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Fuzzy Control of Robotic Arms with Mine Detection GPR Sensor for Unmanned Mission Application on Undulated Terrain

N.Seetharaman[1], R.Sivaramakrishnan[2]

[1, 2]Department of Production Technology,
MIT Campus, Anna University, Chennai, India.

Abstract

Unmanned Ground Vehicle on a tracked platform is a remote vehicle that is controlled by a human operator from a base vehicle through RF wireless communication links. Unmanned Ground Vehicles (UGV) play vital roles to save the precious armed personnel life and promises to increase the effectiveness of the armed forces while reducing the exposure of personnel to dangerous battlefield environments. They intend to be deployed for carrying out mission like detection of buried landmines. They have an inherent potential to work as an effective force multiplier in future warfare scenarios. The mine detection sensor Ground Penetrating Radar GPR is attached at the front end of the vehicle with the help of the 5 DOF robotic manipulator arms in order detect the mines ahead of the UGV passing on it. The GPR will continuously scan the area in front of the UGV. During the mission mobile platform encounters disturbances due to surface unevenness and undulations, which results disturbances in orientation of the vehicle and the GPR. Main purpose of this work is to ensure the desired orientation of GPR irrespective of surface undulations. This has to be achieved by closed loop control of the respective manipulator joints with accelerometer as feedback sensor. For controlling process, FUZZY control logic is used for minimizing the pitch and roll error. This algorithm design is implemented using Matlab/Simulink.

Keywords: Accelerometer, Fuzzy logic, BLDC, GPR, unmanned ground vehicle, robotic arm

1. Introduction

More than 100 million land mines are under the ground all over the globe. These mines not only disturb the economic development of mine-buried nations, but also injure or kill more than 2000 people a month. As a result, the detection and removal of landmines has become a global emergency. The current method of removing mines manually is costly and dangerous. Moreover, removal of all mines by this method would require several hundred years. Hence, it has become inevitable and essential to design and develop unmanned system to carry out this mission.

An unmanned tracked vehicle is designed and developed to carry out the land mine detection as the prime role which can also be used for mine clearing operation. This UGV is realized by converting manned tracked platform by implementing Drive by Wire system, teleoperation module with vehicle perception, localization and obstacle avoidance systems. After successful unmanned operation of the vehicle it has been integrated with land mine detection system. Mine detection system comprises of primary mine detection sensors, robotic manipulator arms with multiple degree of freedom to carry and deploy the sensors, and control system to maneuver the robotic arm. The terrain condition in which the mission to be carried out is unstructured, uneven and undulated in nature. To accomplish the mine detection role Ground Penetrating Radar (GPR) is used as the primary sensor which is integrated to the UGV by means of robotic manipulator arms. It has become essential to develop a robust and dynamic control scheme to ensure the least error in the position and orientation accuracy of the GPR when the UGV is moving on the undulated terrain during the scanning operation.

The roll and pitch control of the GPR has been addressed in this work by means of fuzzy logic control of three motors, viz one for pitch at center of the radar and two of them in linear actuators.

2. UNMANNED TRACKED GROUND VEHICLE

2.1 Methodology

There are two serial arm manipulator fitted in front of the unmanned tracked vehicle. The remote vehicle is controlled from a base vehicle through wireless LAN. The manipulator arms will carry the GPR sensor to detect the buried object under the ground is also remotely operated. But the closed loop control of the end effectors position has to be carried out by an electronic controller system. The suitable control loop to carry out the position and orientation control based on the signals from the onboard sensors like ultrasonic distance sensors, Inertial Measurement Unit and array of accelerometer will reside in the embedded controller. Each arm has five degree of freedom such as base turret twist (T), back arm rotation (R), fore arm rotation (R), fore arm linear actuation (L) and rotation of end effectors (R). The configuration of this arm is TRRLR and is represented in Figure.1

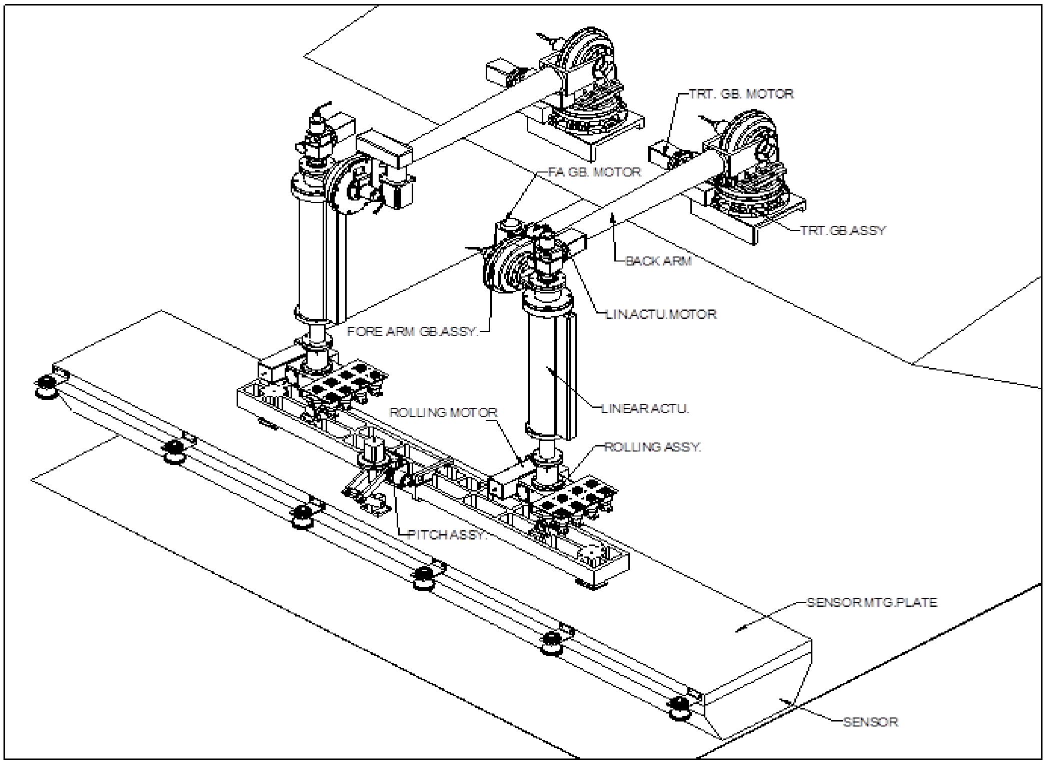
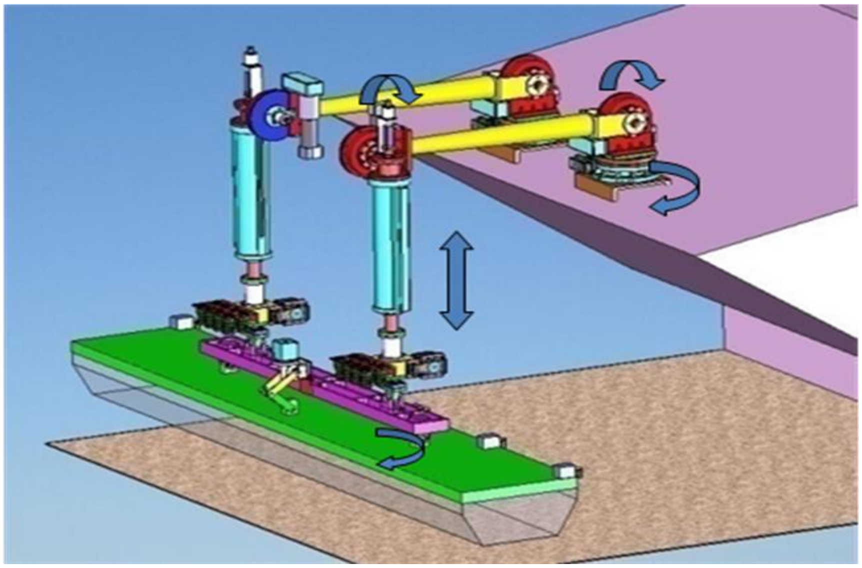


Figure 1 TRRLR mobile manipulator arms with sensor

2.2. ALLOWABLE TILT ANGLE OF GPR

The desired orientation and position of GPR is ensured by means of angular control of individual or combination of rotary or linear joint motors and feedback onboard sensors. Specifically the roll axis orientation is carried by means of adjusting the travel of the prismatic joints and pitch is by means of centrally fitted motor on the GPR frame.



The linear actuator is capable of increase in length of 1000+400mm. The radar has to maintain 300mm from ground level. During the motion of the unmanned vehicle, due to undulation in the ground surface manually maintaining the 300mm stand off from ground becomes challenging task from the base vehicle. In order to overcome that and to maintain the radar in desired orientation, accelerometer sensor is used to acquired the tilt angle data in respective roll and pitch axes. Tilt angle is measured by allowable deviation range in x axis as -50 to 50mm and -300 to300mm in y axis.

To achieve optimum performance of GPR and to avoid damage of GPR from normal terrain obstruction it is mandatory to maintain the air coupled medium of 300mm clearance from the ground level. If there is any undulation along x and y axis then the radar should be moved up or down. Control of radar orientation along roll axis is done by linear actuator which consists of two BLDC (Brushless DC) motor. Control of radar orientation along pitch axis is done by the motor in center of the radar.

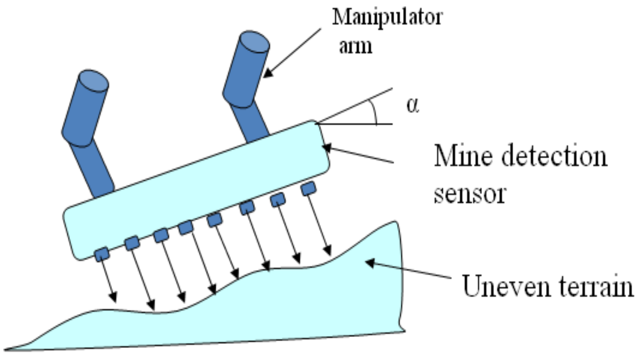


Figure 2 Measurement of unevenness of the ground

Figure 2 shows the angle deviation when the GPR is crossing uneven terrain. There are 6 ultrasonic sensor used to find the change in ground level with respect to GPR. Acoustic sensors data has been used to measure the gap variation and accelerometer data is used to find required tilt angle to orient the GPR with closed loop control to maintain the gap and parallelism to terrain. The simulation for total area coverage by the radar due to change in surface is shown in Figure 3. Here the tilt angle is decided as 0 to 90 degree for y axis and -45 to 45 degree along x axis. The graph is plotted with radar dimensions of length 3400mm, height 200mm and width 500mm.

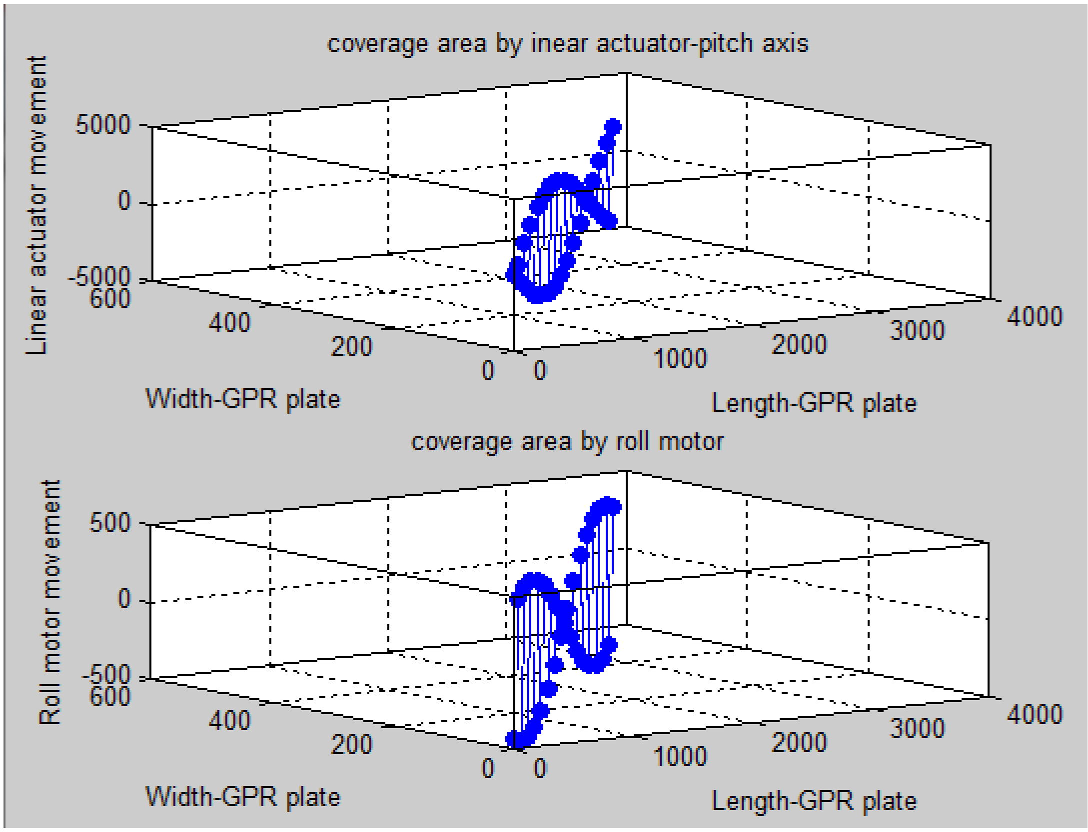


Figure 3 simulation of total area covered by undulation

In this graph, y axis is taken as length of the radar, x axis is taken as linear actuator movement and z axis taken along in width of the radar. The graph is plotted with the following calculation ie., i varies from 0 to 90 degree and j varies from -45 to 45 degree

Linear = (3400)*sin(i) --(1)

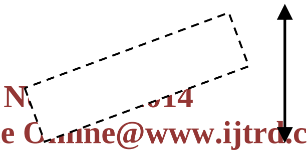
Roll = (500)*sin(j) --(2)

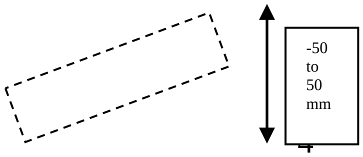
The equation (1) and (2) is obtained by using Pythagoras theorem. The value of i is defined by assumption of allowable moments along y axis with height and length is taken as opposite and adjacent sides for the resultant linear movement. Then the value of j is defined by assumption of radar movement along x axis and with width and height is taken as opposite and hypotenuse sides for the resultant roll movement. This tilted angle is given to Fuzzy Controller and the corresponding motor is driven in clockwise and also anticlockwise direction.

3. ANALYSIS

3.1 Accelerometer and onboard sensors:

ADXL335 is a complete 3-axis acceleration measurement system, the Accelerometer which is used has inbuilt gyroscope module. The ADXL335 has a measurement range of ±3 *g* minimum. Predominately accelerometer data from this IMU is used for fuzzy controller. Pitch and roll is controlled by X and Y axis. The onboard sensors will give the deviation of axis along x and y axis.





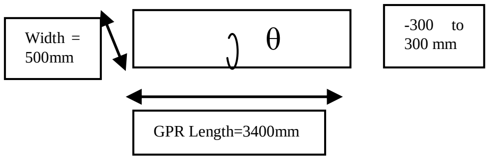


Figure 4 Pitch errors due to undulation

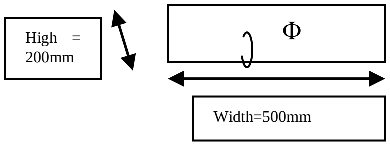


Figure 5 Roll errors due to undulation

Figure 4 shows the pitch error which is considered to be -300 to 300 mm along x axis. Black line shows the initial stage of GPR in even surface and dotted lines shows the deviation in radar when it crosses undulation. This measurement is taken along the front view of vehicle. Here, the range of ΔX is varies from -300 to 300mm instead of onboard sensors. The theoretical calculation is done by taking length of GPR as hypotenuse and -300 to 300 mm variations as opposite value, sine of θ is calculated.

The value of ΔX and ΔY are calculate as below

$$\Delta X = 3400 \sin \theta \qquad \text{--(3)}$$

$$\Delta Y = 500 \sin \Phi \qquad \text{--(4)}$$

Here ΔY is the range between -50 to 50 mm instead of onboard sensors. Black line shows the initial stage of GPR in even surface and dotted lines shows the deviation in radar when it crosses undulation. The theoretical calculation is done by taking width of GPR as hypotenuse and -50 to 50 mm variations as opposite value, sine of θ is calculated.

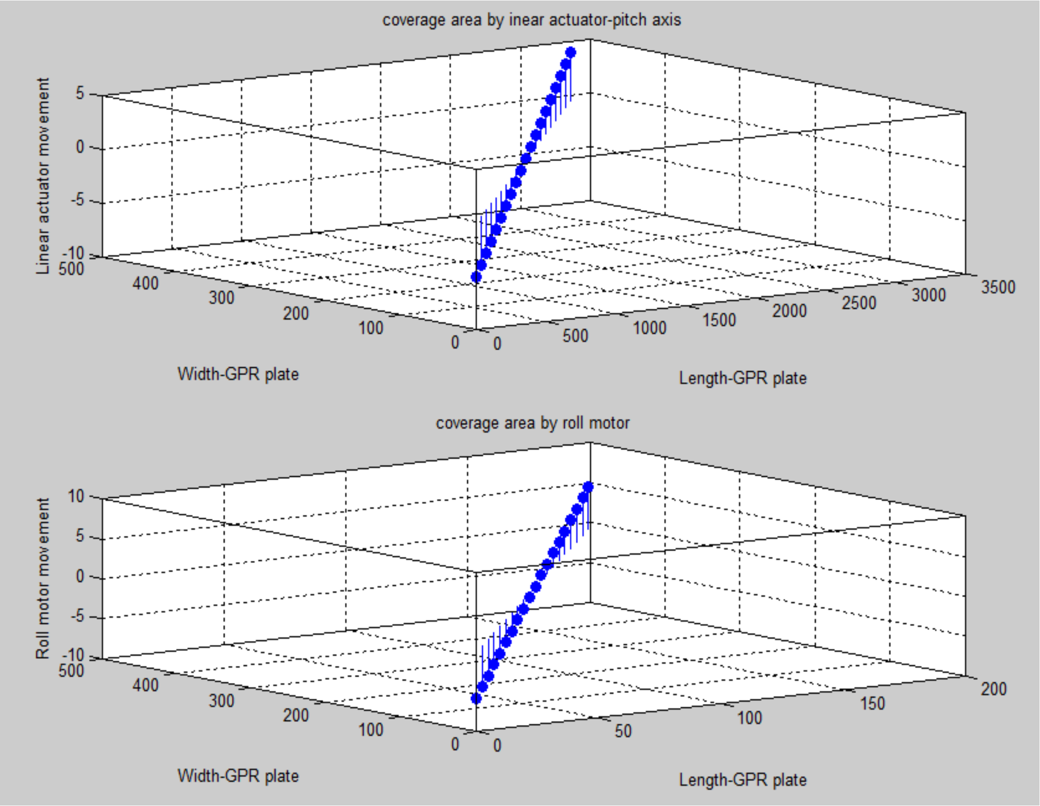


Figure 6 simulation for specified path range

Inverse of θ and Φ are found using the given values as shown in Figure 6. With the help of equation (3) and (4), the graph is plotted.in this graph, for the selected range of ΔX , ΔY value, the tilt angle value is calculated. This is the theoretical tilt angle value without onboard sensors like ultrasonics. The graph shows linear variations for each and every value.

3.2 Simulink Model for Controlling Process

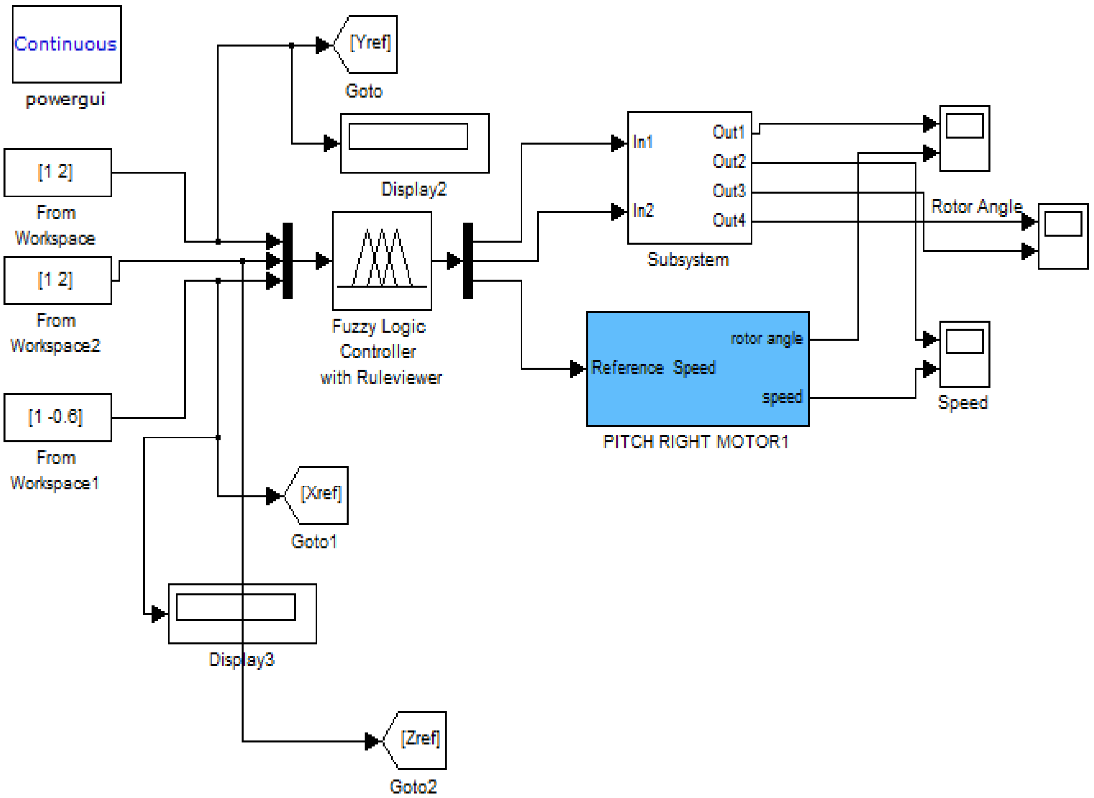
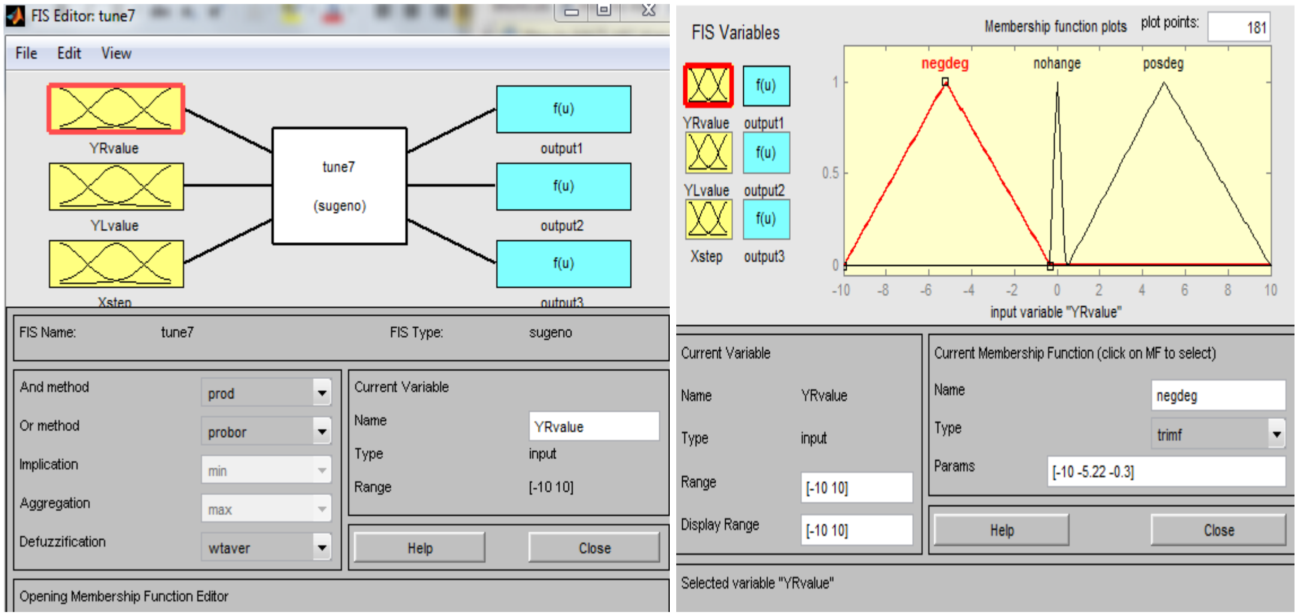


Figure 7 Simulink model for maintain GPR during undulation

The Simulink model consists of input, control and output unit. Here the input unit consists of the data from the workspace. The data which we entered is taken from the equation of (1) and (2). The control unit is done by Fuzzy logic and the output unit is the BLDC motor which runs in the speed of 3000 rpm. The BLDC motor is controlled by PWM (Pulse Width Modulation) signal. In fuzzy logic, the tilt angle which we calculated from equation (3) and (4) is given as input. The motor which taken for the design is Permanent Magnet Synchronous Motor.

3.3 Fuzzy Controller

Fuzzy logic is a mathematical approach which is able to identify the non linear relationships between input and output data sets. Fuzzy logic can be used in any decision making process such as signal processing or data analysis. Here, three dimensional accelerometer data is used as input data for the fuzzy controller. The input unit of the fuzzy Left, Right linear motor and one more BLDC motor which is placed in center of radar. The accelerometer data along X and Y axis is given as input to the fuzzy unit.



FIS Name: tune7
FIS Type: sugeno
And method: prod
Or method: probor
Implication: min
Aggregation: max
Defuzzification: wtaver
Current Variable
Name: YRvalue
Type: input
Range: [-10 10]
Opening Membership Function Editor

plot points: 181
Current Variable
Name: YRvalue
Type: input
Range: [-10 10]
Display Range: [-10 10]
Current Membership Function (click on MF to select)
Name: negdeg
Type: trimf
Params: [-10 -5.22 -0.3]
Selected variable "YRvalue"

Figure 8 & 9 Fuzzy model for tuning system & input model

Figure 8 shows the fuzzy model for the system. It consists of 3 input and three output module to control three motors. The output is given as motor speed parameters.

Fuzzy rules,

(i) If the accelerometer reading is negative in y axis then pitch motor in right side is actuated in anticlockwise direction if distance between ground surface is less than 300mm.

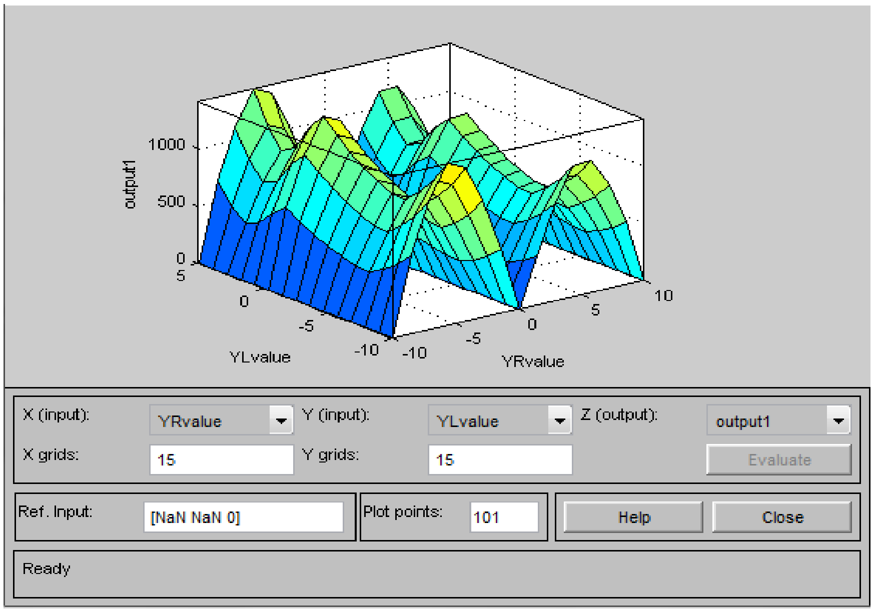
(ii) If the accelerometer reading is negative in y axis then pitch motor in left side is actuated in clockwise direction if distance between ground surface is greater than 300mm.

(iii) If the accelerometer reading is positive in y axis then pitch motor in left side is actuated in anticlockwise direction if distance between ground surface is less than 300mm.

(iv) If the accelerometer reading is positive in y axis then pitch motor in right side is actuated in clockwise direction if distance between ground surface is greater than 300mm.

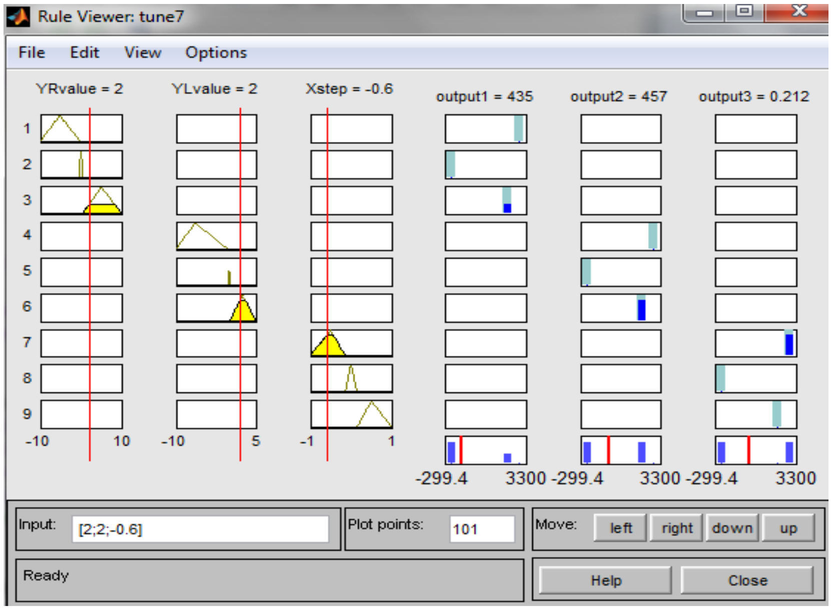
(v) If the accelerometer reading is negative in x axis then roll motor is actuated in anticlockwise direction if distance between ground surface is less than 300mm.

(vi) If the accelerometer reading is positive in x axis then roll motor is actuated in clockwise direction if distance between ground surface is greater than 300mm.



X (input): YRvalue
Y (input): YLvalue
Z (output): output1
X grids: 15
Y grids: 15
Ref. Input: [NaN NaN 0]
Plot points: 101
Ready

Figure10 Surface view



YRvalue = 2
YLvalue = 2
Xstep = -0.6
output1 = 435
output2 = 457
output3 = 0.212
Input: [2;2;-0.6]
Plot points: 101
Ready

Figure11 Rule Viewer

Figure 10 and 11 shows the surface view of the fuzzy model. Here, y axis left motor and right motor tilt angle value is set as 2 degree and x axis tilt value is set as -0.5 degree. Output are the reference speed given to the motors. In the surface view, if the angle is -5 degree along X axis means then the X motor in the center of the radar is actuated to clockwise direction. If the ange is -3.5 degree along Y axis and the left sensor is off means then the left motor should be actuated in clockwise direction. The surface view shows the output of rules in 3D view.

3.4 Controlling Motor

The direction of the BLDC motor is controlled inside the decoder block. The decoder block is replaced by clockwise and also anticlockwise direction. Here the simple direction control block is created with the control of signal builder.

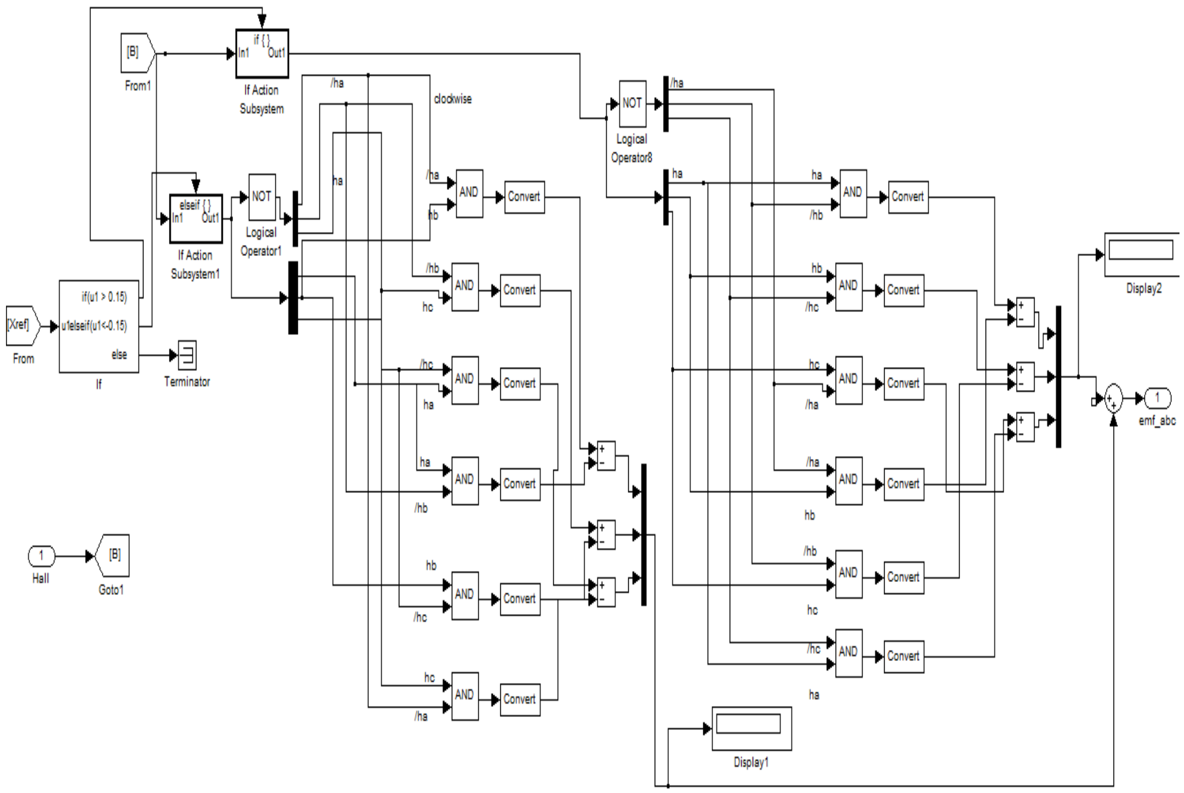


Figure 11 model of motor direction control

The direction of the motor will be controlled according to the tilt angle. If the tilt angle is negative then the motor should rotate in clockwise direction and when the tilt angle is positive then the motor should rotate in anticlockwise direction. If the tilt angle is from -0.2 to 0.2 degree then the motor is static which has no ill effect in the accuracy of control.

4. Real Time Implementation

The real time implementation of accelerometer is done in Simulink. The obtained data is in volts and it's converted to radian and then to degree. For this interfacing, arduinoio software is needed. Load the interfacing file into arduino. Then the interfacing cac be done. In the Simulink block, serial configuration is used to set the baud rate of the arduino board to the matlab and the baud rate is set as 9600. Setup arduino block is used to assign the com port number in which arduino is connected. Then analog pins 0, 1, 2 are used to receive the data along x, y and z axis. These data are given as input for the fuzzy in real time implementation. The intermediate blocks are the conversion of analog values into angle in radian and then to degree.

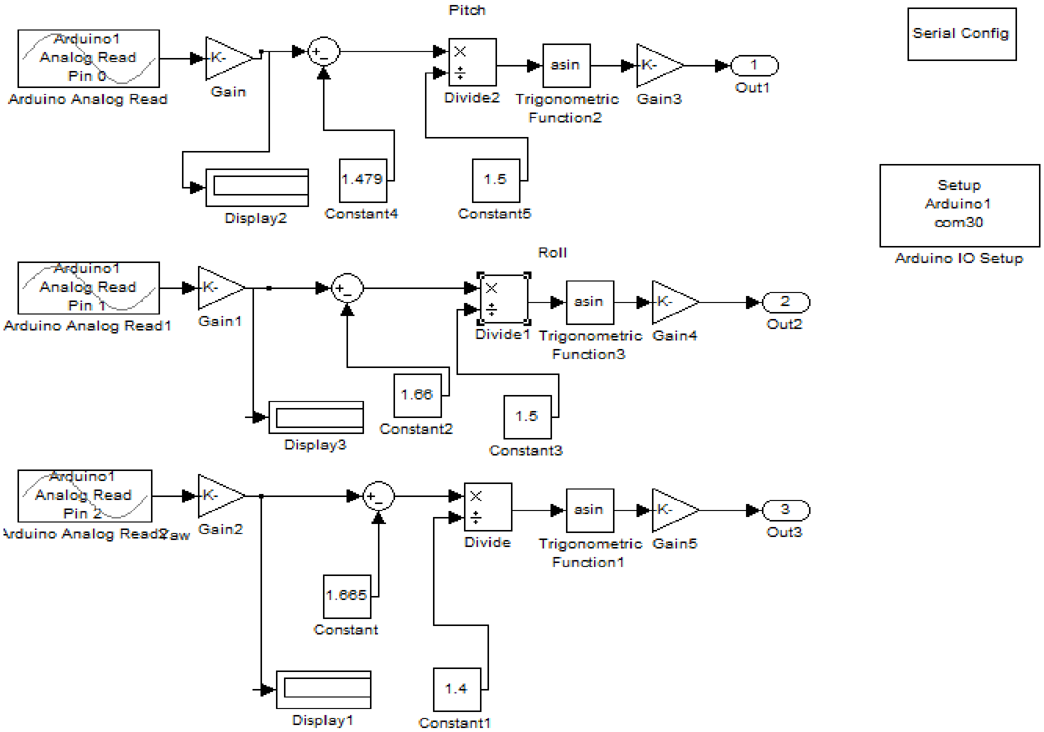


Figure 12 real time model of receiving data from accelerometer

The output of this accelerometer sensor is analog in nature, to digitize these signals and to transmit over wireless medium we are using arduino based ATmega328 micro controller. This micro controller is used at the receiver end to receive data and control the motor speed depending on the received data from fuzzy table.

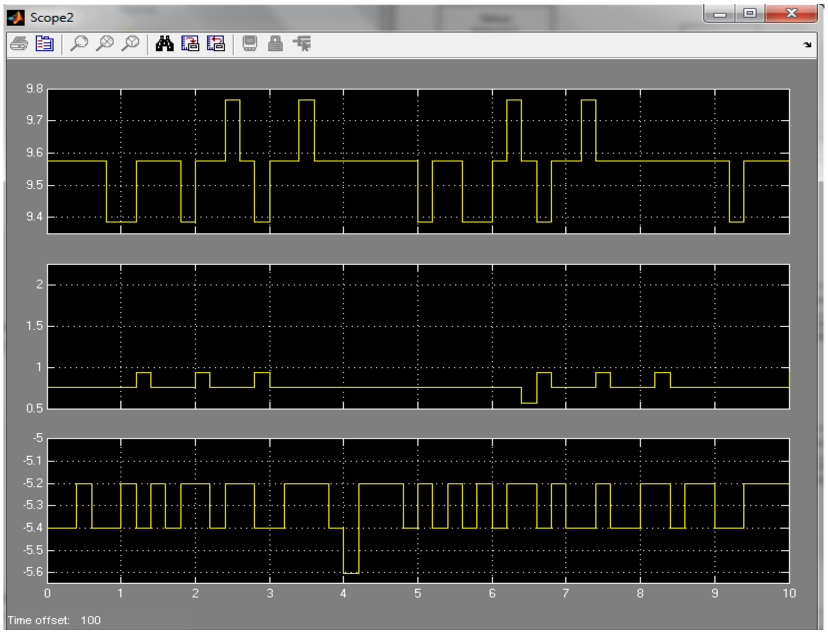


Figure 12 simulation result for accelerometer.

Fig 12 shows the simulation graph of the accelerometer reading. Here top graph shows the x axis tilt angle and middle graph shows the y axis tilt angle and bottom graph shows the z axis tilt angle in degrees along Y axis and time in sec along X axis. In this graph, 1.5v is the reference voltage along x axis which is given in datasheet. Above 1.5v shows the positive tilt values and below the level shows the negative tilt values.

Figure 13 Integrated view of GPR in Robotic arm

Integrated view of GPR sensor with Robotic Manipulator arm on the UGV is shown in Fig.13

5. CONCLUSION

This paper exhaustively addresses the issues related to the control scheme of the mobile manipulator arm used on an unmanned tracked vehicle for carrying out hazardous roles in unstructured terrains. Due to uneven ground surfaces, error in the GPR sensor position and orientation in pitch and roll axes which is of concern has been controlled using fuzzy logic with feedback data of accelerometer. The accelerometer reading is used to tune the joint motors. The linear actuator travel is controlled for GPR roll axis orientation and GPR pitch angle by the centrally positioned motor actuation. PID controller is used to tune the Brushless DC motor. Fine tuning of the accelerometer and motor are done using fuzzy logic. This scheme has the potential to be deployed in a hybrid methodology based controller for the real time robust control of the all the eleven DOF in the manipulators.

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Seetharaman.N. received B.Tech degree in Automobile Engineering from Madras Institute of Technology, Anna University, India in 1987and MTech degree in Modelling and Computer Simulation from University of Poona, India in 1992. Working as Scientist in Defence Research and Development Organization. Awarded Best innovative and futuristic Technology award , 2009 of DRDO. Area of specialization design, development, of systems in Robotics, Unmanned vehicles, Drive By Wire, Mine detection systems,

Dr.R. Sivaramakrishnan–rreceived his B.E. degree in Mechanical Engineering and M.E. in Production Engineering from College of Engineering, Anna University, India, in 1992 and 1994 respectively. He is currently employed as Associate Professor and heading the Division of Mechatronics in the Department of Production Technology, Madras Institute of Technology campus of Anna University. His research interests include Parallel Manipulators, Mechatronics and Computer Integrated Manufacturing