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Autonomous Mobile Robots Using Real Time Kinematic Signal Correction and Global Positioning System Control

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Abstract

This paper presents a framework for controlling an unmanned ground vehicle using real-time kinematic control with a global positioning system (RTK GPS). A golf car is modified as the unmanned vehicle platform, and a kinematic model is developed using a feedback controller. These controller outputs drive the accelerator, steering wheel, and brakes. As the controller receives signals from the RTK GPS inputs, it positions the accelerator, the brake pedal, and the steering wheel angle. We discuss how trajectory tracking of a vehicle is performed using numerical simulations of linearized trajectories. Our results show that for pure pursuit tracking, the lowest look-ahead distance gives the lowest deviation from a desired trajectory.

Introduction

The success of the Predator and Global Hawk unmanned air vehicles has demonstrated the utility of unmanned systems in conducting surveillance and reconnaissance missions for the military (Nutwell 2000). Besides the military, advances in manufacturing automation have also increased demand for unmanned vehicles in factories, warehouses, and hazardous environments. One of the ways to provide automatic control of these vehicles is machine vision. However, vision-based tracking control can be slow and/or expensive due to the substantial demand for memory, data processing speed, and vision interpretation. In this paper, we discuss an approach using Global Positioning System (GPS) technology with real time kinematic (RTK) signal correction, where changes can be recorded with tolerances within an inch.

With this approach, a desired trajectory can be obtained by several navigation techniques, such as pure pursuit, vector pursuit, state feedback control, fuzzy logic control, or neural network control. In pure pursuit, the approach is to calculate the curvature that takes the vehicle from its current position to a goal position. Vector pursuit relies on information about the orientation of the vehicle at the look-ahead point (Wit et al. 2004).

For state feedback control, a GPS can be used to navigate using linear state feedback with system identification (O'Connor et al. 1996 and Bell et al. 1998). This approach was extended by Fang et. al. (2006), who considered a nonlinear controller that allowed for wheel slipping by incorporating a backstepping and variable structure into the controller. Others, such as Lenain et. al. (2006) and Martin et. al. (2008), incorporated adaptive and predictive control laws into their algorithms. In extending the control algorithm for keeping unmanned vehicles on a desired trajectory, Hajjaji (2003) applied fuzzy logic control, while Ye (2008) incorporated combined neural network and backstepping control.

In our current study, we use a golf car as an unmanned vehicle platform to develop a kinematic model for pure pursuit trajectory tracking.

Wheel Mobile Robot Mathematical Model

The frame coordinate systems for our unmanned vehicle are shown in Figure 1. Here, XYZ is an inertial reference frame, while ${}^{V}X{}^{V}Y{}^{V}Z$ is moving with the unmanned vehicle and the origin is located at center of the rear wheel.

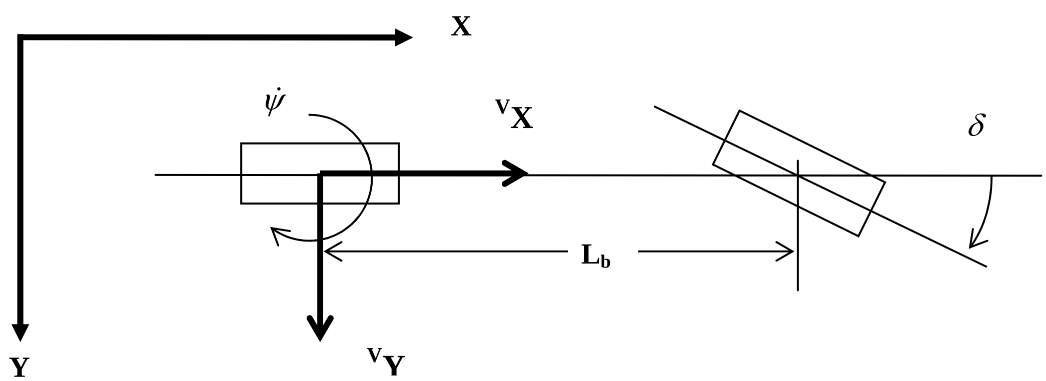


Figure 1: Two Wheel Kinematic Model of WMR

Since the vehicle is symmetric along its centerline, we consider a two wheel kinematic mathematical model, where the X and Y components of velocity is given as

$$\begin{aligned}\dot{X} &= V\cos\psi \\ \dot{Y} &= V\sin\psi\end{aligned} \quad . \qquad (1)$$

Here, V is linear velocity of the unmanned vehicle, and ψ is orientation of the vehicle measured from the X-axis of the inertial reference frame. The vehicle's yaw rate, $\dot{\psi}$, is calculated from the front wheel angle, δ, and V, such that

$$\dot{\psi} = \frac{V\tan\delta}{L_b} . \qquad (2)$$

From Figure 1, wheel angle, δ, can be calculated from radius of turning, R, where

$$\delta = \tan^{-1}\left(\frac{L_b}{R}\right) . \qquad (3)$$

Pure Pursuit Tracking of Wheel Mobile Robot

In Figure 2, the goal point (G_x,G_y) is the intersection of look-ahead circle and the desired trajectory. The center of the look-ahead circle is at the rear wheel axle (V_x,V_y) of the vehicle. L_a is the look-ahead radius. As the vehicle moves from (V_x,V_y) to (G_x,G_y), the vehicle turns with the radius of curvature R, such that

$$\frac{1}{R} = \frac{2\sin(\eta/2)}{L_a}. \qquad (4)$$

To satisfy this requirement, the front wheel angle must follow

$$\begin{aligned} \delta &= \tan^{-1}\left(\frac{L_b}{R}\right) \\ \delta &= \tan^{-1}\left(\frac{2L_b \sin(\eta/2)}{L_a}\right), \end{aligned} \qquad (5)$$

where η is the angle measured from the vehicle orientation to the vector measured from the vehicle origin frame to the goal point.

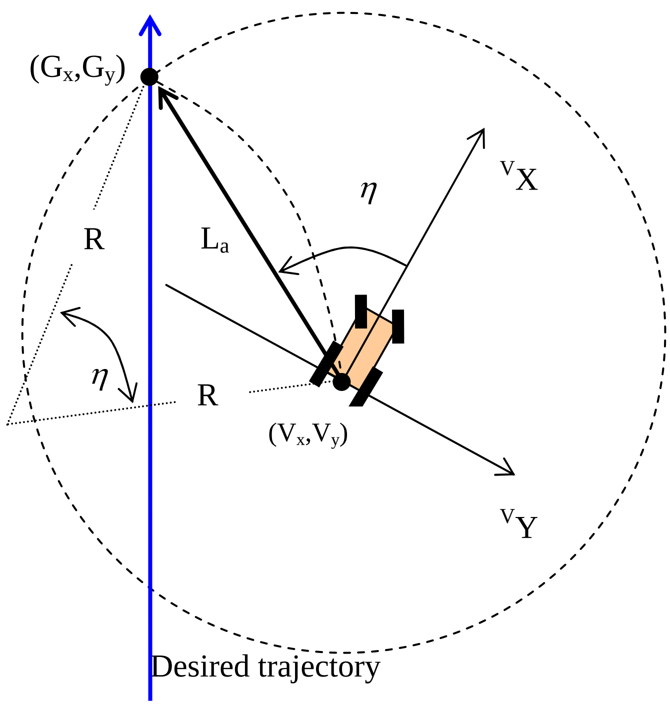


Figure 2: Pure Pursuit Approach

Controller

A block diagram of a control system is shown in Figure 3. The current position (V_x,V_y) and orientation (ψ) of the vehicle are measured by using RTK GPS. Here, we measure the front wheel angle with a potentiometer and send the input to the controller for control of the front wheel angle:

$$\delta = \tan^{-1}\left(\frac{2L_b \sin(\eta/2)}{L_a}\right) \qquad (6)$$

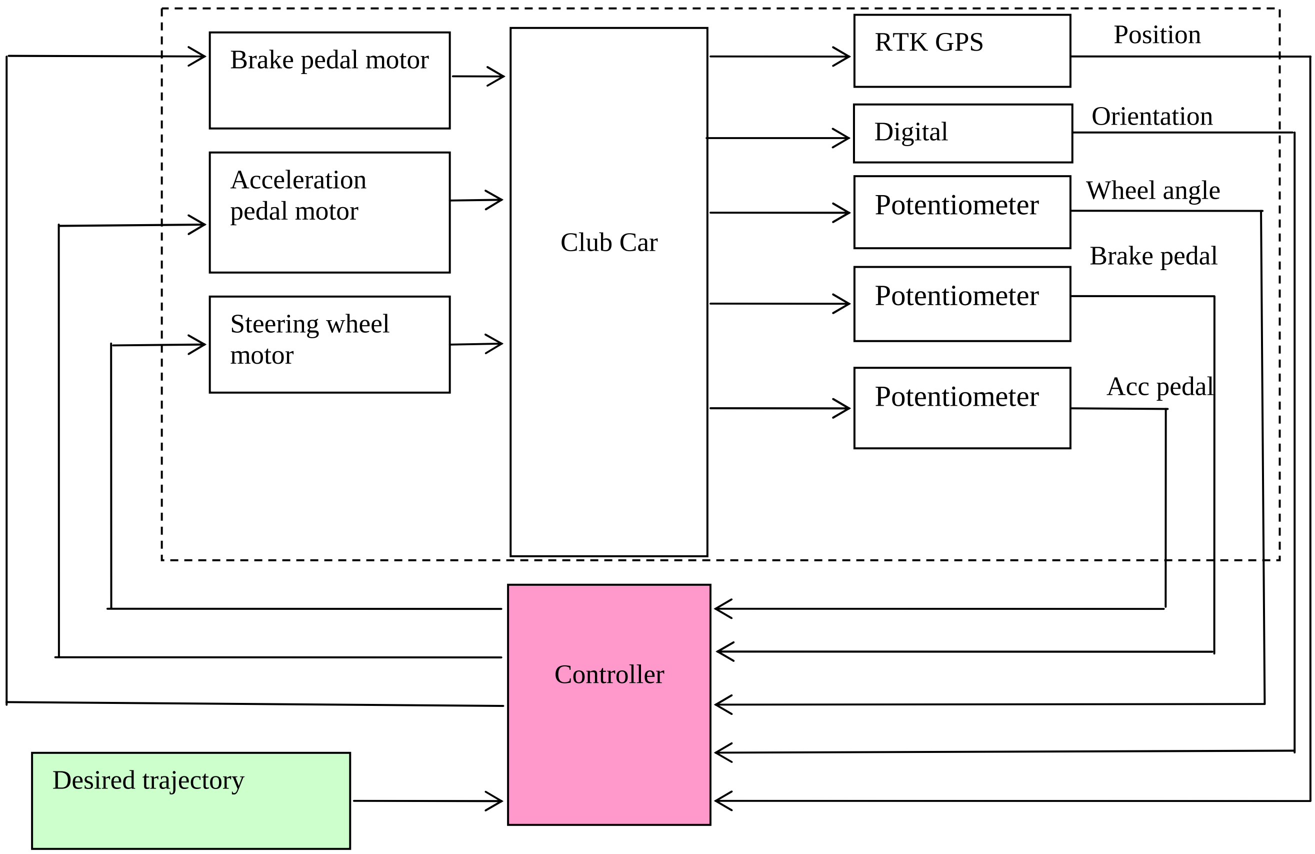


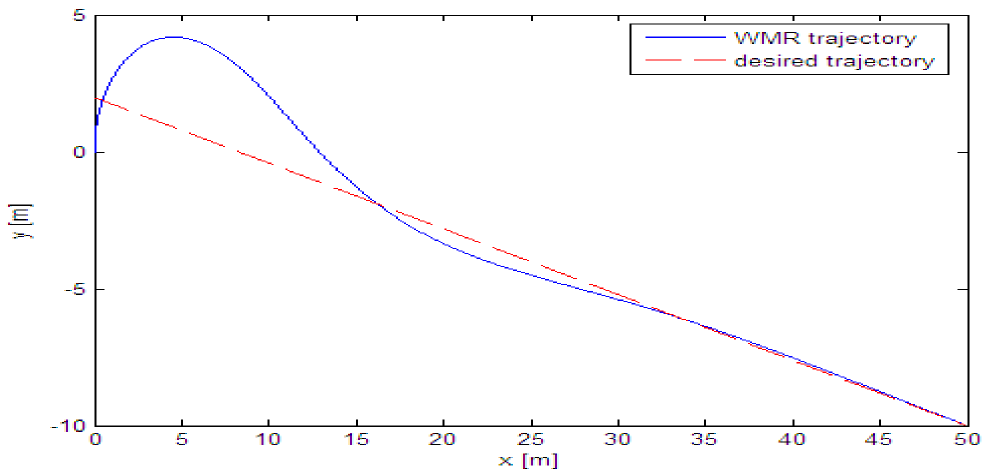
Figure 3: Schematic Block Diagram of Mobile Robot Control

Simulation and Experimental Results

We conducted numerical simulations to assess the performance of the controller. Initially, we selected a vehicle position at (0,0) and a 90-degree orientation in inertial reference frame. For a desired trajectory at starting position (0,2) with angles at –13.5 and 155.3 degrees and a look-ahead distance of 5 meters, the results are shown in Figures 4 and 5. At an angle of –

13.5 degrees and look-ahead distances at 3, 5, and 7 meters, respectively, our results are shown in Figure 6. These results suggest that trajectory tracking has an overshoot response that depends on the initial orientation of the vehicle and the look-ahead displacement. This suggests that lower look-ahead displacements lead to lower overshoot responses. To verify the results of the numerical simulation, we built the experimental setup shown in Figure 7.

In our experimental setup, a DC motor was applied to drive the steering wheel of the golf cart while linear actuators were used to push the accelerator and brake pedals. Linear potentiometers were used to measure the wheel angle and travel distances for the accelerator and brake pedals. An NI USB 6229 data acquisition card was used to record inputs. RTK GPS measured the vehicle position. A Trimble AgGPS 900 served as the base station, while a Trimble AgGPS 332 was installed on the golf cart. In this configuration, the base station sent radio correction signals to the rover unit and data acquisition system where the accuracy of the GPS was within 1-inch standard deviation from the mean. We used a digital compass to measure the orientation of the vehicle.



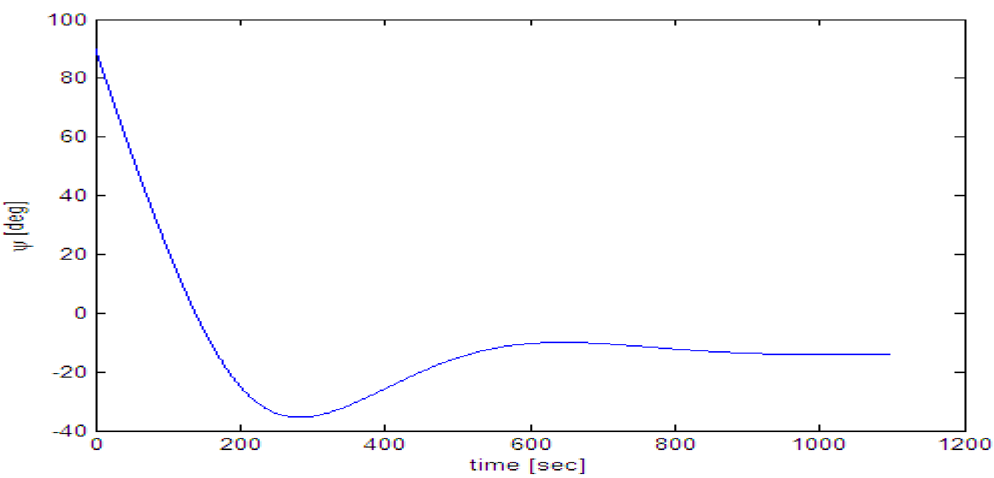


Figure 4: Trajectory Tracking to –13.5 Degree Desired Angle and Orientation Angle with 5 m Look-ahead Distance

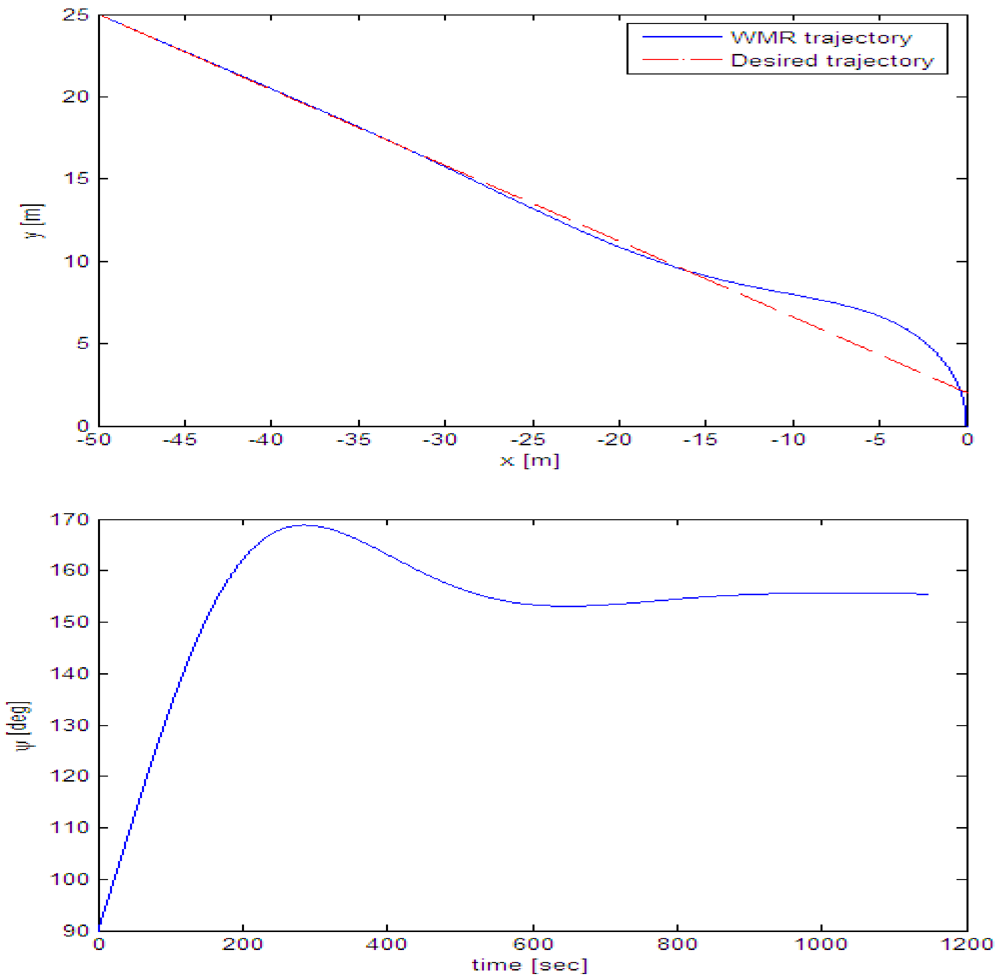
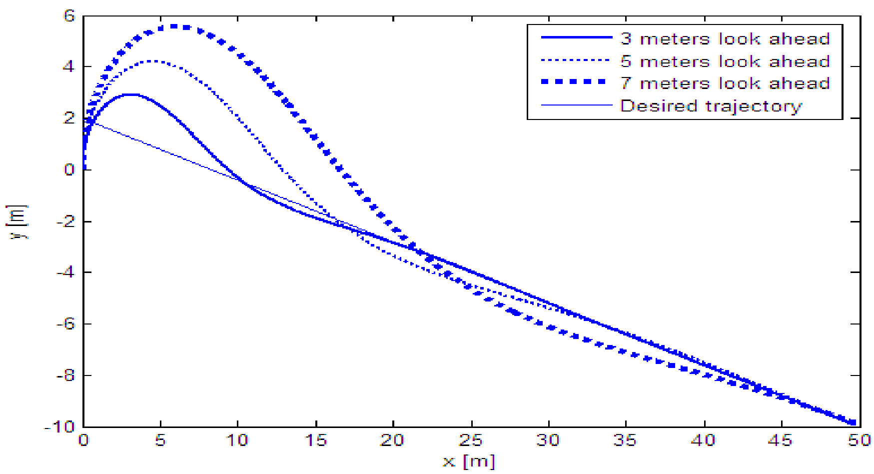


Figure 5: Trajectory Tracking to 155.3 Degree Desired Angle and Orientation Angle with 5 m Look-ahead Distance



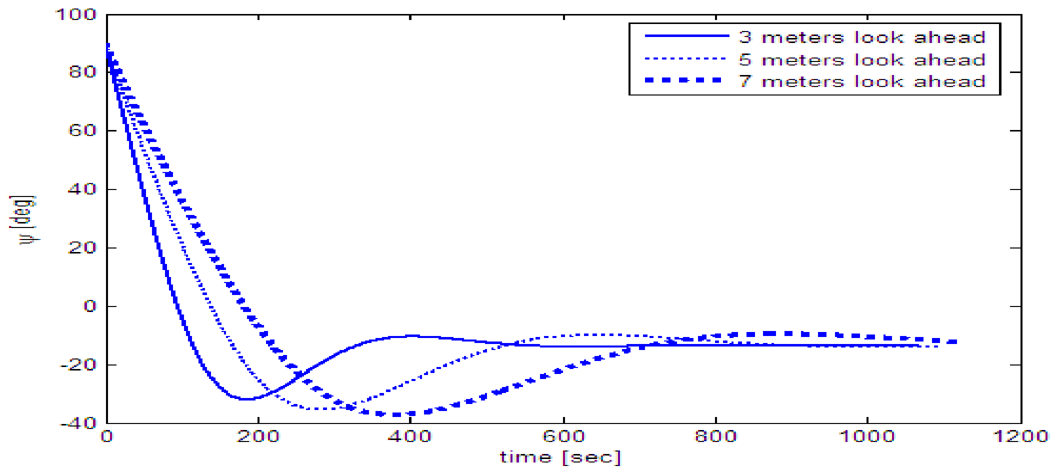


Figure 6: Trajectory Tracking to –13.5 Degree Desired Angle and Orientation Angle with 3, 5, and, 7 meters Look-ahead Distance

Figure 7: Actuator and Sensor Applied for WMR Control

Conclusions

For pure pursuit trajectory tracking, a lower look-ahead distance gives the lowest overshoot response. The initial orientation angles for the unmanned vehicle have less significance than look-ahead distance.

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Biographies

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