

Torque Control of a Robotic Vehicle Based on Predicted Road Profile ¹

Majura F. Selekwa, Patrick J. Hollis, Srinivas Palanki and Emmanuel G. Collins, Jr.
Center for Intelligent Systems, Control and Robotics (CISCOR)
Florida A& M University - Florida State University College of Engineering
Tallahasee, Florida

Email: majura@eng.fsu.edu;hollis@eng.fsu.edu;palanki@eng.fsu.edu;ecollins@eng.fsu.edu

Abstract

Vehicular speed control using standard cruise control is good only when the road profile is uniformly smooth throughout; such a controller is essentially reactive in the sense that it responds after the speed has changed primarily because of the changing road profile. When the road profile is corrugated and has bumps, it is necessary to predict this profile well in advance and determine appropriate control actions that enable the vehicle to run smoothly without experiencing excessive vibrations. Prediction of the road profile for manned vehicles is natural; however, unmanned robotic vehicles do not have this capability. This paper presents preliminary results in the development of a torque control system for a robotic vehicle based on a predicted road profile. The study vehicle is the Army Research Laboratory's Experimental Unmanned Vehicle (XUV), which was modeled using MSC ADAMS software, and the control system is a simple fuzzy logic controller that has prediction capabilities in the same way that human operators do. The results show that with the proper fuzzy model for predicting the road profile, it is possible to control the drive torque such that the vehicle runs smoothly.

1 Introduction

Motion smoothness and safety of any ground vehicle depends on the nature of the road and the speed of the vehicle itself. Structural considerations for ground vehicles make it necessary to control smoothness of the ride even when no human life involved. Speed plays a major role in determining the smoothness of the ride irrespective of the road profile; excessive speed is always associated with undesirable structural effects, which manifest as roughness in the motion of the vehicle. Because of these structural consid-

¹Prepared through collaborative participation in the Robotics Consortium sponsored by the U. S. Army Research Laboratory under the Collaborative Technology Alliance Program, Cooperative Agreement DAAD 19-01-2-0012. The U. S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation thereon.

erations, the speed of unmanned ground vehicles must be properly controlled. There is a substantial amount of literature that discusses automatic cruise control (ACC) systems [1, 4] and their counterpart automatic braking systems [2, 3]. These are advanced forms of the standard cruise control, which is good only when the road profile is uniformly smooth throughout. The standard cruise controller is essentially reactive in the sense that it responds after the speed has changed primarily because of the changing road profile. When the road profile is corrugated or has bumps, it is necessary to predict this profile well in advance and take appropriate control actions that reduce speed and enable the vehicle to run over the bumps smoothly without experiencing excessive vibrations. Prediction of the road profile for manned vehicles is natural; however, unmanned robotic vehicles do not have this capability.

This paper presents preliminary results in the development of an intelligent torque controller that predicts the road profile based on any previously known information along with sensor measurements. More emphasis is put on the methodology for developing such a controller.

2 Bumping Vehicle Dynamics

In order to develop a sound control system for an autonomous vehicle, it is necessary that the vehicle dynamics be well established. This research studied the dynamics of the Experimental Unmanned Vehicle (XUV) developed by Army Research Laboratory's; a picture of this vehicle is shown Figure 1. The bumping vehicle dynamics for the XUV were established computationally. The XUV model was developed in MSC ADAMS/car using a CAD model of the vehicle shell. Mass and inertia properties were estimated from similarly sized vehicles. The suspension was developed from the given wheel locations and chassis locating holes. We were not provided any details of the suspension on the vehicle, so estimates of spring and damper properties, etc., were made from similarly sized small car



Figure 1. The Army Research Laboratory's XUV



Figure 2. The Developed ADAMS/Car Model of the XUV

properties. Figure 2 shows the appearance of the developed ADAMS/Car model of the XUV. It has 4 wheel steering with an adjustable rear steering rate. The tire model selected is the ftire model. This tire model can capture the behavior of impacts with solid objects such as curbs, etc. Road surface models are simple triangulated surface representations of the road and bump profiles.

The developed ADAMS/Car model of the XUV was simulated to run at different speeds across trapezoidal bumps of different sizes h_B as illustrated in Figure 3. Several pa-

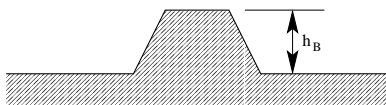


Figure 3. The Shape of Trapezoidal Bumps Studied for the Bumping Dynamics

rameters of the body properties such as vertical displacement, vertical velocity, pitch rate, pitch angle, etc., were recorded. Figures 4 and 5 show the vertical displacement of the vehicle at different vehicle speeds; Figure 4 show the

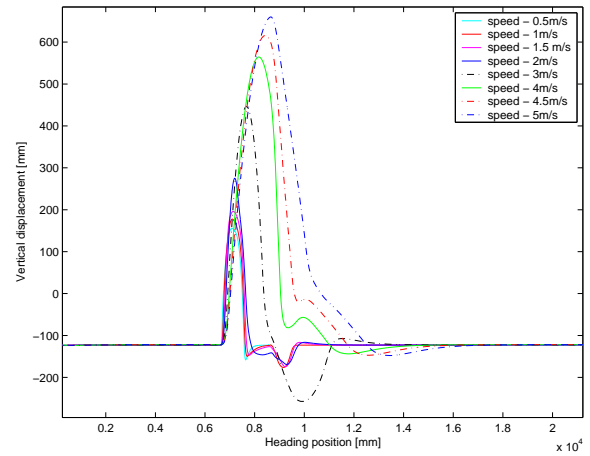


Figure 4. The Vertical Displacement Response of the Vehicle at Different Speeds for a Bump Size of 0.2m

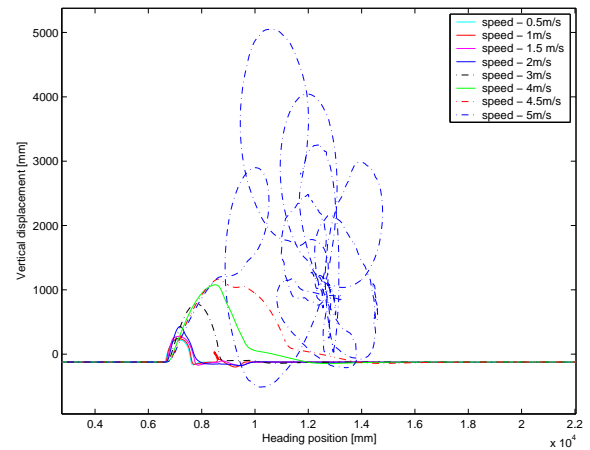


Figure 5. The Vertical Displacement Response of the Vehicle at Different Speeds for a Bump Size of 0.25m

vertical displacement for the bump size of 0.2m and Figure 5 show the vertical displacement for the bump size of 0.25m. It is seen that for a given bump size, the vertical displacement increases as the speed increases. As would be expected, dangerous vertical displacements are reached when speeds exceed certain values as illustrated in Figure 5 for the speed of 5m/s. In that case, the vehicle displays erratic dynamics, which may be an indication of structural failure or vehicle overturn. The values of the maximum vertical displacements that the vehicle experiences at different speeds for different bump sizes were collected. Figure 6 shows the variation of these displacements with speed for three bump sizes as indicated in the figure. It is seen that small bump sizes have less significant effects to the vertical displacements of the vehicle; however, as the bump size increases, the vertical displacement increases rapidly with the speed of the vehicle.

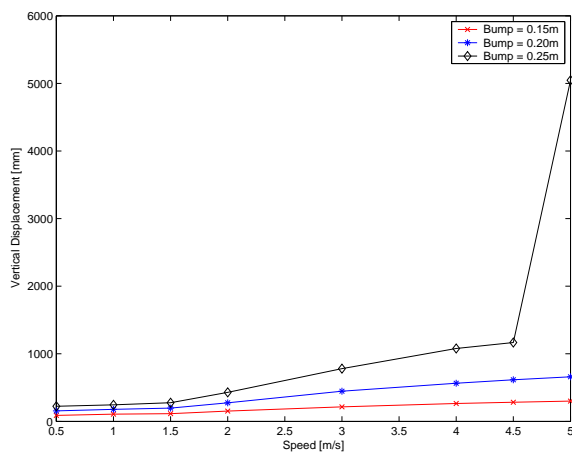


Figure 6. The Maximum Vertical Displacement at Different Speeds and Bump Sizes

3 Torque Control Against Bumping Effects

This section discusses an approach followed in controlling a robotic vehicle against bumping effects. It is divided in two subsections; the first subsection gives a generic overview of the torque control solution, the second subsection presents the structure of the fuzzy controller that was developed to implement this control solution.

3.1 The torque control solution

To control bumping effects, the controller needs information about the current speed v_R of the vehicle, the position $x_{B|R}$ of the bump relative to the vehicle, and the size h_B of the bump. It is assumed that in addition to an onboard computer with sufficient memory to store predetermined road information, the vehicle is also equipped with proper sensors that enable it to determine the location and size of the bump along the road and a speedometer. The control command is the control torque τ_B which is directly related to the acceleration and hence the speed v of the vehicle at the bump. From basic vehicle dynamics it is known that the speed the vehicle v at the time it crosses the bump depends on the current speed v_R , the applied torque τ_B , and the distance $x_{B|R}$ from the current position to the bump, i.e.,

$$v = f(v_R, \tau_B, x_{B|R}). \quad (1)$$

On the other hand, the vehicle speed v at the bump depends on the size h_B of the bump itself. Currently, three types of bumps have been identified. The first type includes large bumps that require the speed to be decreased to the lowest near-stop level after which and the torque has to be applied when the bump is being crossed; the second type includes bumps that require the vehicle speed to be below certain amount and the bump can be crossed without ap-

plying torque, as in coasting. Third and the least significant type includes small bumps that can be withstood by the vehicle, however the vehicle motion across the bump need to be controlled especially when the bump is crossed; typically the torque has to be such that vehicle coasts across the bump. Since the torque control command τ_B depends on the required change in speed Δv and the distance $x_{B|R}$ over which this speed change has to happen, then it can be expressed as

$$\tau_B = g(\Delta v, x_{B|R}), \quad (2)$$

where $\Delta v = v_R - v$. This is explicitly dependent on the current speed v_R of the vehicle, the position $x_{B|R}$ of the bump relative to the vehicle, and the size h_B of the bump; hence, it can be expressed as

$$\tau_B = F(v_R, x_{B|R}, h_B). \quad (3)$$

Note that the torque can be positive, causing the vehicle to accelerate, or negative for decelerating the vehicle. Although advanced formulas for computing the braking torque are available [3], this paper took a simpler approach. The simplest way of computing the control torque is by assuming that it is applied constantly throughout the distance over which the speed change is desired; this assumption leads to

$$\tau_B = \kappa(v_R) \left[\frac{v(h_B)^2 - v_R^2}{x_{B|R}} \right], \quad (4)$$

where $\kappa(v_R)$ is a positive factor that combines the effects of friction and inertial resistance at the current speed v_R , and $v(h_B)$ is the speed that the vehicle must have in order to safely cross the bump of size h_B . In that case it may seem that the control task is that of the bumping speed $v(h_B)$ and the factor $\kappa(v_R)$ provided all other parameters in equation (4). In practice $x_{B|R}$, h_B , and $\kappa(v_R)$ are not precisely known, hence equation (4) cannot be directly used to determine the control torque τ_B .

This paper implements this control solution by using fuzzy logic. The unknown values of $x_{B|R}$, h_B , and $v(h_B)$ are predictively estimated using map and sensor data. The control torque τ_B is determined using fuzzy rules of the form

$$\mathbf{IF} (v_R \text{ and } x_{B|R} \text{ and } h_B) \text{ THEN } \tau_B. \quad (5)$$

The next subsection gives a brief description of the fuzzy control system that was developed for this purpose.

3.2 The fuzzy logic controller

As shown in equation (5), the inputs to the fuzzy logic controller were the current speed of the vehicle v_R , position of the bump relative to the current position of the vehicle $x_{B|R}$

and the estimated bump size h_B . Each of these inputs was fuzzified into three fuzzy sets shown in Figure 7. These fuzzy sets are normalized over the universe of discourse [0,1]. Each input was normalized by a different factor corresponding to the maximum allowable value; the speed was normalized by a factor of 10 m/s, the bump distance was normalized by a factor of 100 m and the bump height was normalized by a factor of 0.4 m. The three fuzzy sets are

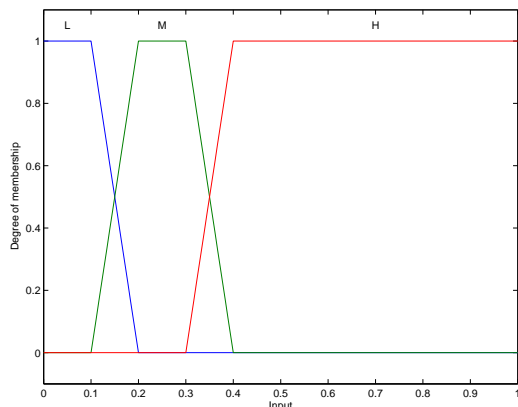


Figure 7. Normalized Fuzzy Sets for the Control Input

denoted as L for Low, M for Medium and H for High. Singleton values computed by using (4) were used to represent outputs of the system for each input combination v_R , $x_{B|R}$, and h_B . None singleton values of that form were developed in the range from -40 kNm to 40 kNm; there were four singletons for the positive torque meant for increasing the speed and four singletons for the negative torque. One singleton was for zero torque. Initially these singleton values were developed heuristically; thereafter the values were tuned gradually following the observed simulation results to match with the vehicle dynamics. In general the tuning may be seen as a way of satisfying equation (4) for under different conditions to represent different values of $\kappa(v_R)$ and $v(h_B)$.

4 Preliminary Results

Preliminary computer simulation results for an XUV model are presented in this section. The XUV was simulated in ADAMS/Car environment with ADAMS/Control along with MATLAB's Simulink. The control system was designed and implemented in Simulink, while the model dynamics computations were carried out in ADAMS/Car. At this time the results could not be compiled and included in this paper because of time constraints, however they will be presented in the oral presentation. The results are based on a bump size h_B of 0.25m and vehicle initial speed of 5.5m/s

which is above the safe speed for this bump size as it was shown in Section 2. In general, the controller was able to reduce the speed to just below 2 m/s for the vehicle to safely cross the bump. After crossing the bump, the speed was again increased to 5m/s, in a similar way that a human being operates a vehicle

5 Conclusion

This paper has presented preliminary results that show the use of a fuzzy logic controller to predictively control the torque of an unmanned ground vehicle on a rough road such that the bumping effects are reduced. The developed fuzzy controller is based on data collected from simulation of bumping dynamics of a vehicle for a range of speeds and trapezoidal bump sizes. The desired vehicle to safely cross a bump tends to decrease as the bump size increases. On the other hand the torque required to propel the vehicle across the bump increases as the bump increases. For that reason, it was found that as the vehicle is the vehicle it is acknowledged that different shapes of bumps such as semicircular, oval, triangular and rectangular need to be studied and the way the vehicle responds to them before a conclusive design can be proposed. Although more work is still needed to validate the results presented in this paper and complete the task of controlling an unmanned ground vehicle across bumps, these results have offered a promising research direction.

Disclaimer

The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Army Research Laboratory or the U. S. Government.

References

- [1] Takenori Hashizume Satoshi Tange Akira Higashimata, Kazutaka Adachi. Design of a headway distance control system for acc. *JSAE Review*, 22:15–22, 2001.
- [2] J.K. Hedrick D.B. Maciuca, J.C. Gerdes. Automatic Braking Control for IVHS,. In *Proceedings of the International Symposium on Advanced Vehicle Control (AVEC 1994)*, Tsukuba, Japan, 1995.
- [3] D.B. Maciuca and J.K. Hedrick. Advanced Nonlinear Brake System Control for Vehicle Platooning. In *Proceedings of the third European Control Conference (ECC 1995)*, Rome, Italy, 1995.
- [4] Jae-Bok Song and Kyung-Seok Byun. Throttle actuator control system for vehicle traction control. *Mechatronics*, 9:477–495, 1999.