ELECTRONICS DESIGN REPORT
M A R S

Team division :

1) Control system
2) Communication
3) Power electronics

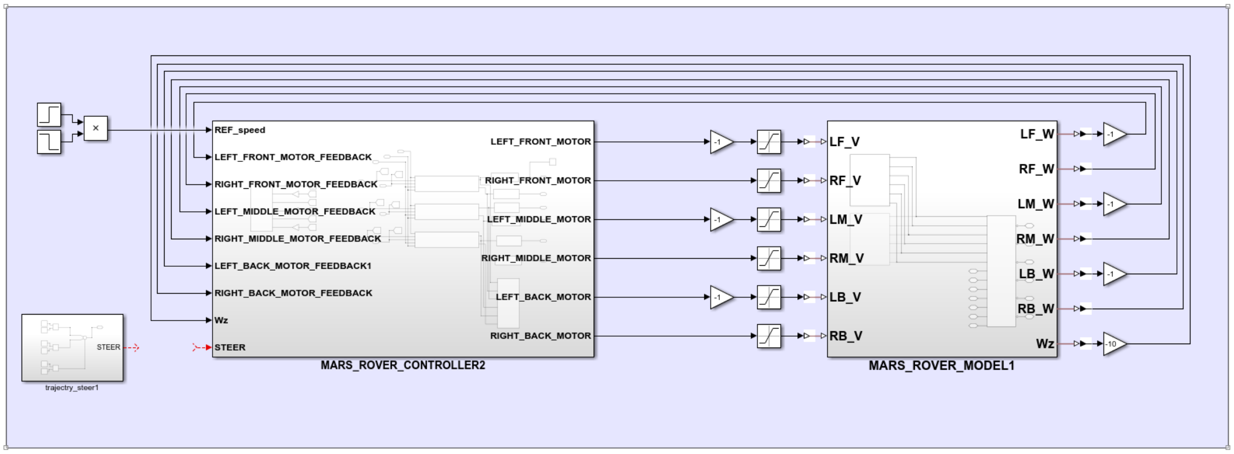
CONTROL SYSTEM

- The aim of the team is to design and build controllers for the rover's robotic arm and mobility unit .
- The mobility controller and manipulator controller are the two main controllers we have to build .

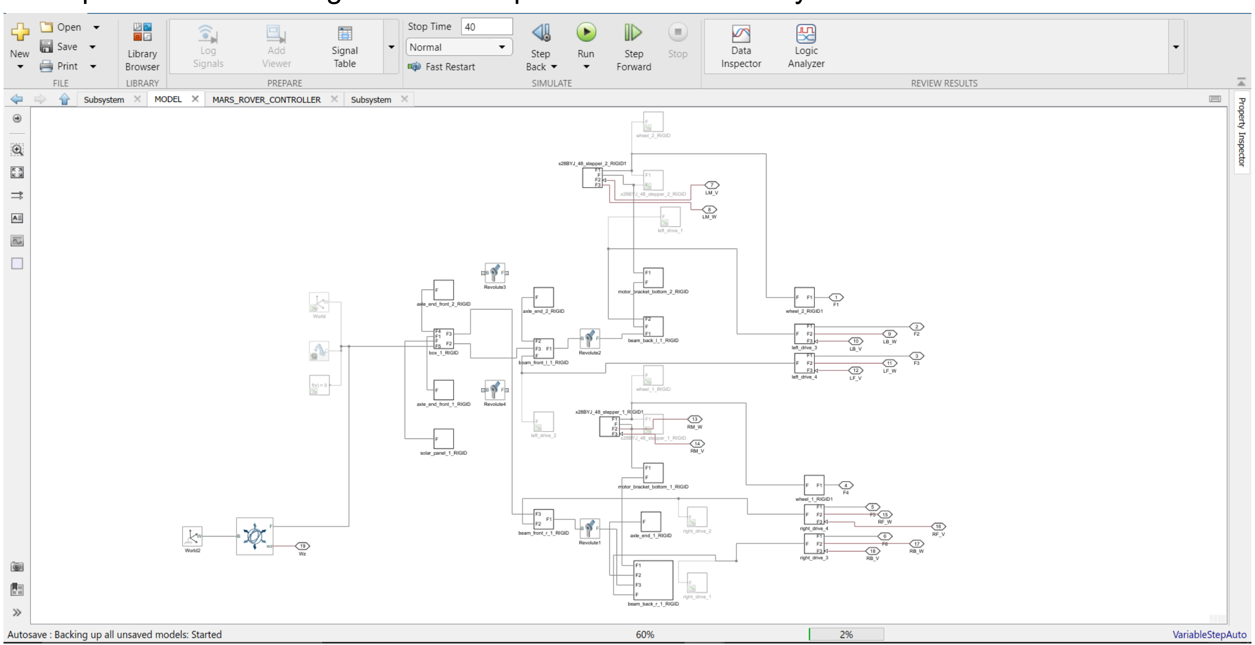
1) MOBILITY CONTROLLER

DESIGN PHASE :

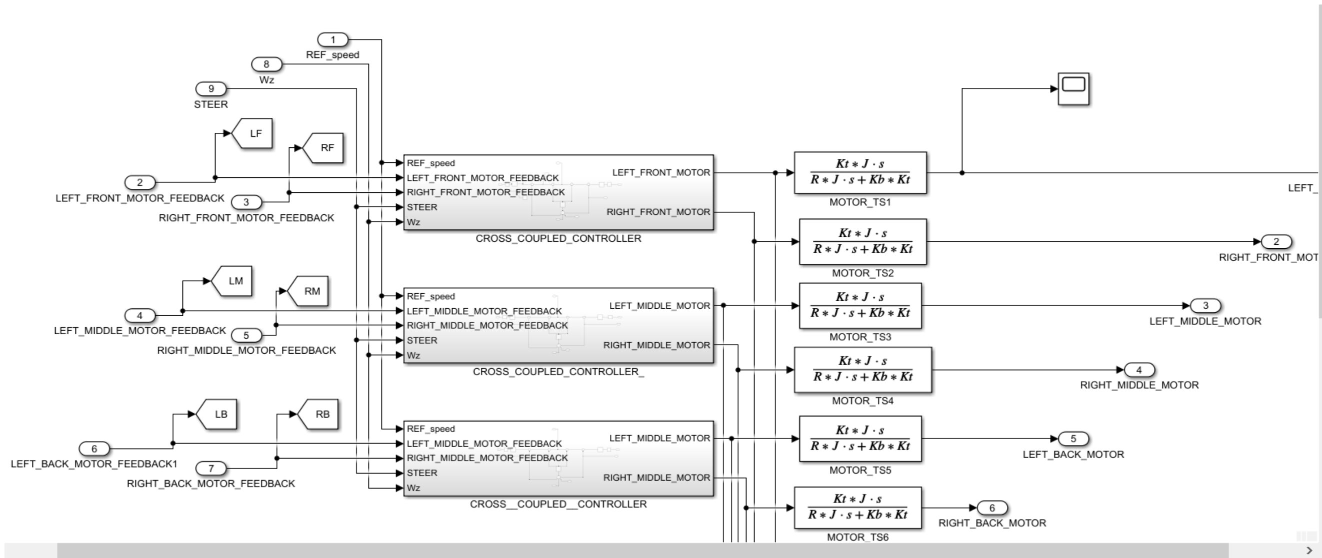
- We started from
- a requirements phase, from the requirements we started building a controller which satisfied the requirements .
- In the design phase we mainly stick to MATLAB for designing and testing the control designs .
- In matlab we started , building the controllers for dc motor speed control to the whole mobility controller .
- Here is the mobility controller model , where the controller will get the feedback from the rover model which is created using multibody .



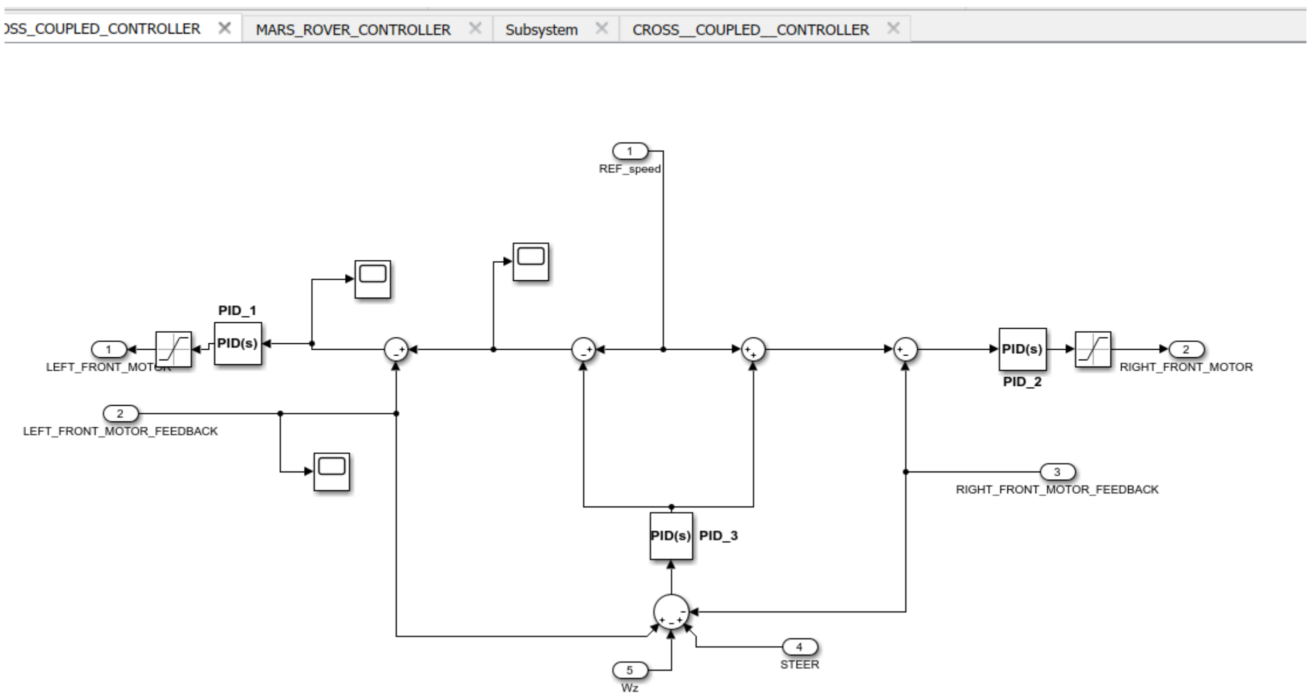
- In matlab , we created an environment using simulink multibody for testing the controller.
- We imported a rover design from onshape to matlab multibody to test the controller.



- This environment used a multibody multiphysics library used to create frictional forces .
- After the environment is created , we can start testing the controller , to control the rover in the environment .
- Our controller design embedded a cross coupled controller for more precise control .



- We designed a controller , which can control two motors, left and right , so these controllers can be used to control all 6 motors of the rover .



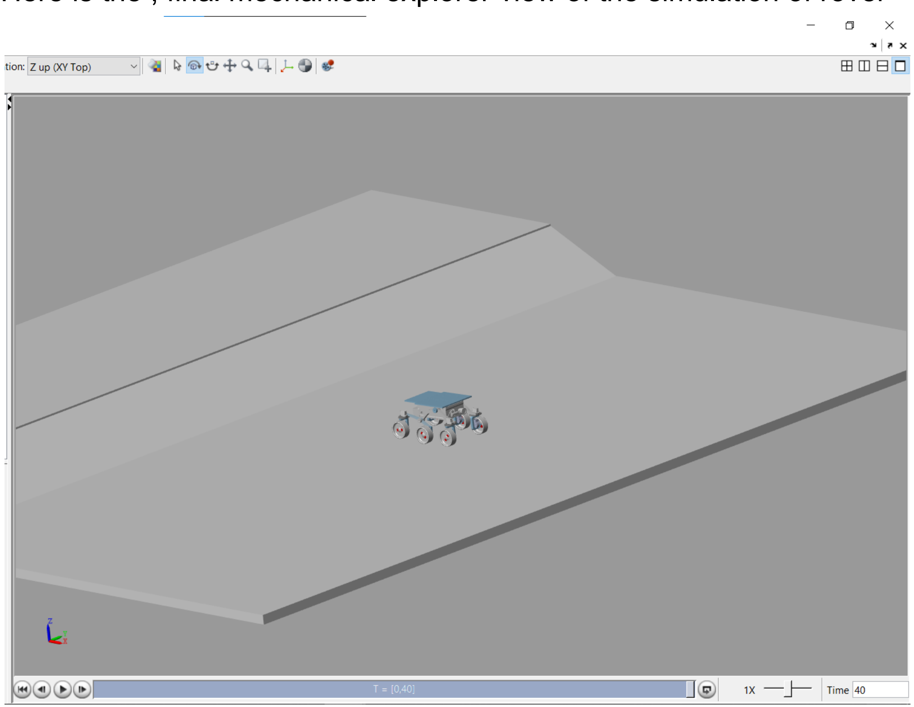
- Here in the cross coupled controller pid_1&2 are responsible for controlling the speed of each motor.
- The pid_3 is responsible for maintaining the relative speed between left and right motors . it is also responsible for eliminating the deflection of the rover from the straight line of motion
- Below is a transfer function of the motor , which gives the torque output from the input voltage, such that we can feed the torque as input to the environment model .

$$\frac{Kt * J \cdot s}{R * J \cdot s + Kb * Kt}$$

Where :

Kt	=	torque constant
J	=	moment of inertia
R	=	resistance of coil
Kb	=	back emf constant

- Here is the , final mechanical explorer view of the simulation of rover



You can find the simulation video in [MARS DRIVE UNDER ELECTRONICS]

- Finally we tested and verified the controller . so now we have to embed this design to the real hardware and software
- So , we planned to use a stm32f103c8 microcontroller for implementing each cross coupled controller , which will control two wheels in the rover . so , total 3 stm's and a nano which is responsible for communicating with three stm's and with the main processor and also provide imu data .

IMPLEMENTATION PHASE :

- In this phase , we are responsible for code the individual controllers so as to act like a controller that we designed .

- So , we splitted this phase into 3
  1) Fetching & decoding the dc motor encoder data, for feedback of speed and position .
  2) Coding the controller according to the design in matlab
  3) Enabling the i2c bus communication for getting commands and data from the master .

  ENCODERS DATA :

  - We are using a quadrature encoder for feedback , where we have to read two signals from the encoder .
  - There will be a lag between two signals which is responsible for detecting the direction of the motor rotation .
  - We are using a stm31 to read the four signals from two encoders .
  - In stm , we are enabling external picchange intercepts , for reading the encoder data .
  - Here is the arduino code for stm.

```
///////////////// READING ENCODER1 DATA USING THE SYSTICK TIMER(MILLIS) ///////////////////

void ENCODER1() {  /// determining value of micros in the time of an interrupt, where micros won't update

  current_state1  = MICROS();
  pulse_time1     = current_state1 - previous_state1;
  previous_state1 = current_state1;
  ////////////////////////////////////////////////////////////////////////////////////////////////////////////////

  if((GPIOB_BASE->IDR >> (uint32_t)13) & 0x1)  DIR1 = 1; // reading PB13 pin  for second encoder signal for direction
  else DIR1 = -1;

  F1 = DIR1*(double(1000000/double(pulse_time1*N*G)));
  E1 = E1 + DIR1;

}
```

- The above code will execute , when a rising edge is detected in the encoder signal .
- Inside the function , we were measuring the time in which interrupt occurred , and stored in current_state_1 ,
- Then , we determined the time period of the encoder pulse to calculate the frequency .
- Every time an edge is detected , the variable E1 increments by 1 .
- We were using a custom made function MICROS() , because if we use micros inbuilt function inside interrupt, NVIC creates a problem , where the millis counter won't update such that we will get the wrong time period .

```
////////////////// MICROS FUNCTION WHICH WORKS INSIDE INTERRUPTS ///////////////////

uint32_t MICROS(void) {

  uint8_t  int_flag;
  int32_t  systick_counter,current_state;

    systick_counter = SYSTICK_BASE->CNT;              // System timer(Systick) base
  if(0b1 & SCB_BASE->ICSR >>26){  //Check if Systick interrupt pending flag is set
    int_flag = 1;
    systick_counter = SYSTICK_BASE->CNT;  //Re-read Systick Timer
  }
  else int_flag = 0;   // Systick interrupt pending flag is not set
current_state = (systick_uptime_millis * 1000) + (SYSTICK_RELOAD_VAL + 1 -
systick_counter) / CYCLES_PER_MICROSECOND;

  if(int_flag) current_state += 1000;

  return current_state;
}
```

For more reference , to understand the above code refer link :
STM32 for Arduino - Connecting an RC receiver should be easy, right?

CONTROLLER CODING IMPLEMENTATION :

- We needed to code the controller design , so we coded the controller in arduino ide for stm32f103 .
- We splitted the coding part into two parts :
  1) Coding the cross coupled motor controller .
     - This code should be implemented in a stm32.
     - This controller code is responsible for controlling the two left & right motors by coding the desired controller according to matlab .
     - We were using PD as a base controller

  2) Coding mobility master controller
     - This master is responsible for running dead reckoning algorithms and fetching data from IMU and the main communication node .
     - We will use an arduino nano for this master .
     - This controller will fetch data from the main communication node via can protocol .

```
//------------------------- CROSS COUPLED CONTROLLER ----------------------------//


// STEERING PID FOR FRONT MOTORS

ERROR_S     = (L_M_VEL - R_M_VEL) - (FEEDBACK_L - FEEDBACK_R) -
FEEDBACK_STEER;
//------------------------------------------------------------------------------------------------------------
S_PID     = PID(ERROR_S, PREV_ERROR_S, &S_I,S_Kp, S_Ki,S_Kd, SAT_S_PID,
S_PID,TIMER1);          // PID FUNCTION USAGE
//------------------------------------------------------------------------------------------------------------
TIMER1      = micros();
SAT_S_PID   = SATURATE(S_PID,-SAT_PID_VALUE,SAT_PID_VALUE);       // SATURATE
THE PID

PREV_ERROR_S = ERROR_S;

// *********************************************************************
```

- The above code is pid_3 which is responsible for maintaining relative speed between the two motors
- This pid feedback also gets the imu data , to avoid the deflection .
- However, the pid_3 controller is also a PI controller .

```
 // PID CONTROLLER FOR LEFT FRONT MOTOR

 ERROR_L      = L_M_VEL - FEEDBACK_L - (S_PID * 0.3);
//-----------------------------------------------------------------------------------------------------------
 L_PID        =
PID(ERROR_L,PREV_ERROR_L,&L_I,L_Kp,L_Ki,L_Kd,SAT_L_PID,L_PID,TIMER2);  // PID
FUNCTION USAGE
//-----------------------------------------------------------------------------------------------------------
 TIMER2       = micros();
 SAT_L_PID    = SATURATE(L_PID,-SAT_PID_VALUE,SAT_PID_VALUE);         // SATURATE
THE PID

 PREV_ERROR_L = ERROR_L;

 // ********************************************************************

 // PID CONTROLLER FOR FRONT RIGHT MOTOR

 ERROR_R      = R_M_VEL - FEEDBACK_R + (S_PID * 0.3);
//-----------------------------------------------------------------------------------------------------------
 R_PID        =
PID(ERROR_R,PREV_ERROR_R,&R_I,R_Kp,R_Ki,R_Kd,SAT_R_PID,R_PID,TIMER3);  // PID
FUNCTION USAGE
//-----------------------------------------------------------------------------------------------------------
 TIMER3       = micros();
 SAT_R_PID    = SATURATE(R_PID,-SAT_PID_VALUE,SAT_PID_VALUE);         // SATURATE
THE PID

 PREV_ERROR_R = ERROR_R;


}
```

- The above code is a PI controller , which is responsible for maintaining a desired set speed .
- We used a custom PID( ) function for implementing the above code .
- This pid function also eliminates the integral windup problem , and saturation problem .

- This controller gets the input data from the main communication node via I2C master arduino nano .

```
//////////////////////////////////////////  PID FUNCTION //////////////////////////////////////
double PID(double ERROR_, double PREV_ERROR_, double *I,byte Kp,byte Ki,byte Kd,double SAT_PID,double PID,uint32_t TIMER){

// calculate the pid according to gains .

double P,D;
double FREQ;

FREQ = micros() - TIMER;

  P = ERROR_ * (double)Kp;              //    finding  proportional
  *I = *I + ERROR_ * (Ki / FREQ);     // finding integral

  *I = *I + 2*(SAT_PID - PID);         // eliminating the integral windup .

  D = (PREV_ERROR_ - ERROR_) * (double)Kd * FREQ;       // finding derivative term

  return (P + *I + D);

}
```

MAIN CONTROLLER CODE :

- This main controller is responsible of doing the following tasks :

    1. Receiving data from the main communication node thusing can protocol and sending it to stm's
    2. Dead reckoning
    3. Collecting data from IMU

1) Receiving data from main communication node

    - We will receive data from a MCP2515 can module
    - We will communicate with spi with the module .

2) Dead reckoning

- This code is responsible for determining the position of the rover with respect to a starting position .
- It will use encoder data and imu data to determine its location

  Below is the corresponding code for dead reckoning

```
/////////////// DETERMINING THE AMOUNT OF DISTANCE THE ROVER HAD MOVED ///////////////
DELTA_D = (DELTA1 + DELTA2 + DELTA3 + DELTA4 + DELTA5 + DELTA6 )/(6*N*G);         //
DETERMINING THE AVERAGE ENCODER COUNT ...
DELTA_D = (DELTA_D + (RPM1 + RPM2 + RPM3 + RPM4 + RPM5 + RPM6)/(F*60*6))/2;     //
APPROXIMATING ROVERS MOTION THROUGH VELOCITY DATA ...
DELTA_D =  DELTA_D*(2*3.1415926*WHEEL_RADIUS);                          // UNITS IN "mm"

///////////////// DETERMINING THE COORDINATES ///////////////////////////////////////
X1 = X1 + DELTA_D*sin(YAW*DEG_RAD)*cos(PITCH*DEG_RAD);         // units in mm
Y1 = Y1 + DELTA_D*cos(YAW*DEG_RAD)*cos(PITCH*DEG_RAD);         // units in mm
```

Here X1 and Y1 are the final coordinates of the rover .

3) Collecting data from IMU
   - We were using an adafruit IMU for getting the whole yaw , pitch and roll orientation data of the rover .

I2C COMMUNICATION :

- Here , we are using 3 stm's for controlling 6 motors , so there is a master controller which is responsible for running dead reckoning algorithms and fetching data from IMU and the main communication node .
- So, we are using I2C communication for sending data from master to the stm's .
- In this communication the stm's are coded as I2C slaves .
- In this communication , we were sending encoder data to master and receive , speed commands for two motos .

THESE ARE FEW DOCS WE PREPARED WHILE DESIGNING PHASE

LINKS :

1) MARS CONTROLL DESIGNS
2) MARS ROVER TEAM
3) Control system design
4) Power modules and devices
5) MARS ROVER STEERING CONTROL DESIGN
6) SENSOR FUSION
7) Motors

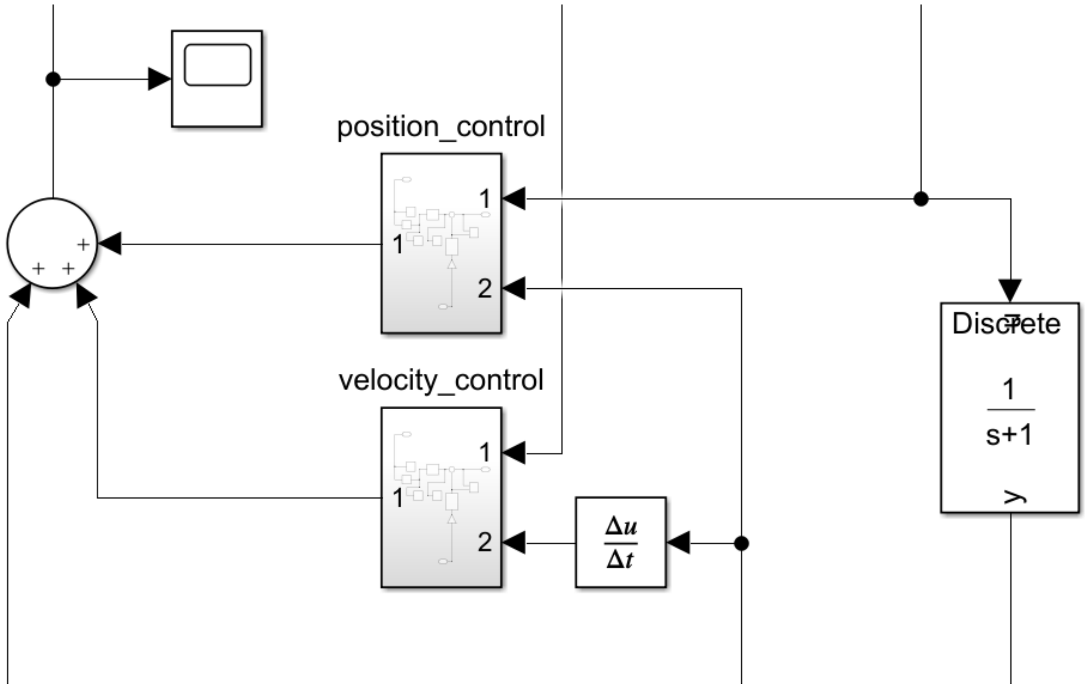
2) ***MANIPULATOR CONTROLLER***

- This manipulator controller's main aim is to position the manipulator joints to its appropriate location .
- So, this controller has two modes :
    1. Getting each joint angle from an external processor (ie.. getting the joint angle data from a rovers on board processor using inverse kinematic algorithm).
    2. (Or) determining its own joint angles from 3 DOF inverse kinematic algorithms running inside the controller (This feature can be used when the processor algorithm fails).

Design phase

- In this phase , our main aim is to design a joint controller in matlab for a manipulator .
- Such that we created a position controller in matlab
- Our main control aim is to develop a current based position controller .
- According to that we developed a controller which controls speed and position

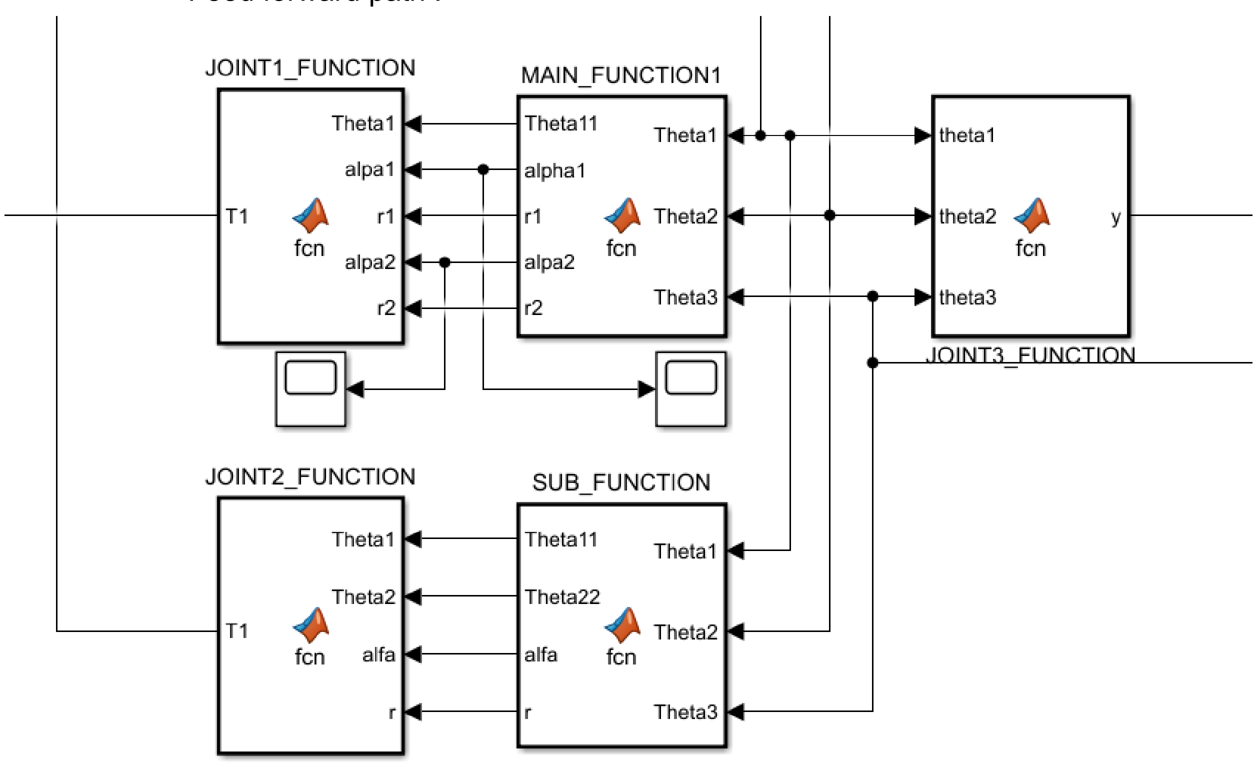
Controller



In the above , the results of the both controllers will together command the joint .

- The third sum is , feedforward path which will provide the appropriate torque to each joint to eliminate the effect due to gravity .

Feed forward path :



These are the matlab code for determining the gravitational torque acting on three joints

MATLAB CODE :

MAIN_FUNCTION CODE :-

```
function [Theta11, alpha1, r1, alpa2, r2]= fcn(Theta1, Theta2, Theta3)

Theta11 = Theta1;
alpha1 = atan((2*sin(Theta1) + sin(Theta1 + Theta2))/(2*cos(Theta1) + cos(Theta1 + Theta2)));
r1 = sqrt((sin(Theta1) + (sin(Theta1 + Theta2))/2)^2  + (cos(Theta1) + (cos(Theta1 + Theta2))/2)^2);
alpa2 = atan((2*sin(Theta1) + 2*sin(Theta1 + Theta2) + sin(Theta1 + Theta2 + Theta3))/(2*cos(Theta1) + 2*cos(Theta1 + Theta2) + cos(Theta1 + Theta2 + Theta3)));
r2 = sqrt((sin(Theta1) + sin(Theta1 + Theta2) + sin(Theta1 + Theta2 + Theta3)/2)^2  +  ( cos(Theta1) + cos(Theta1 + Theta2) + cos(Theta1 + Theta2 + Theta3)/2)^2 );
```

SUB_FUNCTION code :

```
function [Theta11,Theta22,alfa,r]= fcn(Theta1, Theta2, Theta3)

Theta11 = Theta1;
Theta22 = Theta2;
alfa = atan(( 2*sin(Theta1 + Theta2) + sin(Theta1 + Theta2 + Theta3))/( 2*cos(Theta1 + Theta2) + cos(Theta1 + Theta2 + Theta3)));
r = sqrt(( sin(Theta1 + Theta2) + sin(Theta1 + Theta2 + Theta3)/2)^2  +  ( cos(Theta1 + Theta2) + cos(Theta1 + Theta2 + Theta3)/2)^2 );
```

This function takes inputs as angles of three joints , and performs some tegromentric calculations to determine the effective center of mass of the whole three joints .

From that data , we can determine the torques , acting on each joint from manipulator parameters and the data from the main function .

```
function T1 = fcn(Theta1, alpa1,r1, alpa2,r2)
%int m = 1;          % mass of each block m = 1 Kg
%int L = 1;          % length of each block L = 1 m
%int g = 9.80665;    % gravitional const g
%int x1 = sin(Theta1) + (sin(Theta1 + Theta2))/2 ;
%int y1 = cos(Theta1) + (cos(Theta1 + Theta2))/2 ;
%int x2 = sin(Theta1) + sin(Theta1 + Theta2) + sin(Theta1 + Theta2 + Theta3)/2 ;
%int y2 = cos(Theta1) + cos(Theta1 + Theta2) + cos(Theta1 + Theta2 + Theta3)/2 ;

T1 = -9.80665*(sin(Theta1)/2 + r1*sin(alpa1) + r2*sin(alpa2) );
```

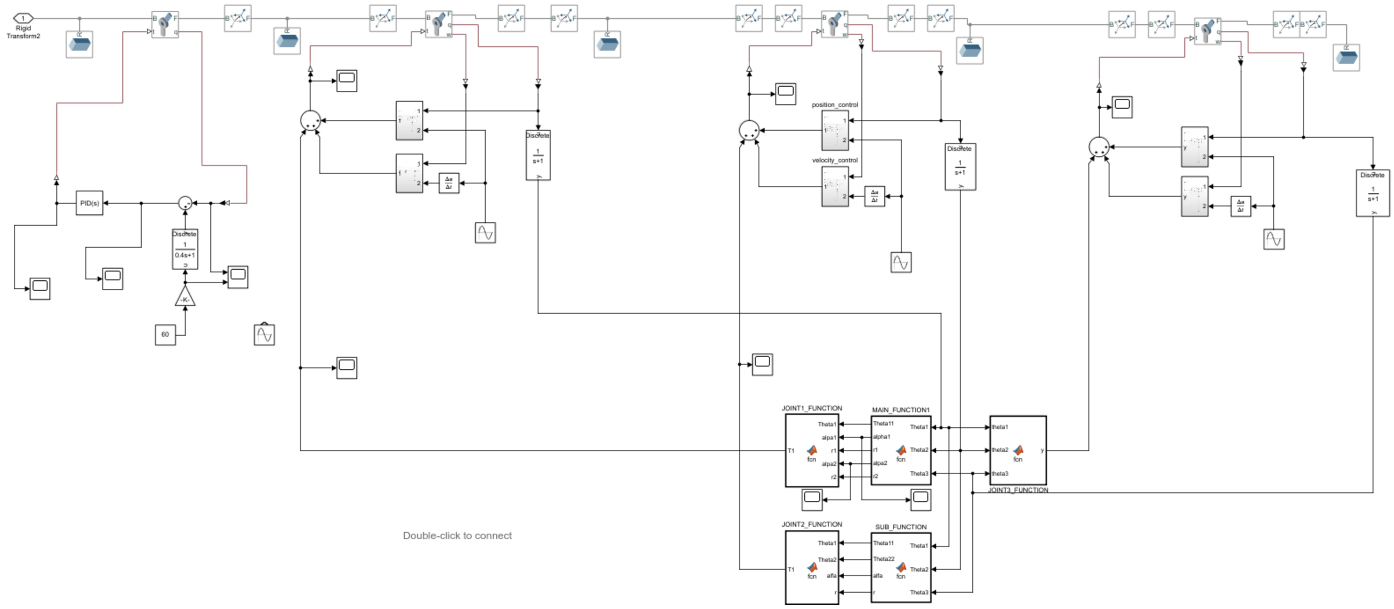
```
function T1 = fcn(Theta1, Theta2,alfa,r)
%int m = 1;          % mass of each block m = 1 Kg
%int L = 1;          % length of each block L = 1 m
%int g = 9.80665;    % gravitional const g
%int x1 = sin(Theta1) + (sin(Theta1 + Theta2))/2 ;
%int y1 = cos(Theta1) + (cos(Theta1 + Theta2))/2 ;
%int x2 = sin(Theta1) + sin(Theta1 + Theta2) + sin(Theta1 + Theta2 + Theta3)/2 ;
%int y2 = cos(Theta1) + cos(Theta1 + Theta2) + cos(Theta1 + Theta2 + Theta3)/2 ;

T1 = -9.80665*(sin(Theta1 + Theta2)/2 + r*sin(alfa) );
```

```
function y = fcn(theta1,theta2,theta3)
y = 1.2*cos(theta1+theta2+theta3)*.5*10;
```

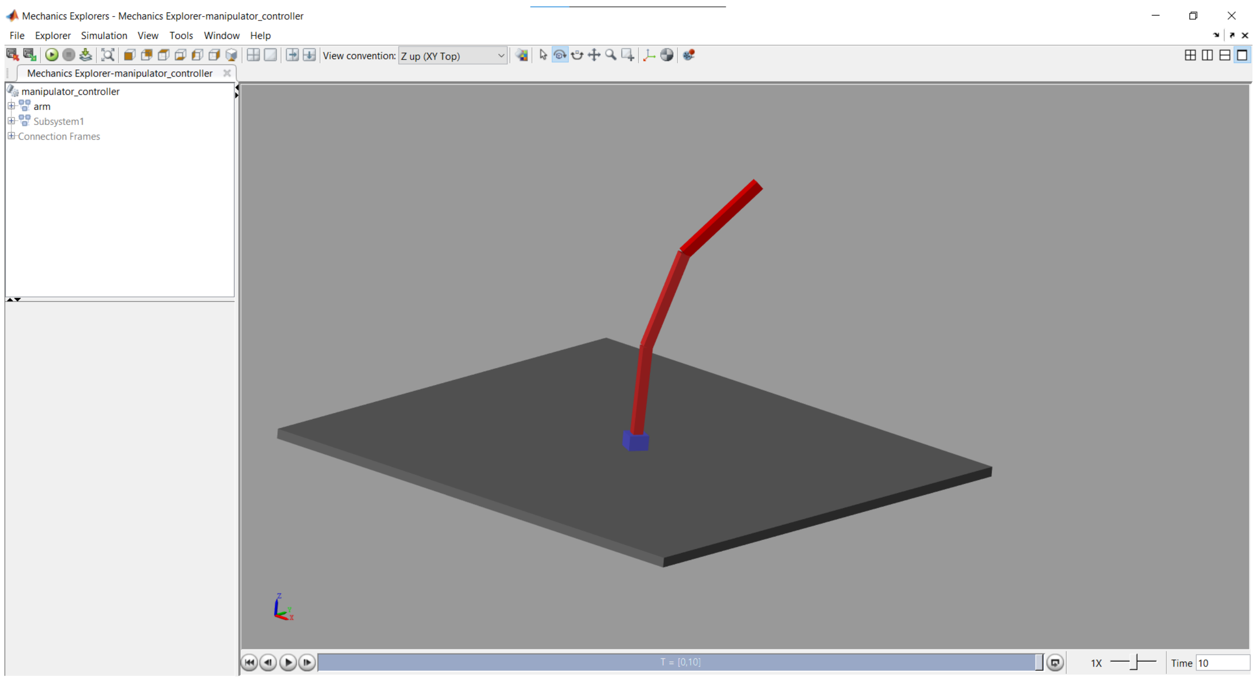
So , these remaining functions are responsible for calculating the torques on each joint .

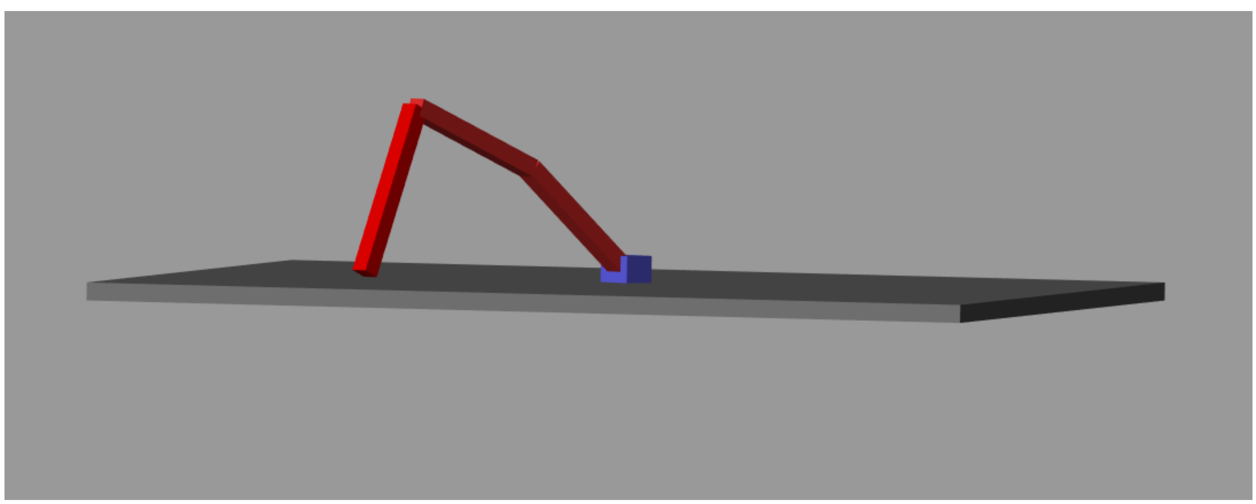
- CREATING THE SIMULATION ENVIRONMENT :

    1. We created a manipulator , using simscape multibody to test our controller with each joint .
    This is the overall view of the whole system .



We simulated using mechanics explorer in matlab ,
This is the final output of the simulation environment of the manipulator which we test .
In the above file each joint had his own controller , to control the manipulator .





IMPLEMENTATION PHASE :

- In this phase we have to create an architecture for the manipulator controller , with appropriate microcontrollers .
- So , our architecture consists of two stm's, one responsible for controlling the end effector and another responsible for controlling below 3 joints .
- And one arduino nano as main controller for both stm's for transferring data from the main communication node .

Stm controller code for end effector :

```
// ----------------------      - FINDING GRIPPER MOTOR TORQUE -------------------------------------
GRIPPER_TORQUE = GRIPPER_FEEDBACK_I*Kt;      // MOTOR TORQUE
//-------------------------------------------------------------------------------------------------------------


// %%%%%%%%% GRIPPER TORQUE CONTROLLER  %%%%%%%%%%%

GRIPPER_ERROR = GRIPPER_SET  - GRIPPER_TORQUE;   // FINDING ERROR

GRIPPER_PID = PID(GRIPPER_ERROR, GRIPPER_PREV_ERROR, &GRIPPER_I,
GRIPPER_Kp, GRIPPER_Ki, GRIPPER_Kd, GRIPPER_SAT_PID, GRIPPER_PID, G_T);  //
CALCULATING PID

GRIPPER_PREV_ERROR = GRIPPER_ERROR;

GRIPPER_SAT_PID  = SATURATE(GRIPPER_PID,-SAT_PID_VALUE,SAT_PID_VALUE);

//%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

G_T = micros();
```

This controller code is responsible for maintaining a constant gripping force on the gripper when activated .
It will get current data from the current sensors for the motor current to determine the torque .

```
// ******************** YAW_ANGULAR_SPEED_PID ************************************

YAW_W_ERROR = YAW_SET_W  - YAW_FEEDBACK_W;

YAW_PID_W = PID( YAW_W_ERROR, YAW_W_PREV_ERROR, &YAW_W_I, YAW_W_Kp,
YAW_W_Ki, YAW_W_Kd,YAW_SAT_PID_W,YAW_PID_W,TIMER_YAW);

YAW_W_PREV_ERROR = YAW_W_ERROR;

YAW_SAT_PID_W = SATURATE(YAW_PID_W,-SAT_PID_VALUE,SAT_PID_VALUE);

// ****************************** YAW_POSITION_PID ************************************

YAW_T_ERROR = (YAW_SET_T  - YAW_FEEDBACK_T)*0.1 - YAW_FEEDBACK_I;

YAW_PID_T = PID( YAW_T_ERROR,YAW_T_PREV_ERROR, &YAW_T_I, YAW_T_Kp,
YAW_T_Ki, YAW_T_Kd,YAW_SAT_PID_T,YAW_PID_T,TIMER_YAW);
```

```
YAW_T_PREV_ERROR = YAW_T_ERROR;

YAW_SAT_PID_T = SATURATE(YAW_PID_T,-SAT_PID_VALUE,SAT_PID_VALUE);

TIMER_YAW = micros();
```

The above controller , had a position controller and a speed controller which is responsible for which appropriately control the joint angle .
The position controller uses current based control .

```
// ********************************* JOINT_5_POSITION_PID ************************************

JOINT_5_T_ERROR = (JOINT_5_SET_T  - JOINT_5_FEEDBACK_T)*0.1 -
JOINT_5_FEEDBACK_I;

JOINT_5_PID = PID( JOINT_5_T_ERROR, JOINT_5_T_PREV_ERROR, &JOINT_5_T_I,
JOINT_5_T_Kp, JOINT_5_T_Ki, JOINT_5_T_Kd,JOINT_5_SAT_PID,JOINT_5_PID,TIMER_5);

JOINT_5_T_PREV_ERROR = JOINT_5_T_ERROR;

JOINT_5_SAT_PID = SATURATE(JOINT_5_PID,-SAT_PID_VALUE,SAT_PID_VALUE);


TIMER_5 = micros();
```

This joint 5 and 4 controller had only a current based position controller , because it will gate the commands from an inverse kinematic controller inside the main controller .

- When the rover is in autonomous mode , we can't give instructions to the manipulator from the base station , so the prosser has to give the data then in this mode each joint controller will implement only the current based position controller .
- When we are controlling the manipulator from the base station, then we only get the speed of each joint rather than position , at this time we will implement the speed controller along with the position controller for three joints .
- But for joints 5, 6 they always implement only with current based position controllers .

INVERSE KINEMATIC CODE :

- This inverse kinematic code is implemented in the main controller

////////////////////// FORWARD KINEMATICS ////////////////////////////

```
X = L1*sin(THETA4) + L2*sin(THETA5) + double(CAN_J_4)/F;
Y = L1*cos(THETA4) + L2*sin(THETA5) + double(CAN_J_5)/F;
```

///////////////////// INVERSE KINEMATICS ///////////////////////////////

```
T2     = acos((X^2 + Y^2 - L1^2 - L2^2)/(2*L1*L2));
J4_SET = T2;
K1     = L1 + L2*cos(T2);
K2     = L2*sin(T2);
T1     = atan2(X/Y) - atan2(K1/K2);
J5_SET = T1;
```

We are only determining the two joint angles from the inverse kinematics.

In forward kinematics , we are updating the X and Y positions from user commands . Then we can apply inverse kinematics to determine the angles .

So the user has control over X , Y , YAW , END EFFECTOR ORIENTATION , JOINT_3 AND GRIPPER .

So , the user can move the manipulator in X and Y direction and he has to control the bottom joint to rotate the manipulator .

User has another three controls to control the end effector orientation and the gripper actions .