# Design Development of Steering and Speed Control for an Intelligent Mobile Robot

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## ABSTRACT

Exploratory research on the design of a modular autonomous mobile robot controller for steering and speed cont described. The high level control of the robot incorporates a fuzzy logic approach. Steering and

speed control are achieved using a three-axis Galil motion controller. The steering mechanism and the speed con involve the parallel control of the robot's two front wheels based on decisions made by the upper level fuzzy logic the robot in a desired direction to follow a specific path and avoid obstacles in that path. The steering motors are Electrocraft brush DC motor. The BDC amplifiers are run in the current loop mode. The overall control is supervi personal computer through the multi-axis controller. The system has been simulated on Matlab and Simulink an values for the digital gains were achieved for desired control. Testing of these systems has been done in a laborat as well as on an outside track with positive results.

**Keywords**: Steering mechanism, zero turning radius, speed control, Matlab, Simulink, mutli-axis controller, pe overshoot, system response.

## 1. INTRODUCTION

Researchers all around the world have been working on autonomous vehicles for some time. One group of resear attend an annual autonomous unmanned vehicle competition (AUVS) sponsored by the Autonomous Unmanned Society, the Army Tank Command, the Society of Automotive Engineers, Fanuc Robotics and others to test conce designs and team approaches to autonomous vehicles. This paper is about the speed and steering control of the A University of Cincinnati Bearcat vehicle.

The design of a mobile robot is a challenging task. One of the specific challenges is to determine what informatio needed, how to use this information in a manner that will satisfy the performance specifications of the machine. specifications were to build a robot, which follows a line, avoids obstacles, and adapts to variations in terrain. Thi necessitates the design of separate subsystems with discrete design objectives integrated in an upper level logic t the robot to function as an integral system meeting all the performance requirements.

Each of the subsystems at the primary level, were designed by keeping in mind the various factors including the s equipment with the desired functional and operational features as well as reliability, commercial availability and affordability. The conceptual design included the use of the 80/20 industrial erector set. Various modules were c for the size and the actual space they would occupy on the mobile robot. Equally important was the compatibility software that controlled these units and their interfaces. Also, all the subsystem level components have been cho modular in design and independent in terms of configuration so as to increase adaptability and flexibility. This e replacing of existing components with more sophisticated or suitable ones, as they become available.
Jones and Flynn[1] give an excellent introduction to the implementation of small mobile robots. Muir and Neuma rigorous mathematical treatise on the kinemaic and dynamic modeling of mobile robots. Cheng and Rajagopalan consider kinematic modeling for mobile robots. Nikam, et al[4], describes the overall design of the previous UC mo

The purpose of this paper is to describe the design of the speed and steering controller for the mobile robot. The

design and speed and steering control is described in Section 2. The experimental results are described in Sectior
Conclusions and recommendations are given in Section 4.

## 2. SYSTEM OVERVIEW

An autonomous mobile robot is a sophisticated, computer controlled, intelligent system. The adaptive capabilitie
mobile robot depend on the fundamental analytical and architectural designs of the sensor systems used. The mc
provides an excellent test bed for investigations into generic vision guided robot control since it is similar to an aı
and is a multi-input, multi-output system. The major components of the robot are: vision guidance system, steeri
system, obstacle avoidance system, speed control, safety and braking system, power unit and the supervisor cont

Following is a brief description on the design and development of the main subsystems of the mobile robot. A blo
diagram of the system is shown in Figure 1.

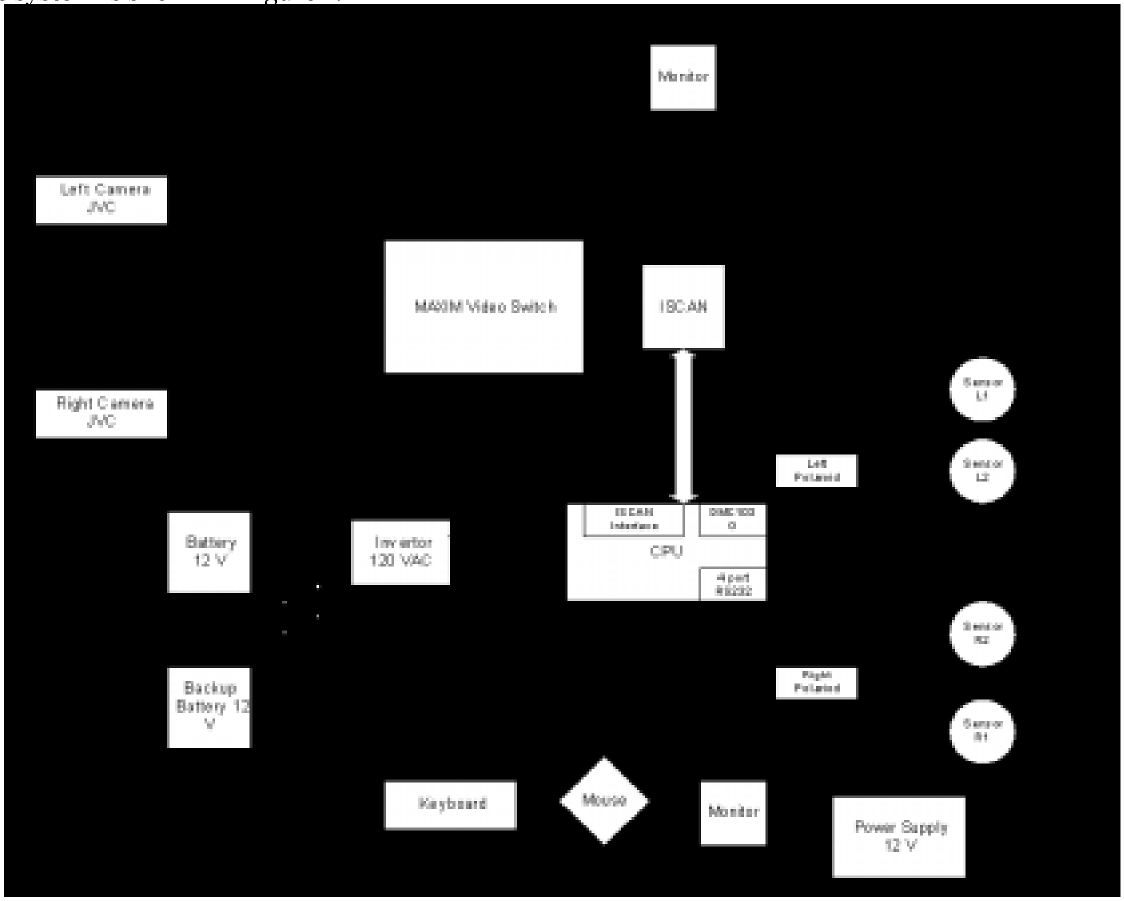


**Figure 1. System block diagram**

**The actuators of the vehicle were designed using MATHCAD 6.0, initially estimat
mass of the vehicle and iterating the calculation after the selection of each compo
The mass was translated into the required torque of the motor using the followin
equation:**

$$T_{motor} = \frac{(J_{motor} + J_{transmission} + J_{inertiaatmotor} \times a) \times 4 \times a \times \pi}{2} + \frac{\mu \times Mass \times g \times R_{wheel}}{i} + T_{frictionalto}$$

Where T represents torque, J inertia, a is the radius of gyration of the motor, μ is the coefficient of friction, g is th acceleration of gravity, and R is the radius of the drive wheels. Following is a description on the design and devel the main subsystems of the mobile robot.

## SPEED AND STEERING CONTROL

The motion control of the AGV designed, has the capability of zero turning radius (ZTR) feature which is gaining and expanding commercially in the U.S. mowing market. ZTR is the ability to make a turn about the center of the drive wheels. This design offers exceptional maneuverability especially for sharp turns. Rotating one wheel forwa other wheel backward accomplish the ZTR function. However, in our design we can also vary the speeds of the le drive wheels while negotiating a curve. This enables the AGV to make a curved turning parallel to the track lines.

The robot base is constructed from an 80/20 aluminum industrial erector set. The AGV is driven and steered by independent 36 volt, 12 amp motors. These motors drive the left and right drive wheels respectively through two independent gearboxes, which increase the motor torque by twenty times. The power to each individual motor is from a BDC 12 amplifier that amplifies the signal from the Galil DMC motion controller. To complete the control position encoder is mounted on each of the drive motors. A castor wheel in the rear of the vehicle, is free to swing vehicle has to negotiate a turn. The encoder position signal is numerically differentiated to provide a velocity fee signal.

Control of the AGV motion is done by differential speed drive wheels. These are drive wheels whose speed can be according to the change in the direction of the track being followed. This task can be reduced to the control of tw variables:

The instantaneous speed of the vehicle is $V_{M.}$ The orientation of the vehicle,θ , is controlled by controlling the sun difference of the two wheel speeds. This also permits control of the velocity of the vehicle.

$$V_M = (V_L + V_R)/2$$
$$\theta = (V_L - V_R)/WT$$

where $V_L$ = velocity of the left wheel, $V_R$ = velocity of the right wheel, W = distance between the center of the two and T is the sampling time.

The design objective was to obtain a stable control over the steering system with a good phase and gain margin a unit step response. For this purpose a Galil motion control board was used which has the proportional integral d controller (PID) digital control to provide the necessary compensation required in the control of the motor. The s modeled in MATLAB[12] using SIMULINK and the three parameters of the PID controller were selected using a si model to obtain the optimum response.

The SIMULINK model is shown in Figure 4 and starts with a step input signal fed to a summation block. The val PID controller are set with a MATLAB file calculating the analog gains, for the equivalent digital filter used on th

system. These analog values in the PID controller model adjust the input signal and feed it to the zero order hold.
order hold produces a pulse signal. The digital signal is fed to a digital to analog converter and then to an amplifi
amplified signal is then fed to the load, which are the motor and the steering wheels. The encoder detects the mo
the wheel and gives signal that is fed back to the summation block for correction.

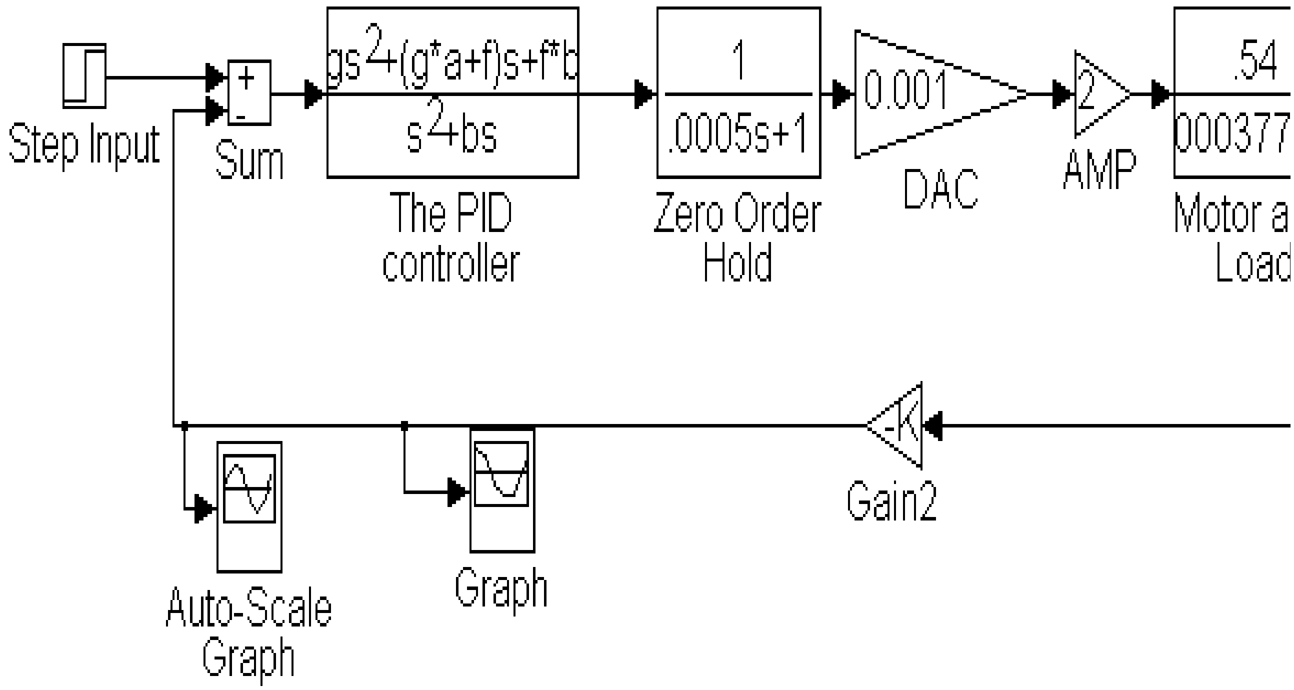


Figure 2. SIMULINK model

**The unit step response was simulated in MATLAB. The values for the PID control
were tested on the actual vehicle and were fine tuned using the software kit supp
Galil Motion Inc., WSDK 1000. This software also allowed us to experimentally e
the frictional losses in the gearbox and bearing mechanisms. A conservative tuni
performed and values for the PID controller were identified suitable for the syst
Bode plot frequency response was measured by supplying a sinusoidal input sign
the open loop system and recording the response through the encoder. A phase r
of 40 degrees and a gain margin of 10 decibels were achieved. Then, the step resp
was checked to minimize the overshoot and select a critically damped response.
actual tests were made in three conditions: steering wheel off the ground, steerin
wheel on the ground with robot moving and steering wheel on the ground with r
stationary. Tuning of the amplifier parameters, especially loop gain and selectio
PID parameters were very important and required iterative adjustments.**

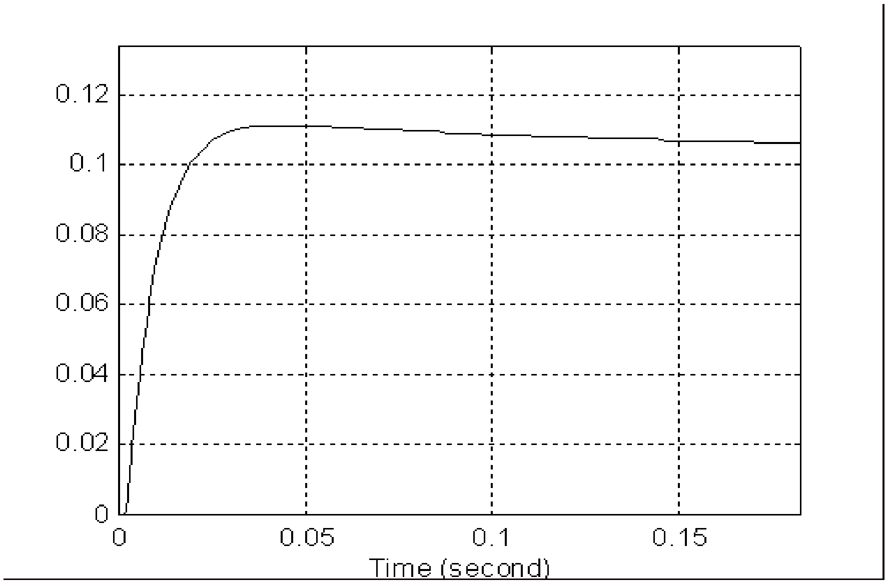
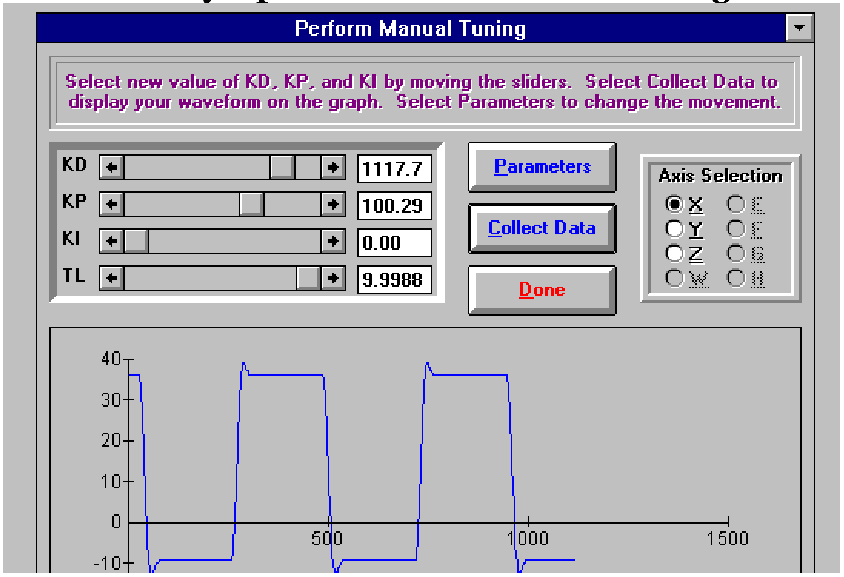


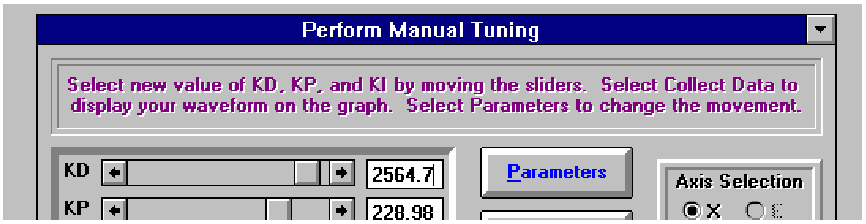
**Figure 3 Step response graph showing percent overshoot.**

**The interface for the system was implemented using a Galil 1030-motion control computer interface board. A Galil breakout board permits the amplifier and enc be easily connected. The steering mechanism gets its input for the angle to be mo from three inputs: the distance from the obstacle avoidance and the angle of the and distance from the robot centroid from the vision algorithm. Feedback is pro a low level by a position encoder and at a high level by the vision and sonar syste**


Perform Manual Tuning

Select new value of KD, KP, and KI by moving the sliders. Select Collect Data to display your waveform on the graph. Select Parameters to change the movement.

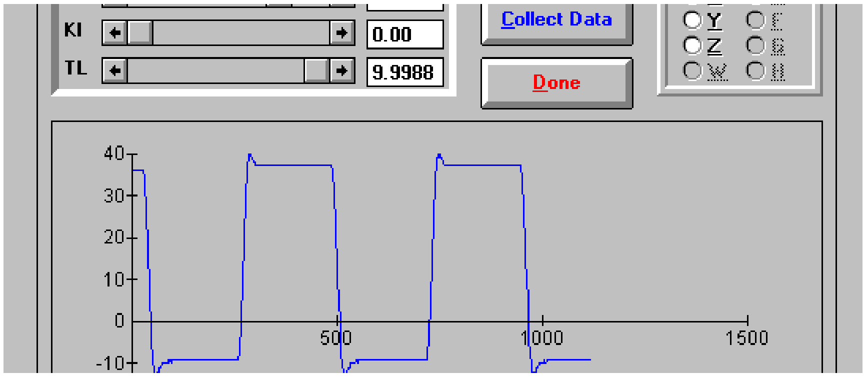
KD 1117.7
KP 100.29
KI 0.00
TL 9.9988


Perform Manual Tuning

Select new value of KD, KP, and KI by moving the sliders. Select Collect Data to display your waveform on the graph. Select Parameters to change the movement.

KD 2564.7
KP 228.98

In the design process an inco
estimation of the inertial
overloading and burning
amplifier. As a solution a
limit was specified in the
motion program, which li
drive **Figure 4 Screen c**
**from the tuning of the**



KI 0.00

TL 9.9988

**wheel**

torque, current, and volta
supplied by the amplifier.
problems faced were setti
appropriate

hardware control bias vol
the amplifier and estimat
turning torque. These we
through experimental me

Essentially the testing of
response of the two front wheels was accomplished using the WSDK windows module software for tuning the mo
amplifiers. After the amplifiers were tuned and the hardware gains set in the next step was to tune the individual
through the software. Each of the wheels had its control parameters despite of the fact that every single compone
same. This inherent tendency of the systems to have the different control responses was the basis for tuning both
systems separately and in a manner that both the system responses matched the basic design objective.

The software has a number of modules with which to tune the system. After initially modeling the systems with t
parameters plugged in the closed loop response was obtained. Figure 3 and Figure 4 below show the responses fo
PID gains on the right wheel and left wheel respectively.

## Analytical design

The operations of the velocity loop where the motor velocity is sensed by a tachometer and is feedback to the comparator.

The transfer function between the input voltage, V, and the output velocity ω is of the form:

[illegible]

Where the constants are defined as:

$K_t$ is the motor torque constant or ratio of the output torque to the input current,

$K_a$ is the amplifier gain or ration of the output drive current to the input voltage.

$K_g$ is the tachometer gain or ratio of output voltage to input speed,

J is the combined inertia of the motor and load.

$\tau_1 = J / K_a K_t K_g$ The time constant $\tau_1$ is given by:

The Galil motion controller permits one to implement a PID (Proportional, Integral, and Derivative) controller th equivalent digital filter. The form of the digital filter is:

$$D(z) = K^*(z-A)/z + C^*z/(z-1)$$

The sampling time is T. The filter parameters K, A and C are selected by the instructions KP, KD, and KI and are follows:

K = KP+KD

A = KD/(KP+KD)

C = KI/8

This digital filter includes a lead compensator and an integrator. It is equivalent to a continuous PID filter with tr function G(s) where:

G(s) = P+ sD + I/s

Where

P = K(1-A) = KP

D = T*K*A = T*KD

I = C/T = KI/(8*T)

The filter parameters may be determined either analytically or experimentally. One analytical method is describe and lets one select a phase margin at a given crossover frequency depending on the system parameters. In our ca the system parameters such as the motor torque constant Kt, the motor and load inertia, J, the motor resistance, amplifier constant, Ka, the encoder constant N were not known. Therefore an experimental design was performe

SDK1000 servo design software.

## CONTROL SYSTEM

The upper level control scheme is based on a fuzzy logic, hierarchical control system. The cart is, at its lowest leve go straight, at a variable speed. It is only when either of the sensors interrupts it, does it change direction or spee vision system, when it recognizes a discrepancy between the actual and desired position, will correct the steering the ultrasound detects an obstacle, it will override the straight motion as well as the vision system. This order is for the AUVS competition where the vehicles main objective is to go as far in as short of time, as possible, for oth applications the order may be different, where the cart would only go if there were lines in sight.

## 3. RESULTS OF TESTING

After extensive laboratory testing of individual subsystems an oval outdoor test track was constructed to simulat contest track with double lines, 4 inches wide spaced 10 feet apart with dashed segments and obstacles. The first test was conducted on May 20, 1998. The observations on the performance of the individual subsystems are sum below:

**Vision guidance system**: The vision system was able to successfully track straight lines and curves, negotiate as well as switch control between cameras when the line on either side disappeared. However, the external condi present some problems. If the weather turned sunny to cloudy or vice versa during the actual run the Iscan thres be manually readjusted. Also, in certain cases the reflection of the wet grass on the track appeared brighter than line itself and the vision system

picked those points and went off-track. Both these observations were incorporated in the fault diagnostic progra remedies suggested to over them.

**Obstacle Avoidance System**: The sonar system reliably detected obstacles between 6 inches and 8 feet within accuracy of 1 inch. The system interfaces between the Polaroid unit, Galil controller and the supervisory controll found to be successful. The fuzzy logic controller computed correction angles

to drive the robot around the obstacles. Going downslope on a ramp, it was observed that the sonars detected gro obstacle. This problem was taken care of by modifying the sonar algorithm such that if sonars on either side gave readings, the obstacle shall be ignored.

**Steering control system**: The front wheels of the robot were individually tuned and tested using the WSDK w module. After the design requirements were met and satisfactory levels of performance were obtained the vehicl successfully tested on various terrain. The steering mechanism worked satisfactorily. Implementing the PID cont variables as obtained from the SIMULINK model gave a stable response with almost zero overshoot.

**Safety and Emergency Stop Braking System**: This system was found to be reliable and effective. To protect circuit from any power spikes in the system, fuses were connected in the circuits. Also, it was found that the trans the remote control unit drained its battery within 45 minutes. Though, this would not have presented any proble actual run at the contest, as a precautionary measure a provision was made to recharge the battery without physi removing it from the unit so as to ensure peak performance of the unit.

## 4. CONCLUSIONS and RECOMMENDATIONS

A stable test platform has been designed, constructed and tested. However, advanced control techniques need to investigated. The system's modular design lends itself to a subsumption architecture, whereby any number of ser systems could be connected and with a minimal programming effort be efficiently utilized. Also the use of a more methodology in the obstacle avoidance should be investigated. For the system to be more efficient and able to go speeds, interrupt handling is a must. The program would then not have to constantly poll the obstacle avoidance systems. Also, the motor control needs to have an interrupt to inform the control program when it has completed

A modular intelligent robotic system has been developed for the AUVS competition. The design team spent over person hours. The replacement costs of the vehicle is about $18,600. The system embodies speed control, vision tracking and ultrasonic obstacle avoidance. The design utilizes independent sensor modules. These modules coul placed on any system to control it with minimal modifications.

## *ACKNOWLEDGEMENTS*

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