Steering Control System for a Mobile Robot

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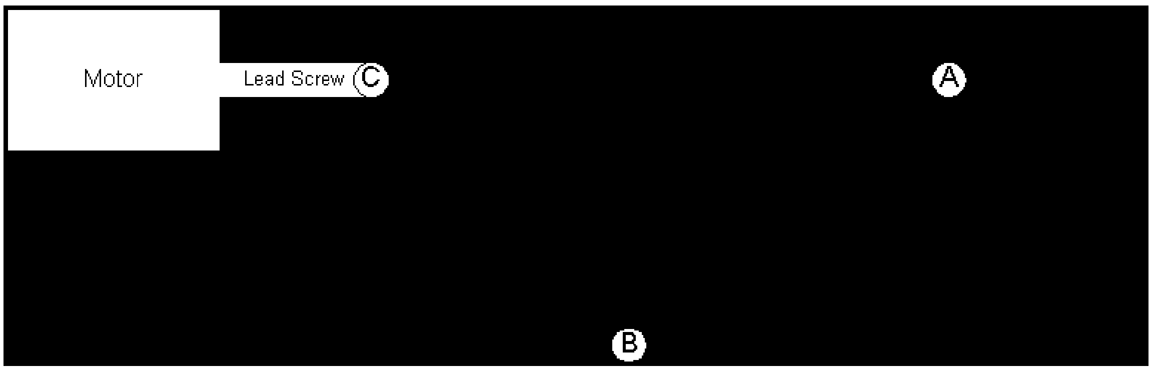


ABSTRACT

Automated Guided Vehicles (AGV's) have many potential applications in manufacturing, medicine, space and defense. The purpose of this paper is to describe the design of a steering mechanism for an autonomous mobile robot. The steering mechanism repl aces a manually turned rack and pinion arrangement with a crank mechanism driven by a linear actuator that in turn is powered by a brushless DC motor. The system was modeled, analyzed, and redesigned to meet the requirements. A 486 computer through a 3-ax is motion controller supervises the steering control. The steering motor is a brushless DC motor powered by three phase signals. It is run in current loop mode. The steering control system is supervised by a personal computer through a multi-axis motion controller. Testing of these systems has been done in the lab as well as on an outside test track with positive results.

1. INTRODUCTION

The specific challenge of designing an intelligent controller for an automated guided vehicle (AGV) is in determining what information is needed, how to measure it and how to use this information in a manner that will satisfy the performan ce specifications of the machine. The design specifications were to build a robot, which follows a line, avoids obstacles, and adapts to variations in terrain. This implied the design of separate subsystems with discrete design objectives integrated in a n upper level control logic that enables the robot to function as an integral system meeting all the performance requirements.

At the subsystem level, the primary design considerations included the selection of equipment with the desired functional and operational features as well as reliability, commercial availability and affordability. Equally important was the compatibilit y of the software that controlled these units and their interfaces. Also all the subsystem components have been chosen to be modular in design and independent in terms of configuration so as to increase adaptability and flexibility. This enables replaceme nt of existing components with more sophisticated or suitable ones, as they become available.

2. STEERING MECHANISM

The steering linkage for the mobile robot is a crank mechanism shown in Figure 1. The crank length is L and the connecting rod length is R. Point A is a fixed pivot point about which the steering wheel rotates.

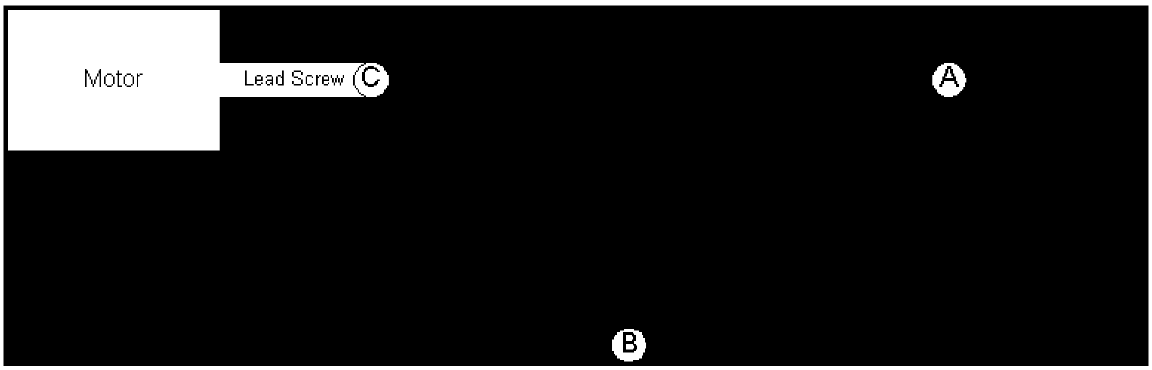


Figure 1 Crank mechanism

The amount of rotation of the connecting rod AB about point A is measured by θ. The rotation of the crank about point C is measured by β. The distance points B moves is given d = R θ. Using the law if sines, the angle β between the connecting rod BC and the horizontal axis can be determi ned by:

$$\frac{\sin(\theta)}{L} = \frac{\sin(\beta)}{R} \quad \text{or} \quad \beta = \operatorname{asin}\left(\sin(\theta)\cdot\frac{R}{L}\right)$$

Note that this assumes that the motion of point C is horizontal. If point C moves vertically, a different analysis is required. The main question is: if the lead screw advances a distance, x, what is the change of the angle, q? Also, given a change of angle, what is the distance x?

The motion of connecting rod BC may be written in vector form as:

$$v_C = v_B + v_{CB}$$

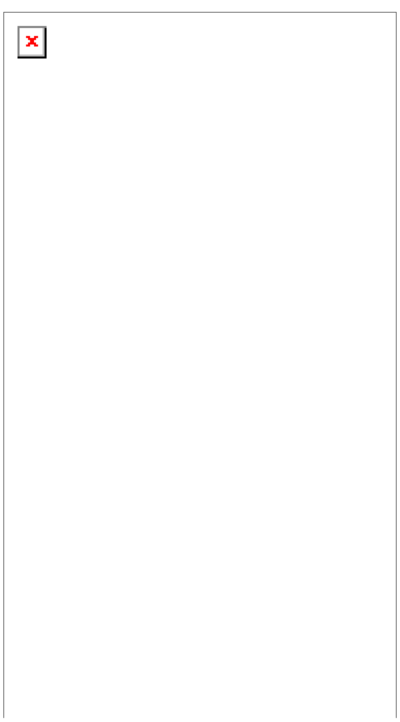
$$v_{CB} = L \cdot \frac{d}{dt} \beta$$

$$d_{CB} = L \cdot \beta$$

This relative velocity relationship is shown in Figure 2.

Figure 2 Relative velocities

One way to simplify the analysis is to consider the vertical and horizontal components of the vector velocity. The vertical components are given by the following.



The vertical component does not involve the variable x and is presented just for completeness.

An analysis of the horizontal components gives the following.

Integrating this expression assuming x = 0 when θ = 0, gives:

$$x = R\cdot(1-\cos(\theta)) + R\cdot\left[\sqrt{\left(\frac{L}{R}\right)^2 - \sin(\theta)^2} - \frac{L}{R}\right]$$

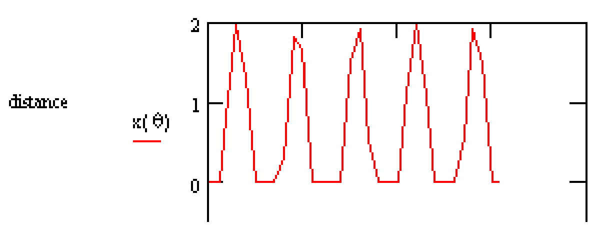
This is the forward kinematic solution, that is, given θ , we can compute x.

For example, if L=R=1, then x is shown below as a function of θ .

$L := 1$

$R := 1$

$$x(\theta) := R\cdot(1-\cos(\theta)) + R\cdot\left[\sqrt{\left(\frac{L}{R}\right)^2 - \sin(\theta)^2} - \frac{L}{R}\right]$$



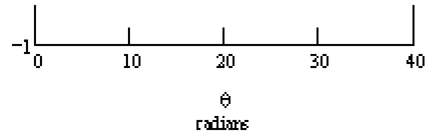
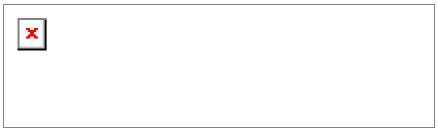
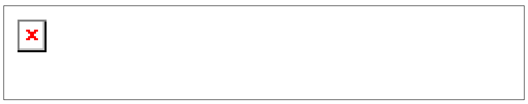
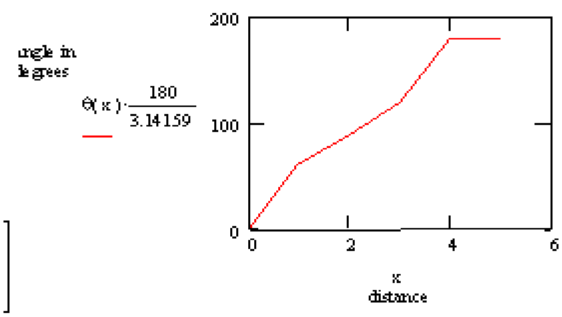


Figure 3 Crank distance versus angle

We can also determine the inverse kinematic solution, that is, given x, determine θ







$$x := 0..5 \qquad \theta(x) := \pi - \operatorname{acos}\left[\frac{\left(2\cdot x\cdot L + 2\cdot x\cdot R - 2\cdot L\cdot R - 2\cdot R^2 - x^2\right)}{\left(-2\cdot x\cdot R + 2\cdot L\cdot R + 2\cdot R^2\right)}\right]$$

Figure 4 Inverse kinematic solution

Although the graph only shows one, there are two solutions for a given a value of x. These correspond to mirror image positions of the crank.

3. SYSTEM DESIGN and DEVELOPMENT

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

Following is a brief description on the design and development of the main subsystems of the mobile robot. A block diagram of the system is shown in Figure 6.

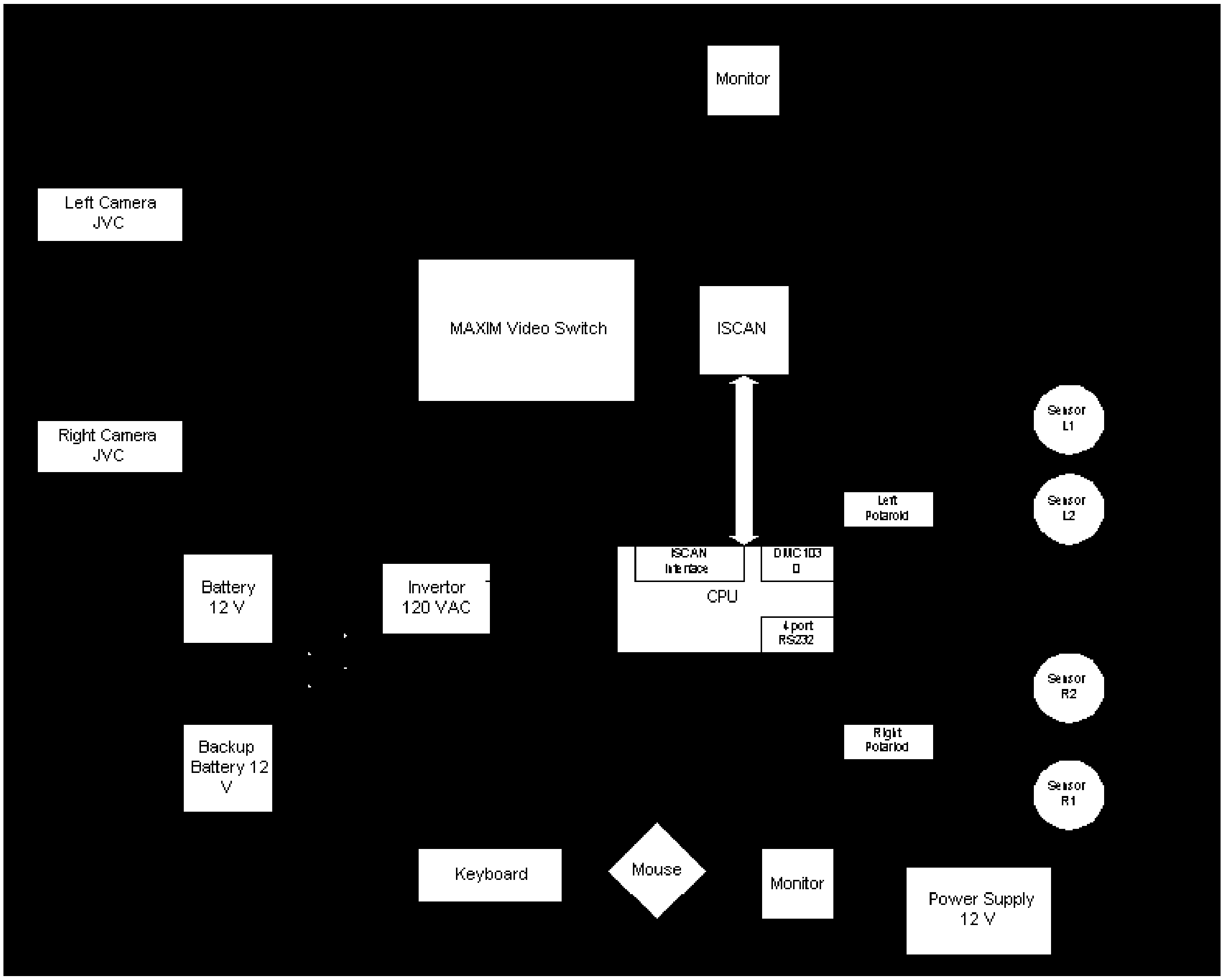


Figure 5 System block diagram

4. STEERING CONTROL

The steering system of the AGV helps maneuver it to negotiate curves and obstacles. The original steering system of the 3-wheeled cart used a rack and pinion design. This was replaced by a computer controlled steering mechanism that is a lead screw li near actuator. This linear actuator produces 110 ft-lb. of torque creating a maximum turning speed of 20 degrees a second. This motor is controlled from the computer through the Galil DMC-1030. The DMC 1030 signal is amplified by an Electro-Craft ampli fier, which provides three phase voltages to the brushless DC motor amplifier. For position feedback, a BEI encoder is directly mounted on the steering wheel giving a positive position feedback with 0.20-degree resolution.

The design objective was to obtain a stable control over the steering system with a good phase and gain margin and a unit step response with small overshoot. For this purpose a Galil motion control board was used which has the proportional integral de rivative controller (PID) digital control to provide the necessary compensation required in the control of the motor. The system was modeled in MATLAB using SIMULINK and the three parameters of the PID controller were tried on the simulation model to obt ain the optimum response.

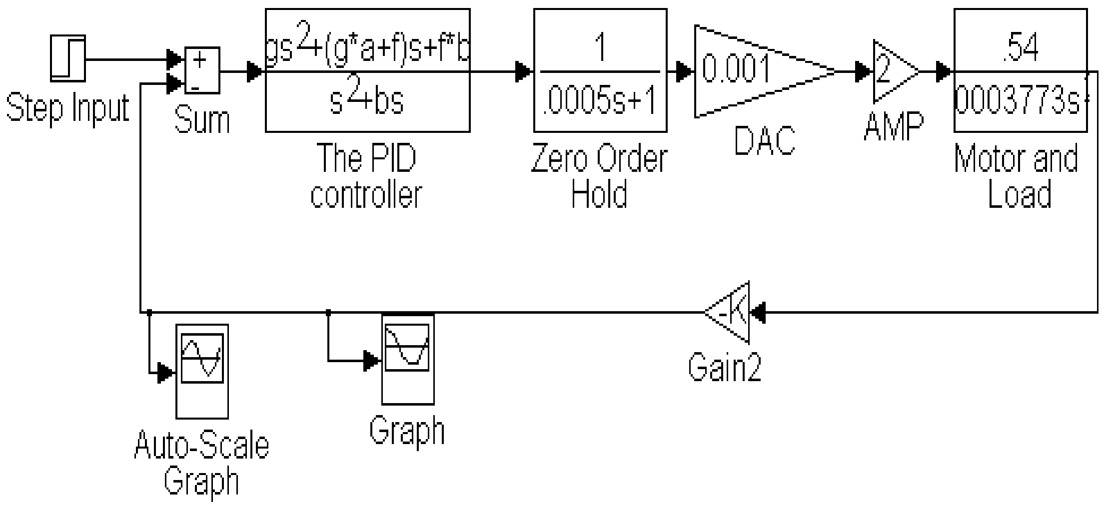


Figure 6. SIMULINK model

The SIMULINK model consists of a step input signal fed to a summation block. The values for the PID controller are set with a MATLAB file calculating the analog gains for the various equivalent digital filter values tried on the actual system. The se analog values in the PID controller model then adjusts the error signal and feeds it to the zero order hold. The zero order hold holds the input level until the next input is given in order to smoothen the input wave, the sampling time of which is mode led in the zero-order block. This digital signal is then fed to a digital to analog converter and then to an amplifier. The gain on the amplifier was fixed at 2.0 in the model but has several adjustments on the actual device. This amplified signal is then fed to the load, which are the motor and the steering wheel. The actuator is a linear lead screw that drives a crank mechanism. The encoder to give a feed back signal that is fed back to the summation block for correction detects the movement of the whee l.

Figure 7. Graph showing % overshoot

The unit step response was simulated in MATLAB and it was found that the phase margin was around 40 dB and the percentage overshoot was less than 15% as shown in Figure 7. The values for the PID controller were tested on the actual vehicle and were fine tuned using the Windows servo Design Kit software supplied by Galil Motion Inc.--WSDK 1000. This software also allowed us to estimate the frictional losses in the gear mesh, the linear actuator and the rack and pinion mechanisms. A conservative tuning was performed and values for the PID controller were identified suitable for the system. The Bode plot frequency response was measured by supplying a sinusoidal input signal to the open loop system and recording the response through the encoder. A phase margin of 40 degrees and a gain margin of 10 decibels were achieved. Then the step response was checked to minimize the overshoot and select a critically damped response. The actual tests were made in three conditions: steering wheel off the gro und, steering wheel on the ground with robot moving and steering wheel on the ground with robot stationary. The torques for these conditions were measured at 15 foot pounds, 20 foot-pounds, and 30 foot pounds respectively. Tuning of the amplifier parame ters especially loop gain and selection of the PID parameters were very important and required iterative adjustments.

The interface for the system was implemented using a Galil 1030-motion control computer interface board. A Galil breakout board permits the amplifier and encoded to be easily connected. The steering mechanism received its input from the angle to be moved by two inputs: the angle from the obstacle avoidance and the angle from the vision algorithm. Feedback was provided at a low level by a position encoder and at a high level by the vision and sonar systems.

In the design process an incorrect estimation of the inertial load led to overloading and burning out of the amplifier. As a solution a torque limit was specified in the Galil motion program, which limited the drive torque, current, and voltage su pplied by the amplifier. Other problems faced were setting of appropriate hardware control bias voltages on the amplifier and estimating turning torque. These were solved through experimental methods.

5. CONTROL SYSTEM

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

6. RESULTS OF TESTING

After extensive laboratory testing of individual subsystems an oval outdoor test track was constructed to simulate the contest track with double lines, 4 inches wide spaced 10 feet apart with dashed segments and obstacles. The steering mechanism worke d satisfactorily. Implementing the PID controller variables as obtained from the SIMULINK model gave a stable response with small overshoot.

7. CONCLUSIONS and RECOMMENDATIONS

A computer controlled steering mechanism has been designed, developed and tested. The mechanism is a crank rod. A kinematic analysis was performed to determine the relationship between the linear lead screw displacement and the an gular motion of the steering wheel. This relationship is approximately linear for small angles. A dynamic analysis was performed with the aid of powerful software tools, MATLAB and SIMULINK from the Math Works and the DMC WSDK from Galil. These tools p ermitted a simulation of the control system and permitted several design optimizations for stability and transient response to be determined. Experimental tests were then made to test the simulation and design parameters.

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