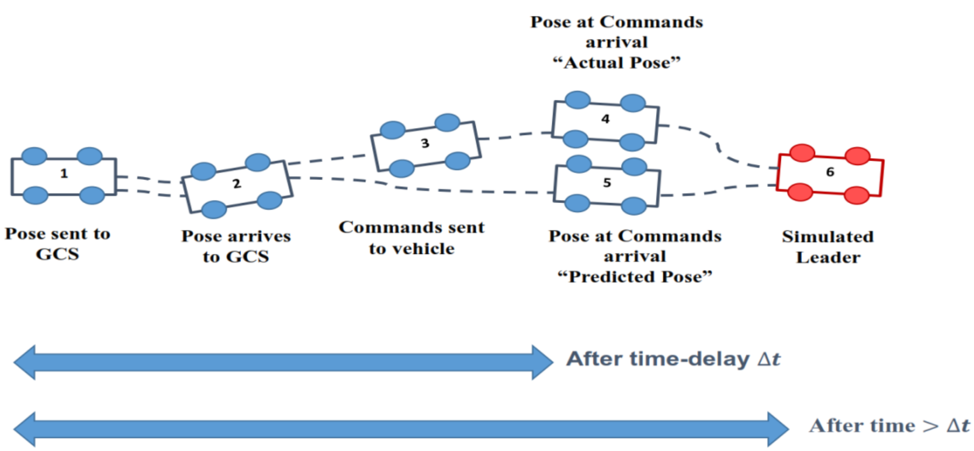


Fig. (3) The predicted vehicle appears in the future after time slightly more than Δt.

5. MATHEMATICAL MODEL FOR TELEOPERATION ENVIRONMENT CONSTRUCTION WITH RESPECT TO PREDICTED POSITION:

As mentioned in section 3, we construct the environment around the vehicle using laser scanner data (range and angle). For compensating time-delay we have to find the laser data of the environment around the vehicle relative the future position (predicted position) at time $(t + \Delta t)$ and these data should be available in the currenttime (t)so as the operator makes the teleoperation orders with respect to the future position as it will be executed when the vehicle will be in this position (predicted position).

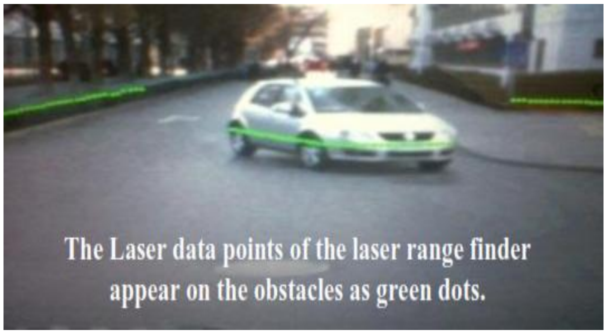


Fig. (4)

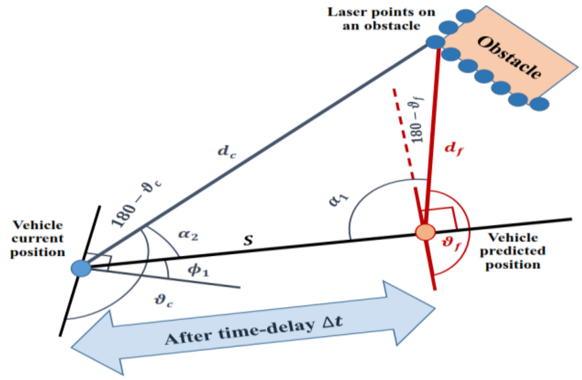


Fig. (5)

The laser range finder data are the range distance d and the angle ϑ for each laser point on the obstacles. As shown in figure (5), the vehicle current position, the vehicle predicted position, the laser points on the obstacles and the angles and the range distances of thelaser data. The angle and range distanceof the laser point with respect to the current position areϑ_c andd_c respectively.And,the angle and range distance of the laser point with respect to the future (predicted) position are ϑ_f andd_f respectively. Also, α_1 and α_2 are the angles opposite to d_c andd_f respectively.

To calculate the laser data for the environment around the vehicle relative the future position which are the angle $\vartheta_f$and range distance $d_f$foreach laser point.From figure(5) there is a virtual triangle between the obstacles, the vehicle in the current position and the vehicle in the future position. The angle and range distance of the laser point with respect to the current position are ϑ_c andd_c respectively are available in the current time. Then,we get the following relations;

$$\alpha_2 + (180 - \vartheta_c) + \phi_1 = 90,$$
$$\alpha_2 = \vartheta_c - \phi_1 - 90$$

$d_f$the range distance of laser point with respect to the predictedposition

$$\left\{ \quad d_f = \sqrt{d_c^2 + S^2 - 2d_c S \cos(\alpha_2)} \right.$$

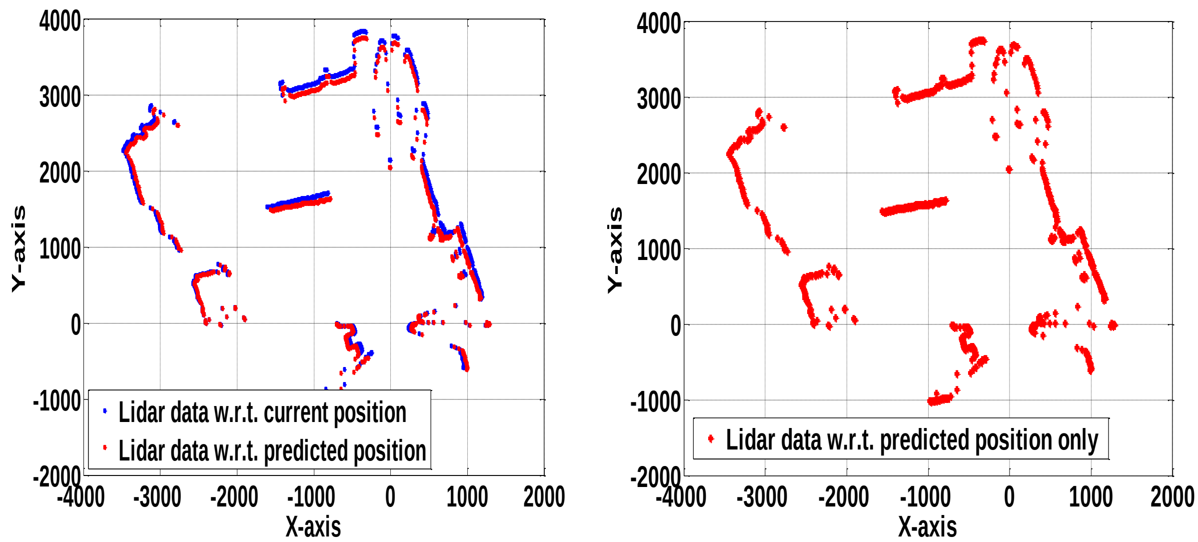
$$\sin(\alpha_1) = \frac{1}{d_f}\,[d_c.\ \sin(\alpha_2)]$$
$$\alpha_1 - \left(180 - \vartheta_f\right) = 90,$$

$\vartheta_f$the angle of laser point with respect to the predicted position

$$\left\{ \quad \vartheta_f = 270 - \alpha_1 \right.$$

6. EXPERIMENTAL RESULTS

The mathematical model shows that the environment is continuously available in real time with no latency achieving Telepresence [5], [6].Moreover, figure (6) shows the experiments results of the environment construction compensating time-delay; the blue and red points are the environment constructed using the laser data w.r.t. the vehicle current and predicted positions respectively which are available in the current time [7].



(a) Both data are available in the same time.

(b) Laser data w.r.t. predicted positions only.

Fig. (6) the environment construction using laser range finder data in the current time.

This model is based on that the vehicle path is planned autonomously and the laser range finder constructs the environment continuously with respect to the current position [7], [8]. Firstly, the path planned and the laser data is sent to the operator in the ground control station. Then, in the control station the predicted vehicle position in the future is available and the laser data is computed with respect to this predicted position and the environment around the vehicle is constructed according to the future position in the current time using the mathematical model. Thirdly, the operator generates the control signal for the predicted vehicle with the environment constructed in the monitor of the control station, these signal is sent to the real vehicle in the proper time to be executed and so the vehicle follows the predicted vehicle and so on[9], [10]. These procedures are repeated continuously and the operator feels like he/she drives the vehicle directly with no latency.

7. CONCLUSION AND FUTURE WORK

This paper has proposed a solution to the latency in environment construction using Laser range finder which is considered as a part of the work done in modifying the BIT AGV in order to be remotely controlledfor the teleoperation purpose.In this approach, we construct the environment using the laser scanner with a predefined time offsetΔt. This offset causes the laser scanner to construct the environment ahead of the current time, such that this constructed environment is always and readily available at the time it is supposed that the vehicle is driven in.This offset time is calculated such that it is the time required for transmitting sensor data to the GCS and transmitting the control signals from the GCS to the vehicle[15, 16]. The experiments show very good results in performance and transparency since the Teleoperation environment w.r.t. to the predicted position is available for the operator in the current time compensating latency. And also, the simulation results ofthe algorithm show that it is applicable for short and long time-delays.

The future work, we will be incorporating on the dynamic environment and integrating the algorithm in the BIT AGV control systemto validate its efficiency. Also, we examine the algorithm using theVelodyne data for 3D environment construction.

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