An Experimental Skid Steering Mobile Platform using Active Force Control

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Abstract: - This paper deals with the experimental study of a skid steering mobile robot. A mobile robot with four wheel skid steering system was attached to two servo motors controlled by a digital signal processor (DSP). Active force control (AFC) algorithm was embedded into the DSP and data was recorded using serial communication between the DSP and a PC. A custom data acquisition system (DAQ) was also developed to record the data in MATLAB software using Lubin Kerhuel blockset. AFC algorithm creates a force or torque feedback within the dynamic system to allow the compensation of sudden disturbance spike in the dynamic system, before passing the loop to the position and velocity controller. AFC also allows for a faster computational performance by using a fixed estimated inertia matrix $IN$ of the system dynamic instead of the entire system dynamic model. The mobile robot was commanded to make various movements with the position, velocity and acceleration of the mobile robot wheels were recorded from the servo motor encoder. The result from the recorded data provides valuable real time experimental study on the effect of AFC on a four wheel skid steering mobile robot platform.

Key-Words: - Mobile platform, active force control, digital signal processor, skid steering, robust control, torque feedback dynamic

1 Introduction

The work described here is focused on developing an experimental setup of a mobile robot with four wheels skid steering system. The development process can be divided into two categories – hardware and software design. The mobile robot hardware design can be further divided into mechanical and electronic system. The mechanical system is based on skid steering locomotion system. The skid steering is usually common in tracked vehicle such as farm machinery and military tank but wheel skid steering are mechanically easier to construct and more suitable for a mobile platform application. The skid steering however causes some slippage to occur while the mobile robot is turning. This is because all of the wheels were aligned to the longitudinal axis of the mobile robot. The slippage can be difficult to include in the mobile platform kinematic thus predicting the position of the mobile platform just from the movement of the left and right wheel is difficult to achieve. [1-3].

The electronics of the experimental mobile robot consist of a 32 bit digital signal processor (DSP), a servo motor driver for the servo motor, a power circuit system and a communication circuit system. The DSP was program with the AFC algorithm and control the servo motor by sending pulse width modulation (PWM) signal to the servo motor driver. The servo motor was equipped with an encoder which allow for a close loop control of the AFC to be implemented. The power circuit provides power management to all of the electronic and electrical system. The communication circuit manages the communication between the DSP and a PC for data recording [4]. The software design of the mobile robot was develop using MATLAB/Simulink and a Simulink blockset develop by Lubin Kerhuel. The MATLAB/Simulink was used to record data from the mobile robot DSP. The Lubin Kerhuel blockset was used to develop the AFC algorithm and create an embedded machine code for the mobile manipulator DSP [5-8].

The AFC algorithm embedded into the mobile robot DSP is known for its ability to provide better dynamic control of the mobile robot motors[9, 10]. The servo motor drive provides an actual current sensor reading of the motor and this can be used to provide torque information to the AFC controller. The torque feedback will monitor any sudden spike or disturbance applies to the motor and provides
adjustment accordingly through the closed loop feedback. However the torque feedback needs to be combined with a positioning loop which will provide the position control of the whole system.

The challenges of AFC controller is to relate to the tuning of inertia matrix \( (\mathbf{IN}) \) in the AFC itself. Several online tuning method using neural network, genetic algorithm, fuzzy logic and interactive learning have been introduce \([11-13]\). However implementing these algorithms in an experimental setting can be difficult to achieve. Thus in this paper the IN can be obtained through crude approximation or manual fine-tuning of the parameter by heuristic guess \([14]\). Combining all of the different element of the design stage prove to be a challenging task in developing an experimental mobile robot as mention above. Hopefully further insight can be gain by other from the study of this experimental mobile robot.

2 Hardware Design

The aim of the mobile robot is to be able to mount an articulated three (3) degree of freedom (DOF) arm manipulator on top of it. Thus the mobile robot design needs to be stable and have certain level of maneuverability. The mobile platform also needs to be easy to control as combining an arm manipulator can further complicated the overall control system. The hardware design can be divided into mechanical and electronic design as describe in the following sub sections.

2.1 Mechanical

The mechanical system is based on skid steering locomotion system. Two wheels on the left side of the mobile robot were connected together through belt pulley systems which make them rotate at the same speed. On the right side the same configuration was applied. The mobile robot thus can be control by controlling the speed of the wheels on the left and right side. If the left wheel is turning clockwise and the right wheel is turning anti clockwise then the mobile robot will turn clockwise. If it is the opposite then the mobile robot will turn anti clockwise. Moving the mobile robot forward or backward can be performed by turning both the left and right wheels clockwise or anti clockwise.

A DC servo motor from Maxon motor was connected to the pulley belt gear system on each side of the mobile platform. The motor is couple with a planetary gear head with 111:1 gear ratio. The servo motor operates on 36V power supply and capable of producing 20 watt of power. The maximum available torque when combine with the planetary gear is 6 N/m. The maximum speed of the motor after gear reduction is around 18 rpm and this translate to approximately 0.2 m/s linear velocity of the mobile platform. The DC servo motor is also equipped with an optical encoder which allows for position and speed sensing. The mechanical layout of the mobile platform is shown in Fig. 1.

The pulley belt can be seen connected to the two wheels on the right and left side of the mobile platform. The pulley belt gear is set to 1:1 ratio and should allow for same speed operation for the front and back wheel. Fig. 2 shows the intended application of the mobile platform which is to mount a 3 DOF arm manipulator on top.

![Fig.1: Mechanical layout of the mobile platform](image1.png)

![Fig.2: Mobile platform attached with a 3 D.O.F arm manipulator in (a) 3D model and (b) actual mobile platform](image2.png)

2.2 Electronic

The design of the electronics system of the mobile platform centers on the DSP controller which host the AFC algorithm. The DSP controller used is dsPIC30H30F3014 manufactured by microchip. The DSP controller sends a PWM signal to the servo
motor driver upon receiving input command from a PC. The servo motor driver will amplify the signal and move the servo motor. The motor driver is also connected to the servo motor digital encoder. The motor driver will process the input from the digital encoder and transmit a digital to analogue (DAC) signal of the motor speed back to the DSP controller. This allows for position and speed control of the motor. However to implement AFC there is a requirement to measure the torque of the motor. Fortunately, the motor driver is also equipped with a current sensor that can measure how much current is being supplied to the servo motor. Current can be converted to torque by multiplying it with the motor torque constant. The motor driver will transmit the current reading back to the DSP controller also through DAC signal.

The DSP controller will process the input from the motor driver and implement the AFC algorithm until the desire output of the servo motor meet the intended input of the system. The DSP controller and the motor driver each will require 2 set one for each of the DC servo motor. The input command receive from PC is transmitted through serial communication. A communication board that manages the communication is connected between the DSP controller and PC. Power board circuit will manage the power distribution to all of the electronic system mention above. Power is provided from 3 set of lithium polymer batteries with 11.1V and 5500mAh capacity each. The batteries are connected in series to deliver the 36V needed to drive the DC servo motors. Fig. 3 shows the connection layout between the electronic components of the mobile platform. The actual electronics system of the mobile platform is presented in Fig. 4.

The software design of the mobile platform is centered on programming the AFC algorithm into the DSP controller. The program for the DSP controller needs also to manage communication from PC, DAC measurement from the motor driver and sending PWM signal to the motor driver. Typically all of these programming is perform in c language and then compile using a C compiler available from the DSP controller manufacturer to a hex file or machine code. The hex file can then be uploaded into the DSP controller using a dedicated programmer. Writing the C code can be challenging and requires high level of programming skill to be able to produce a reliable and bug free program.

3 Hardware Programming

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A blockset for MATLAB Simulink and Microchip dsPIC microcontroller develop by Lubin Kerhuel was used to simplify the process of writing a C program for the DSP controller. The blockset can be installed into MATLAB/Simulink and viewed in the Simulink library browser. This blockset was used to help minimize the time needed to create a C program for the DSP controller. The AFC algorithm was design using the MATLAB/Simulink standard block and combine with the blockset from Lubin Kerhuel the program can be compile in MATLAB/Simulink to generate the hex code for the DSP controller.

In the blockset a block call Master can be used to set the proper initialization of the DSP controller. In this setup the microcontroller used is dsPIC30H30F3014 with 20 MIPS and the oscillator set at external crystal. Reading analog signal from the DSP controller ADC function can be perform by using the ADC input peripheral block. The ADC input block will provide an unsigned integer 16 data type output and the control algorithm can then be implemented using standard MATLAB Simulink block. The speed measurement from ADC input block was integrated using the Discrete-time integrator to get the angular position of the DC servo motor. The speed measurement was also differentiated using the discrete derivative block to get the angular acceleration of the motor. The current measurement from the ADC input block can be converted to torque by multiplying with the motor torque constant. Sending PWM signal form the DSP controller to the DC motor driver can be performed using the PWM motor output block. The velocity of the motor can be control by increasing or decreasing the duty cycle value of the PWM motor output block.

Displaying data back into Simulink can be implemented by using the TX Output Multiplexed for MATLAB/LabVIEW block. This block provides easy interface in sending multiple 16 bits data back to the Simulink software from the microcontroller through the serial communication protocol.

Fig. 5: Initialization block for programming DSP controller from Microchip available in the Lubin Kerhuel Blockset

Setting for the UART communication was performed using the UART Configuration block and was set at 115200kb/s, 1 stop byte, no parity and 8 bit data with interrupt routine. Fig. 5 shows the initialization block used in the program. Fig. 6 displays the peripheral I/O block commonly used in the program.

Fig. 6: Commonly used peripheral I/O block from the Lubin Kerhuel Blockset

Fig. 7 presents the block diagram of the DSP controller program in MATLAB/Simulink.

Fig. 7: MATLAB/Simulink block diagram of the mobile manipulator DSP controller

Once the design of the control algorithm was performed in Simulink, the block diagram can be compiled seamlessly by clicking the Generate Code block. A hex file will be generated from the block diagram without writing a single line of C code. After downloading the hex file into the microcontroller, the hardware setup can be run and ready to read the analog signal while sending data to PC. In Simulink, the rs232gui Graphical interface block can be used to record the data send from the microcontroller into MATLAB as standard variable.

4 Controller Design

Fig. 8 shows the block diagram of an AFC controller. \( \theta_{ref} \) is represented by a vector of the generalized coordinate of the mobile platform, i.e., \( (\theta_1, \theta_2) \). Here \( \theta_1 \) and \( \theta_2 \) represent the right and left side wheel positions. \( K_m \) is the motor torque constant for each DC servo motors and \( Q \) is the vector of external disturbances applied to the mobile platform system. One of the advantages of the AFC-based scheme is its ability to reduce the mathematical complexity of the modeled inertia matrix (IN) of the system.
A set of parameters is used to replace the complex mathematical model of the IN. In this study, the IN parameters were estimated using a crude approximation method. The AFC is required to be coupled with a position controller such as PID or resolved acceleration controller (RAC) to provide the position control of the system.

3 Experimental Result
A simple experiment was performed to test the capability of the mobile platform. The mobile platform was commanded to move forward and backward in a straight line by moving the right and left wheel 450° clockwise and then back to 0° anti-clockwise. The results of these movements were recorded into the MATLAB software and were presented in Fig. 9. The performance of the controller can be seen that the first 30 second of the experiment the controller was having problems reaching the desired position of 450° and 0°. The right DC motor can be seen overshooting the 450° and 0° target and the left DC motor was undershooting the 450° and 0° target. This result was believed to be cause by slippage between the wheel and the ground floor at the start of the mobile platform movement.

The AFC controller tries to compensate such slippage which cause the under and overshooting of the DC motors. However after 30 second the controller was able to reach the desired target as the traction of the mobile platform continue to improve. As mentioned in the section 1 (Introduction), four wheel skid steering can cause slippage to occur more often than the mobile platform using other type of driving system.

![Fig. 8: AFC controller](image)

![Fig. 9: Position of right and left wheel recorded from the motor encoder](image)

![Fig. 10: Left and right wheel speed (a) and acceleration (b) recorded from the DC motor encoder](image)

The speed and acceleration of the DC motor was also recorded and presented in Fig. 10. The speed and acceleration represent the actual speed $\dot{\theta}_{act}$ and the actual acceleration $\ddot{\theta}_{act}$ in the AFC block diagram from Fig. 8. The torque of the DC motor for the mobile platform is shown in Fig. 11.
The measurement shows that the torque increases dramatically as the motor starts to move as expected of any motor control system. The value gradually decreases as the motor approaches its desired position.

4 Conclusion
In this paper, an experimental study on the application of AFC controller to a four wheel skid steering mobile platform was presented. The development of the mechanical system using the pulley belt connecting the left and right side of the wheel allows for skid steering to be achieve. The electronic hardware with an embedded AFC controller program into a DSP controller successfully manages the control aspect of the mobile platform. Software development using the MATLAB/Simulink combine with Lubin Kerhuel Blockset allow for faster design process of the mobile platform. The result from the experimental study shows promising capability of the mobile platform.

References: