State Prediction for Outdoor Autonomous High-Speed UGVs

Graeme Neff Wilson, Alejandro Ramirez-Serrano, Qiao Sun

Abstract—In this abstract techniques for predicting the states of an Unmanned Ground Vehicle (UGV) traveling at high speeds in outdoor terrains are presented. State prediction is desired to allow for navigational decision making such that states are maintained below an allowable threshold. Simulations of the state prediction technique are presented, as well as experimental results of the technique using terrain profile estimates from a geometric sensor that produces a 3D point cloud. Finally a combined vibration-appearance based technique for detecting terrain input profile is proposed.

I. INTRODUCTION

The navigation of outdoor terrain at high speed by an Unmanned Ground Vehicle (UGV) is a current challenge in the area of mobile robotics. High speed motion of a UGV is defined as speeds at which the dynamic effects of the ground acting on the vehicle must be explicitly considered to avoid vehicle damage. The development of a high speed autonomous UGV for outdoor terrains has applications in military, surveillance, search and rescue, and disaster response.

In order to effectively navigate at high speeds in outdoor terrains a UGV must have a method of sensing (characterizing) the terrain in order to react to it. Methods of terrain characterization have been identified by Papadakis as belonging to three major categories [1]: i) geometric based [2], ii) proprioceptive (vibration) based [3], iii) appearance based [4]. The challenge is to use one, or a combination of, these methods to identify the terrain such that the terrain-vehicle interaction can be predicted in real-time while traveling at high-speeds. Predicted terrain-vehicle interaction would allow the UGV to make effective navigation decisions through choosing vehicle speed and path such that states are maintained bellow allowable (safe) thresholds.

This abstract presents a methodology of predicting vehicle-terrain interaction through identification of the ground profile of the terrain using sensors, and prediction of vehicle state responses through a vehicle model. Presented are simulated results for vehicle state prediction for a known terrain input, experimental results for vehicle state prediction using a geometric sensing method, and a novel proposed method of combined appearance-vibration based estimation of upcoming terrain profile. The details of this abstract are expanded further in the full paper by Wilson et al. [5].

II. VEHICLE STATE ESTIMATION

Using the developed model for an n-wheel vehicle it can be shown that if the inputs to the wheels are known, then the model can be used to estimate the vehicle states in response to the known inputs. With the linearized vehicle model this is a straight forward and fast procedure. It can also be shown that the reverse is also true; that if the vehicle states are measured, then the terrain inputs can be estimated using the model with known vehicle states.

III. STATE PREDICTION: SIMULATION

Using a known set of terrain inputs, and a 4-wheeled UGV with known parameters, preliminary validation of this state prediction methodology was conducted in Simulink. Randomly generated terrain profiles were used as inputs to the model. Simulations were run and the estimated states from the linearized model (called estimated) were compared to the calculated states from the non-linear model (called true). This resulted in root mean squared error (RMSE) between the estimated states and the true states of 3.23 m/s² for the z-acceleration of the body, 0.56 rad/s for the angular x-velocity of the body, and 0.41 rad/s for the angular y-velocity of the body. An example of how close the estimations appeared in shown in Figure 1.

It was concluded that the state estimation performed well in simulation and warranted further investigation.

IV. STATE PREDICTION: EXPERIMENTAL

With promising simulation results, this state prediction methodology was tested on existing experimental data from previous research [6]. This experimental data was collected using the Loc8 UGV platform for four different terrain: grass, gravel, pavement, and root terrain.

![Body z-acceleration](image)

Fig. 1. Body z-Acceleration Comparison

The authors are with Department of Mechanical and Manufacturing Engineering, University of Calgary, 2500 University Drive NW, T2N1N4 Calgary, Alberta {wilsongn, aramirez, qsun}@ucalgary.ca
Data was collected on Loc8 to produce position estimates using a Kalman filter of GPS and encoder reading, z-accelerations from accelerometers on the suspension attachment points, and a point cloud of upcoming terrain from a 3D camera called the Swiss Ranger SR4000. Terrain input profile was calculated through interpolation of the point cloud.

Applying the interpolated terrain input profile to the vehicle model, state estimation for the z-acceleration of the vehicle was performed. The results for these estimates were compared to existing methods of vertical acceleration prediction, namely the Sinusoidal Base Excitation Method: Excitation Force (SBEM:EF), and Sinusoidal Base Excitation Method: Transmitted Force (SBEM:TF) [6].

The results where compared using three metrics: i) exceed percentage, ii) average difference, and iii) absolute average acceleration. Exceed percentage refers to the percentage of acceleration measurements that exceeded the acceleration predictions. Average difference is the average difference between the acceleration predictions and the measured value. Absolute average acceleration is the average value of the predicted and measured vertical acceleration of the vehicle body. Results are shown in Table I.

While SBEM:EF and SBEM:TF performed better at exceed percentage, the n-wheel method of produces predictions much closer to actual acceleration as indicated by average difference and absolute average acceleration. For these experimental results it was also noted that errors in position estimates for the 3D point cloud data were substantial and may have significant effect on the results. For Loc8 the position estimation error from the Kalman filter for 95% confidence was expected to be $\pm 0.16 m$. With the added error from the SR4000 the expected 95% confidence error for position estimates may be up to $\pm 0.2 m$.

V. Discussion

While the n-wheel model performed better than existing techniques for average difference and absolute average acceleration, it could be substantially improved for exceed percentage. The error due to position estimation proves to be a significant challenge for improving geometric 3D point cloud based techniques. To avoid geometric sensing, it is proposed that a combined vibration-appearance based technique be developed. While traveling over a terrain a UGV would take camera images of the appearance while recording the vibration of the terrain. With this data a machine learning technique would be used to determine the relationship between visual appearance of terrain and its vibration signature. Thus, the terrain input vibration would be sensed from visual appearance of the terrain. This predicted terrain input would then be used as input to the n-wheel model to predict the vehicle states for upcoming terrain.

VI. Conclusion

This abstract presents an approach to using sensed terrain input profile to estimate vehicle states for a high-speed autonomous Unmanned Ground Vehicle (UGV). Simulation results for this methodology are presented, as well as experimental results using a geometric sensor that return the terrain input profile from interpolation of a 3D point cloud. Simulation results were shown to be promising, and experimental results were found to have advantages over current techniques. Additionally, a method of detecting the terrain input profile using a combined vibration-appearance based technique was proposed.

REFERENCES