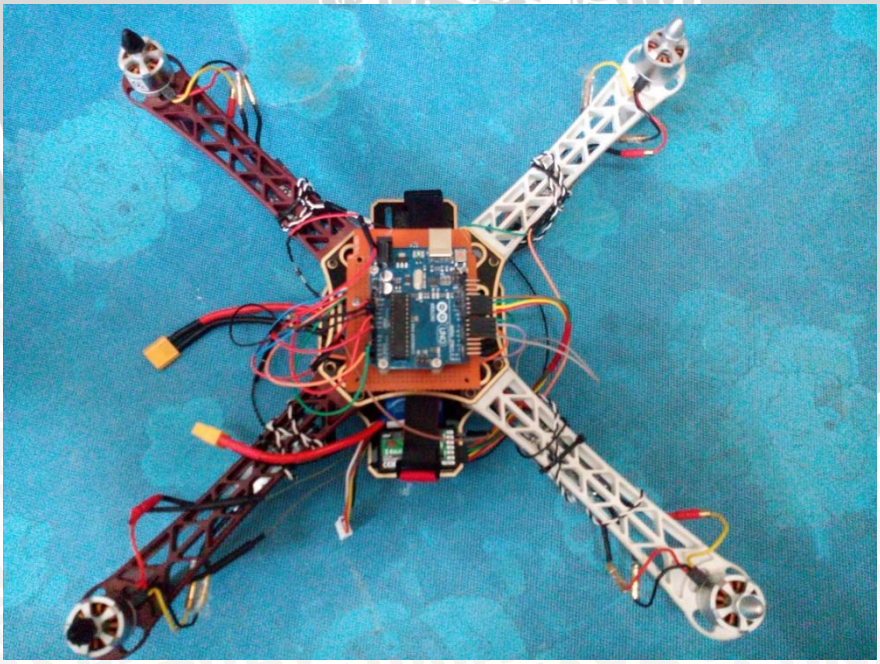
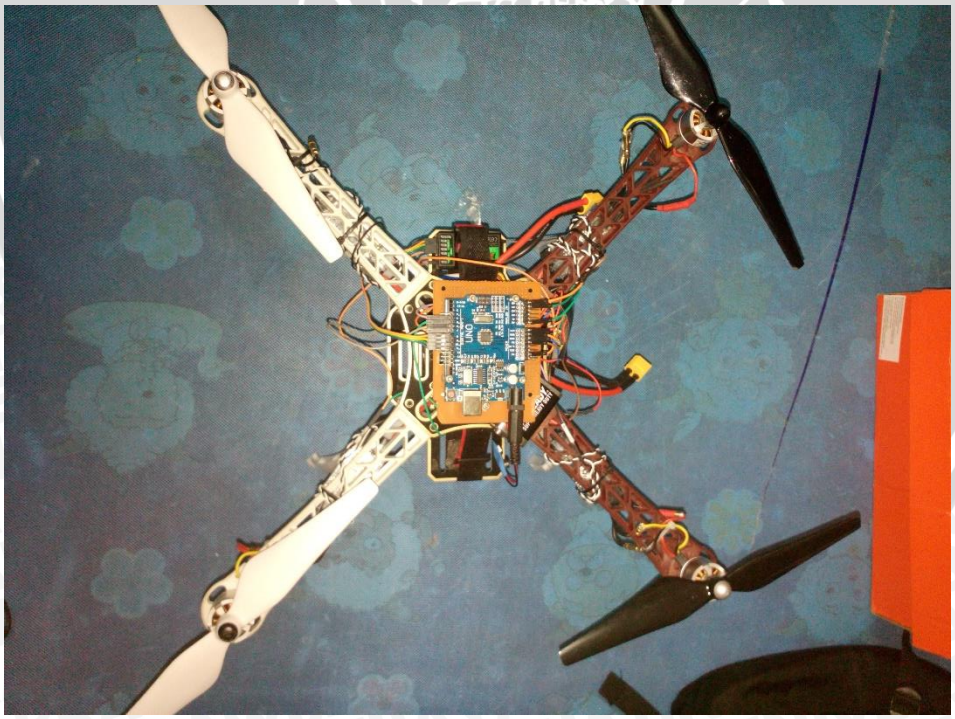
LAMPIRAN I
FOTO ALAT

Gambar alat pada saat motor BLDC berputar



Gambar keseluruhan quadcopter

Gambar quadcopter dan *remote control*



Gambar tampak atas quadcopter dengan baling-baling terpasang

Gambar tampak samping quadcopter dengan baling-baling terpasang

LAMPIRAN II

HASIL PENGUJIAN SENSOR MPU 6050

repository.ub.ac.id
UNIVERSITAS BRAWIJAYA

pitch	roll	yaw		gerak roll				gerak pitch				gerak yaw		
1	-2	0		pitch	roll	yaw		pitch	roll	yaw		pitch	roll	yaw
1	-2	0		1	-2	0		1	-2	0		1	-2	0
1	-2	0		1	-2	0		1	-2	0		1	-2	0
1	-2	0		1	-2	0		2	-2	0		1	-2	0
1	-2	0		1	-2	0		2	-2	0		1	-2	2
1	-2	0		1	-1	0		2	-2	0		1	-2	2
1	-2	0		1	-1	0		2	0	0		1	0	8
1	-2	0		2	-1	0		2	0	0		1	0	19
1	-2	0		2	-1	3		2	0	0		1	0	17
1	-2	0		3	3	15		3	0	0		1	0	23
1	-2	0		4	10	11		10	0	1		1	0	7
1	-2	0		5	13	9		15	1	0		1	1	8
1	-2	0		5	16	8		15	1	0		1	1	12
1	-2	0		5	19	7		19	1	0		1	1	6
1	-2	0		5	22	5		20	0	0		1	0	-1
1	-2	0		6	26	10		20	0	-1		1	0	0
1	-2	0		6	29	0		20	0	13		1	0	0
1	-2	0		6	30	2		21	-2	14		1	-2	0
1	-2	0		6	30	1		28	0	16		1	0	0
1	-2	0		6	31	0		28	0	10		1	0	0
1	-2	0		6	31	0		28	0	5		5	0	0
1	-2	0		6	31	1		28	-1	0		5	-1	0
1	-2	0		6	31	2		29	-1	0		5	-1	0
1	-2	0		6	31	1		29	0	0		5	0	0
1	-2	0		6	31	1		29	-1	0		5	-1	0
1	-2	0		7	32	0		29	1	0		6	1	0
1	-2	0		7	32	1		29	1	0		6	1	0
1	-2	0		7	32	2		29	1	0		6	1	0
1	-2	0		7	32	0		29	1	0		6	1	0
1	-2	0		7	33	0		29	1	0		1	1	0
1	-2	0		7	33	0		1	2	0		1	2	0
1	-2	0		7	33	0		1	2	0		1	2	0
1	-2	0		7	33	0		1	2	0		1	2	0
1	-2	0		7	33	0		1	2	0		1	2	0
1	-2	0		7	33	0		1	2	0		5	2	-2
1	-2	0		7	33	0		-2	1	0		5	1	-6
1	-2	0		7	33	0		-2	1	0		5	1	-29
1	-2	0		7	31	0		-2	1	0		5	1	-26
1	-2	0		7	31	0		-2	0	0		5	0	-11
1	-2	0		6	30	0		-2	1	0		5	1	-9
1	-2	0		6	30	0		-5	0	0		3	0	-7
1	-2	0		6	30	0		-5	1	0		3	1	-33
1	-2	0		5	30	0		-11	1	0		1	1	0
1	-2	0		5	25	0		-11	-1	0		1	-1	0

1	-2	0		5	25	0		-12	-1	0		1	-1	0
1	-2	0		1	18	-13		-20	-1	0		1	-1	0
1	-2	0		1	12	-23		-24	-2	-12		4	-2	-12
1	-2	0		1	7	-17		-24	-2	-15		5	-2	-15
1	-2	0		1	7	-11		-24	-2	-15		5	-2	-15
1	-2	0		-3	-2	-9		-17	-2	-11		5	-2	-11
1	-2	0		-6	-10	-10		-17	-3	-2		5	-3	-2
1	-2	0		-8	-17	-6		-14	-1	0		5	-1	0
1	-2	0		-11	-17	0		-14	0	-2		5	0	-2
1	-2	0		-13	-26	-1		-14	0	0		5	0	0
1	-2	0		-16	-31	-1		-14	0	0		5	0	-2
1	-2	0		-17	-44	-1		-14	0	-1		5	0	-8
1	-2	0		-17	-52	1		-14	-3	1		5	-3	-29
1	-2	0		-17	-60	-1		-15	0	0		1	0	-27
1	-2	0		-18	-60	0		-15	-1	0		1	-1	-23
1	-2	0		-18	-66	0		-15	1	0		1	1	-5
				-18	-66	0		-15	-3	0		1	-3	-12
				-18	-66	0		-15	-3	0		1	-3	-6

LAMPIRAN III
LISTING PROGRAM

repository.ub.ac.id
UNIVERSITAS BRAWIJAYA

PROGRAM UTAMA

```
#include <Wire.h>                    //Include the Wire.h library so we can communicate with the gyro.
#include <EEPROM.h>                  //Include the EEPROM.h library so we can store information onto the
EEPROM

//////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//PID gain and limit settings
//////////////////////////////////////////////////////////////////////////////////////////////////////////////////
float pid_p_gain_roll = 1.3;         //Gain setting for the roll P-controller
float pid_i_gain_roll = 0.04;        //Gain setting for the roll I-controller
float pid_d_gain_roll = 18.0;        //Gain setting for the roll D-controller
int pid_max_roll = 400;              //Maximum output of the PID-controller (+/-)

float pid_p_gain_pitch = pid_p_gain_roll;  //Gain setting for the pitch P-controller.
float pid_i_gain_pitch = pid_i_gain_roll;  //Gain setting for the pitch I-controller.
float pid_d_gain_pitch = pid_d_gain_roll;  //Gain setting for the pitch D-controller.
int pid_max_pitch = pid_max_roll;          //Maximum output of the PID-controller (+/-)

float pid_p_gain_yaw = 4.0;          //Gain setting for the pitch P-controller. //4.0
float pid_i_gain_yaw = 0.02;         //Gain setting for the pitch I-controller. //0.02
float pid_d_gain_yaw = 0.0;          //Gain setting for the pitch D-controller.
int pid_max_yaw = 400;               //Maximum output of the PID-controller (+/-)

boolean auto_level = true;           //Auto level on (true) or off (false)

//////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//Declaring global variables
//////////////////////////////////////////////////////////////////////////////////////////////////////////////////
byte last_channel_1, last_channel_2, last_channel_3, last_channel_4;
byte eeprom_data[36];
byte highByte, lowByte;
int receiver_input_channel_1, receiver_input_channel_2, receiver_input_channel_3,
receiver_input_channel_4;
int counter_channel_1, counter_channel_2, counter_channel_3, counter_channel_4, loop_counter;
int esc_1, esc_2, esc_3, esc_4;
int throttle, battery_voltage;
int cal_int, start, gyro_address;
int receiver_input[5];
int temperature;
int acc_axis[4], gyro_axis[4];
float roll_level_adjust, pitch_level_adjust;

long acc_x, acc_y, acc_z, acc_total_vector;
unsigned long timer_channel_1, timer_channel_2, timer_channel_3, timer_channel_4, esc_timer,
esc_loop_timer;
unsigned long timer_1, timer_2, timer_3, timer_4, current_time;
unsigned long loop_timer;
double gyro_pitch, gyro_roll, gyro_yaw;
double gyro_axis_cal[4];
float pid_error_temp;
float pid_i_mem_roll, pid_roll_setpoint, gyro_roll_input, pid_output_roll, pid_last_roll_d_error;
float pid_i_mem_pitch, pid_pitch_setpoint, gyro_pitch_input, pid_output_pitch, pid_last_pitch_d_error;
float pid_i_mem_yaw, pid_yaw_setpoint, gyro_yaw_input, pid_output_yaw, pid_last_yaw_d_error;
float angle_roll_acc, angle_pitch_acc, angle_pitch, angle_roll;
boolean gyro_angles_set;

//////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//Setup routine
//////////////////////////////////////////////////////////////////////////////////////////////////////////////////
```

```
void setup(){
  //Serial.begin(57600);
  //Copy the EEPROM  data for fast access data.
  for(start = 0; start <= 35; start++)eeprom_data[start] = EEPROM.read(start);
  start = 0;                                                  //Set start back to zero.
  gyro_address = eeprom_data[32];                             //Store the gyro address in the variable.

  Wire.begin();                                               //Start the I2C as master.

  TWBR = 12;                                                  //Set the I2C clock speed to 400kHz.

  //Arduino (Atmega) pins default to inputs, so they don't need to be explicitly  declared as inputs.
  DDRD |= B11110000;                                          //Configure digital poort 4, 5, 6 and 7 as output.
  DDRB |= B00110000;                                          //Configure digital poort 12 and 13 as output.

  //Use the led on the Arduino for startup indication.
  digitalWrite(12,HIGH);                                      //Turn on the warning led.

  //Check the EEPROM  signature to make sure that the setup program is executed.
  while(eeprom_data[33] != 'J' || eeprom_data[34] != 'M' || eeprom_data[35] != 'B')delay(10);

  //The flight controller needs the MPU-6050  with gyro and accelerometer
  //If setup is completed without MPU-6050  stop the flight controller program
  if(eeprom_data[31] == 2 || eeprom_data[31] == 3)delay(10);

  set_gyro_registers();                                       //Set the specific gyro registers.

  for (cal_int = 0; cal_int < 1250 ; cal_int ++){             //Wait 5 seconds before continuing.
    PORTD |= B11110000;                                       //Set digital poort 4, 5, 6 and 7 high.
    delayMicroseconds(1000);                                  //Wait 1000us.
    PORTD &= B00001111;                                       //Set digital poort 4, 5, 6 and 7 low.
    delayMicroseconds(3000);                                  //Wait 3000us.
  }

  //Let's take multiple  gyro data samples so we can determine the average gyro offset (calibration).
  for (cal_int = 0; cal_int < 2000 ; cal_int ++){             //Take 2000 readings for calibration.
    if(cal_int % 15 == 0)digitalWrite(12, !digitalRead(12));  //Change the led status to indicate
calibration.
    gyro_signalen();                                          //Read the gyro output.
    gyro_axis_cal[1] += gyro_axis[1];                         //Ad roll value to gyro_roll_cal.
    gyro_axis_cal[2] += gyro_axis[2];                         //Ad pitch value to gyro_pitch_cal.
    gyro_axis_cal[3] += gyro_axis[3];                         //Ad yaw value to gyro_yaw_cal.
    //We don't want the esc's to be beeping annoyingly. So let's give them a 1000us puls while calibrating the
gyro.
    PORTD |= B11110000;                                       //Set digital poort 4, 5, 6 and 7 high.
    delayMicroseconds(1000);                                  //Wait 1000us.
    PORTD &= B00001111;                                       //Set digital poort 4, 5, 6 and 7 low.
    delay(3);                                                 //Wait 3 milliseconds before the next loop.
  }
  //Now that we have 2000 measures, we need to devide by 2000 to get the average gyro offset.
  gyro_axis_cal[1] /= 2000;                                   //Divide the roll total by 2000.
  gyro_axis_cal[2] /= 2000;                                   //Divide the pitch total by 2000.
  gyro_axis_cal[3] /= 2000;                                   //Divide the yaw total by 2000.

  PCICR |= (1 << PCIE0);                                      //Set PCIE0 to enable PCMSK0 scan.
  PCMSK0 |= (1 << PCINT0);                                    //Set PCINT0 (digital input 8) to trigger an
interrupt on state change.
  PCMSK0 |= (1 << PCINT1);                                    //Set PCINT1 (digital input 9)to trigger an
interrupt on state change.
```

```
  PCMSK0 |= (1 << PCINT2);                                    //Set PCINT2 (digital input 10)to trigger an
interrupt on state change.
  PCMSK0 |= (1 << PCINT3);                                    //Set PCINT3 (digital input 11)to trigger an
interrupt on state change.

  //Wait until the receiver is active and the throtle is set to the lower position.
  while(receiver_input_channel_3 < 990 || receiver_input_channel_3 > 1020 || receiver_input_channel_4 <
1400){
    receiver_input_channel_3 = convert_receiver_channel(3);          //Convert the actual receiver signals
for throttle to the standard 1000 - 2000us
    receiver_input_channel_4 = convert_receiver_channel(4);          //Convert the actual receiver signals
for yaw to the standard 1000 - 2000us
    start ++;                                                 //While waiting increment start whith every loop.
    //We don't want the esc's to be beeping annoyingly. So let's give them a 1000us puls while waiting for the
receiver inputs.
    PORTD |= B11110000;                                       //Set digital poort 4, 5, 6 and 7 high.
    delayMicroseconds(1000);                                  //Wait 1000us.
    PORTD &= B00001111;                                       //Set digital poort 4, 5, 6 and 7 low.
    delay(3);                                                 //Wait 3 milliseconds before the next loop.
    if(start == 125){                                         //Every 125 loops (500ms).
      digitalWrite(12, !digitalRead(12));                     //Change the led status.
      start = 0;                                              //Start again at 0.
    }
  }
  start = 0;                                                  //Set start back to 0.

  //Load the battery voltage to the battery_voltage variable.
  //65 is the voltage compensation for the diode.
  //12.6V equals ~5V @ Analog 0.
  //12.6V equals 1023 analogRead(0).
  //1260 / 1023 = 1.2317.
  //The variable battery_voltage holds 1050 if the battery voltage is 10.5V.
  battery_voltage = (analogRead(0) + 65) * 1.2317;

  loop_timer = micros();                                      //Set the timer for the next loop.

  //When everything is done, turn off the led.
  digitalWrite(12,LOW);                                       //Turn off the warning led.
}
////////////////////////////////////////////////////////////////////////////////////////////////////
//Main program loop
////////////////////////////////////////////////////////////////////////////////////////////////////
void loop(){

  //65.5 = 1 deg/sec (check the datasheet of the MPU-6050 for more information).
  gyro_roll_input = (gyro_roll_input * 0.7) + ((gyro_roll / 65.5) * 0.3);   //Gyro pid input is deg/sec.
  gyro_pitch_input = (gyro_pitch_input * 0.7) + ((gyro_pitch / 65.5) * 0.3);//Gyro pid input is deg/sec.
  gyro_yaw_input = (gyro_yaw_input * 0.7) + ((gyro_yaw / 65.5) * 0.3);      //Gyro pid input is deg/sec.


  ////////////////////////////////////////////////////////////////////////////////////

  ////////////////////////////////////////////////////////////////////////////////////

  //Gyro angle calculations
  //0.0000611 = 1 / (250Hz / 65.5)
  angle_pitch += gyro_pitch * 0.0000611;                      //Calculate the traveled pitch angle and add
this to the angle_pitch variable.
  angle_roll += gyro_roll * 0.0000611;                        //Calculate the traveled roll angle and add this
to the angle_roll variable.
```

```
  //0.000001066  = 0.0000611  * (3.142(PI)  / 180degr) The Arduino sin function is in radians
  angle_pitch -= angle_roll * sin(gyro_yaw * 0.000001066);                 //If the IMU has yawed transfer the
roll angle to the pitch angel.
  angle_roll += angle_pitch * sin(gyro_yaw * 0.000001066);                 //If the IMU has yawed transfer the
pitch angle to the roll angel.

  //Accelerometer angle calculations
  acc_total_vector = sqrt((acc_x*acc_x)+(acc_y*acc_y)+(acc_z*acc_z));       //Calculate the total
accelerometer vector.

  if(abs(acc_y) < acc_total_vector){                                        //Prevent the asin function to produce a NaN
   angle_pitch_acc = asin((float)acc_y/acc_total_vector)* 57.296;           //Calculate the pitch angle.
  }
  if(abs(acc_x) < acc_total_vector){                                        //Prevent the asin function to produce a NaN
   angle_roll_acc = asin((float)acc_x/acc_total_vector)* -57.296;           //Calculate the roll angle.
  }

  //Place the MPU-6050  spirit level and note the values in the following  two lines  for calibration.
  angle_pitch_acc -= 0.0;                                                   //Accelerometer calibration value for pitch.
  angle_roll_acc -= 0.0;                                                    //Accelerometer calibration value for roll.

  angle_pitch = angle_pitch * 0.9996  + angle_pitch_acc * 0.0004;           //Correct the drift  of the gyro pitch
angle with the accelerometer pitch angle.
  angle_roll = angle_roll * 0.9996  + angle_roll_acc * 0.0004;              //Correct the drift of the gyro roll angle
with the accelerometer roll angle.

  pitch_level_adjust = angle_pitch * 15;                                    //Calculate the pitch angle correction
  roll_level_adjust = angle_roll * 15;                                      //Calculate the roll angle correction

  if(!auto_level){                                                          //If the quadcopter is not in auto-level mode
   pitch_level_adjust = 0;                                                  //Set the pitch angle correction to zero.
   roll_level_adjust = 0;                                                   //Set the roll angle correcion to zero.
  }


  //For starting the motors: throttle low and yaw left (step 1).
  if(receiver_input_channel_3 < 1050  && receiver_input_channel_4 < 1050)start  = 1;
  //When yaw stick is back in the center position start the motors (step 2).
  if(start  == 1 && receiver_input_channel_3 < 1050  && receiver_input_channel_4 > 1450){
   start = 2;

   angle_pitch = angle_pitch_acc;                                           //Set the gyro pitch angle equal to the
accelerometer pitch angle when the quadcopter is started.
   angle_roll = angle_roll_acc;                                             //Set the gyro roll angle equal to the accelerometer
roll angle when the quadcopter is started.
   gyro_angles_set = true;                                                  //Set the IMU started flag.

   //Reset the PID controllers for a bumpless start.
   pid_i_mem_roll  = 0;
   pid_last_roll_d_error = 0;
   pid_i_mem_pitch  = 0;
   pid_last_pitch_d_error = 0;
   pid_i_mem_yaw  = 0;
   pid_last_yaw_d_error = 0;
  }
  //Stopping the motors: throttle low and yaw right.
  if(start  == 2 && receiver_input_channel_3 < 1050  && receiver_input_channel_4 > 1950)start  = 0;

  //The PID set point in degrees per second is determined by the roll receiver input.
```

```
  //In the case of deviding by 3 the max roll rate is aprox 164 degrees per second ( (500-8)/3 = 164d/s ).
  pid_roll_setpoint = 0;
  //We need a little dead band of 16us for better results.
  if(receiver_input_channel_1 > 1508)pid_roll_setpoint = receiver_input_channel_1 - 1508;
  else if(receiver_input_channel_1 < 1492)pid_roll_setpoint = receiver_input_channel_1 - 1492;

  pid_roll_setpoint -= roll_level_adjust;                    //Subtract the angle correction from the
standardized receiver roll input value.
  pid_roll_setpoint /= 3.0;                                  //Divide the setpoint for the PID roll controller by 3
to get angles in degrees.


  //The PID set point in degrees per second is determined by the pitch receiver input.
  //In the case of deviding by 3 the max pitch rate is aprox 164 degrees per second ( (500-8)/3 = 164d/s ).
  pid_pitch_setpoint = 0;
  //We need a little dead band of 16us for better results.
  if(receiver_input_channel_2 > 1508)pid_pitch_setpoint = receiver_input_channel_2 - 1508;
  else if(receiver_input_channel_2 < 1492)pid_pitch_setpoint = receiver_input_channel_2 - 1492;

  pid_pitch_setpoint -= pitch_level_adjust;                  //Subtract the angle correction from the
standardized receiver pitch input value.
  pid_pitch_setpoint /= 3.0;                                 //Divide the setpoint for the PID pitch controller by
3 to get angles in degrees.

  //The PID set point in degrees per second is determined by the yaw receiver input.
  //In the case of deviding by 3 the max yaw rate is aprox 164 degrees per second ( (500-8)/3 = 164d/s ).
  pid_yaw_setpoint = 0;
  //We need a little dead band of 16us for better results.
  if(receiver_input_channel_3 > 1050){  //Do not yaw when turning off the motors.
   if(receiver_input_channel_4 > 1508)pid_yaw_setpoint = (receiver_input_channel_4 - 1508)/3.0;
   else if(receiver_input_channel_4 < 1492)pid_yaw_setpoint = (receiver_input_channel_4 - 1492)/3.0;
  }

  calculate_pid();                                           //PID inputs are known. So we can calculate the pid
output.

  //The battery voltage is needed for compensation.
  //A complementary filter is used to reduce noise.
  //0.09853 = 0.08 * 1.2317.
  battery_voltage = battery_voltage * 0.92 + (analogRead(0) + 65) * 0.09853;

  //Turn on the led if battery voltage is to low.
  if(battery_voltage < 1000 && battery_voltage > 600)digitalWrite(12, HIGH);


  throttle = receiver_input_channel_3;                       //We need the throttle signal as a base signal.

  if (start == 2){                                           //The motors are started.
    if (throttle > 1800) throttle = 1800;                    //We need some room to keep full control at full
throttle.
    esc_1 = throttle - pid_output_pitch + pid_output_roll - pid_output_yaw; //Calculate the pulse for esc 1
(front-right - CCW)
    esc_2 = throttle + pid_output_pitch + pid_output_roll + pid_output_yaw; //Calculate the pulse for esc 2
(rear-right - CW)
    esc_3 = throttle + pid_output_pitch - pid_output_roll - pid_output_yaw; //Calculate the pulse for esc 3
(rear-left - CCW)
    esc_4 = throttle - pid_output_pitch - pid_output_roll + pid_output_yaw; //Calculate the pulse for esc 4
(front-left - CW)

    if (battery_voltage < 1240 && battery_voltage > 800){    //Is the battery connected?
```

```
    esc_1 += esc_1 * ((1240  - battery_voltage)/(float)3500);          //Compensate the esc-1 pulse for voltage
drop.
    esc_2 += esc_2 * ((1240  - battery_voltage)/(float)3500);          //Compensate the esc-2 pulse for voltage
drop.
    esc_3 += esc_3 * ((1240  - battery_voltage)/(float)3500);          //Compensate the esc-3 pulse for voltage
drop.
    esc_4 += esc_4 * ((1240  - battery_voltage)/(float)3500);          //Compensate the esc-4 pulse for voltage
drop.
  }

  if (esc_1 < 1200) esc_1 = 1200;                                      //Keep the motors running.
  if (esc_2 < 1200) esc_2 = 1200;                                      //Keep the motors running.
  if (esc_3 < 1200) esc_3 = 1200;                                      //Keep the motors running.
  if (esc_4 < 1200) esc_4 = 1200;                                      //Keep the motors running.

  if(esc_1 > 2000)esc_1  = 2000;                                       //Limit  the esc-1 pulse to 2000us.
  if(esc_2 > 2000)esc_2  = 2000;                                       //Limit  the esc-2 pulse to 2000us.
  if(esc_3 > 2000)esc_3  = 2000;                                       //Limit  the esc-3 pulse to 2000us.
  if(esc_4 > 2000)esc_4  = 2000;                                       //Limit  the esc-4 pulse to 2000us.
 }

 else{
  esc_1 = 1000;                                                //If start is not 2 keep a 1000us  pulse for ess-1.
  esc_2 = 1000;                                                //If start is not 2 keep a 1000us  pulse for ess-2.
  esc_3 = 1000;                                                //If start is not 2 keep a 1000us  pulse for ess-3.
  esc_4 = 1000;                                                //If start is not 2 keep a 1000us  pulse for ess-4.
 }

 ////////////////////////////////////////////////////////////////////////////////////

 ////////////////////////////////////////////////////////////////////////////////////

 //!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
 //Because of the angle calculation the loop time is getting very important. If the loop time is
 //longer or shorter than 4000us the angle calculation is off. If you modify the code make sure
 //that the loop time is still 4000us and no longer! More information can be found on
 //the Q&A page:
 //!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

 if(micros()  - loop_timer > 4050)digitalWrite(12,  HIGH);             //Turn on the LED  if  the loop time
exceeds  4050us.

 //All the information  for controlling the motor's is available.
 //The refresh rate is 250Hz.  That means the esc's need there pulse every 4ms.
 while(micros()  - loop_timer < 4000);                                 //We wait until 4000us  are passed.
 loop_timer = micros();                                               //Set the timer  for the next loop.

 PORTD |= B11110000;                                                  //Set digital  outputs 4,5,6 and 7 high.
 timer_channel_1 = esc_1 + loop_timer;                                //Calculate the time  of the faling edge of the
esc-1 pulse.
 timer_channel_2 = esc_2 + loop_timer;                                //Calculate the time  of the faling edge of the
esc-2 pulse.
 timer_channel_3 = esc_3 + loop_timer;                                //Calculate the time  of the faling edge of the
esc-3 pulse.
 timer_channel_4 = esc_4 + loop_timer;                                //Calculate the time  of the faling edge of the
esc-4 pulse.

 //There is always 1000us  of spare time. So let's do something usefull that is very time consuming.
 //Get the current gyro and receiver data and scale it to degrees per second for the pid calculations.
 gyro_signalen();
```

```
  while(PORTD  >= 16){                                    //Stay in this loop until output 4,5,6 and 7 are low.
    esc_loop_timer = micros();                            //Read the current time.
    if(timer_channel_1 <= esc_loop_timer)PORTD  &= B11101111;          //Set digital output 4 to low if
the time is expired.
    if(timer_channel_2 <= esc_loop_timer)PORTD  &= B11011111;          //Set digital output 5 to low if
the time is expired.
    if(timer_channel_3 <= esc_loop_timer)PORTD  &= B10111111;          //Set digital output 6 to low if
the time is expired.
    if(timer_channel_4 <= esc_loop_timer)PORTD  &= B01111111;          //Set digital output 7 to low if
the time is expired.
  }
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
ISR(PCINT0_vect){
  current_time = micros();
  //Channel 1=========================================
  if(PINB  & B00000001){                                  //Is input 8 high?
    if(last_channel_1 == 0){                              //Input 8 changed from 0 to 1.
      last_channel_1 = 1;                                 //Remember  current input state.
      timer_1  = current_time;                            //Set timer_1  to current_time.
    }
  }
  else if(last_channel_1 == 1){                           //Input 8 is not high and changed from 1 to 0.
    last_channel_1 = 0;                                   //Remember  current input state.
    receiver_input[1] = current_time  - timer_1;                  //Channel 1 is current_time  - timer_1.
  }
  //Channel 2=========================================
  if(PINB  & B00000010  ){                                //Is input 9 high?
    if(last_channel_2 == 0){                              //Input 9 changed from 0 to 1.
      last_channel_2 = 1;                                 //Remember  current input state.
      timer_2  = current_time;                            //Set timer_2  to current_time.
    }
  }
  else if(last_channel_2 == 1){                           //Input 9 is not high and changed from 1 to 0.
    last_channel_2 = 0;                                   //Remember  current input state.
    receiver_input[2] = current_time  - timer_2;                  //Channel 2 is current_time  - timer_2.
  }
  //Channel 3=========================================
  if(PINB  & B00000100  ){                                //Is input 10 high?
    if(last_channel_3 == 0){                              //Input 10 changed from 0 to 1.
      last_channel_3 = 1;                                 //Remember  current input state.
      timer_3  = current_time;                            //Set timer_3  to current_time.
    }
  }
  else if(last_channel_3 == 1){                           //Input 10 is not high and changed from  1 to 0.
    last_channel_3 = 0;                                   //Remember  current input state.
    receiver_input[3] = current_time  - timer_3;                  //Channel 3 is current_time  - timer_3.

  }
  //Channel 4=========================================
  if(PINB  & B00001000  ){                                //Is input 11 high?
    if(last_channel_4 == 0){                              //Input 11 changed from 0 to 1.
      last_channel_4 = 1;                                 //Remember  current input state.
      timer_4  = current_time;                            //Set timer_4  to current_time.
    }
  }
```

```
 else if(last_channel_4 == 1){                                  //Input 11 is not high and changed from 1 to 0.
   last_channel_4 = 0;                                          //Remember current input state.
   receiver_input[4] = current_time - timer_4;                  //Channel 4 is current_time - timer_4.
 }
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//Subroutine for reading the gyro
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
void gyro_signalen(){
 //Read the MPU-6050
 if(eeprom_data[31] == 1){
   Wire.beginTransmission(gyro_address);                        //Start communication with the gyro.
   Wire.write(0x3B);                                            //Start reading @ register 43h and auto increment
with every read.
   Wire.endTransmission();                                      //End the transmission.
   Wire.requestFrom(gyro_address,14);                           //Request 14 bytes from the gyro.

   receiver_input_channel_1 = convert_receiver_channel(1);      //Convert the actual receiver signals
for pitch to the standard 1000 - 2000us.
   receiver_input_channel_2 = convert_receiver_channel(2);      //Convert the actual receiver signals
for roll to the standard 1000 - 2000us.
   receiver_input_channel_3 = convert_receiver_channel(3);      //Convert the actual receiver signals
for throttle to the standard 1000 - 2000us.
   receiver_input_channel_4 = convert_receiver_channel(4);      //Convert the actual receiver signals
for yaw to the standard 1000 - 2000us.

   while(Wire.available() < 14);                                //Wait until the 14 bytes are received.
   acc_axis[1] = Wire.read()<<8|Wire.read();                    //Add the low and high byte to the acc_x
variable.
   acc_axis[2] = Wire.read()<<8|Wire.read();                    //Add the low and high byte to the acc_y
variable.
   acc_axis[3] = Wire.read()<<8|Wire.read();                    //Add the low and high byte to the acc_z
variable.
   temperature = Wire.read()<<8|Wire.read();                    //Add the low and high byte to the
temperature variable.
   gyro_axis[1] = Wire.read()<<8|Wire.read();                   //Read high and low part of the angular data.
   gyro_axis[2] = Wire.read()<<8|Wire.read();                   //Read high and low part of the angular data.
   gyro_axis[3] = Wire.read()<<8|Wire.read();                   //Read high and low part of the angular data.
 }

 if(cal_int == 2000){
   gyro_axis[1] -= gyro_axis_cal[1];                            //Only compensate after the calibration.
   gyro_axis[2] -= gyro_axis_cal[2];                            //Only compensate after the calibration.
   gyro_axis[3] -= gyro_axis_cal[3];                            //Only compensate after the calibration.
 }
 gyro_roll = gyro_axis[eeprom_data[28] & 0b00000011];           //Set gyro_roll to the correct axis that
was stored in the EEPROM.
 if(eeprom_data[28] & 0b10000000)gyro_roll *= -1;               //Invert gyro_roll if the MSB of
EEPROM bit 28 is set.
 gyro_pitch = gyro_axis[eeprom_data[29] & 0b00000011];          //Set gyro_pitch to the correct axis
that was stored in the EEPROM.
 if(eeprom_data[29] & 0b10000000)gyro_pitch *= -1;              //Invert gyro_pitch if the MSB of
EEPROM bit 29 is set.
 gyro_yaw = gyro_axis[eeprom_data[30] & 0b00000011];            //Set gyro_yaw to the correct axis
that was stored in the EEPROM.
 if(eeprom_data[30] & 0b10000000)gyro_yaw *= -1;                //Invert gyro_yaw if the MSB of
EEPROM bit 30 is set.
```

```
  acc_x = acc_axis[eeprom_data[29] & 0b00000011];                 //Set acc_x to the correct axis that was
stored in the EEPROM.
  if(eeprom_data[29] & 0b10000000)acc_x *= -1;                    //Invert acc_x if the MSB of EEPROM
bit 29 is set.
  acc_y = acc_axis[eeprom_data[28] & 0b00000011];                 //Set acc_y to the correct axis that was
stored in the EEPROM.
  if(eeprom_data[28] & 0b10000000)acc_y *= -1;                    //Invert acc_y if the MSB of EEPROM
bit 28 is set.
  acc_z = acc_axis[eeprom_data[30] & 0b00000011];                 //Set acc_z to the correct axis that was
stored in the EEPROM.
  if(eeprom_data[30] & 0b10000000)acc_z *= -1;                    //Invert acc_z if the MSB of EEPROM
bit 30 is set.
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//Subroutine for calculating pid outputs
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
void calculate_pid(){
  //Roll calculations
  pid_error_temp = gyro_roll_input - pid_roll_setpoint;
  pid_i_mem_roll += pid_i_gain_roll * pid_error_temp;
  if(pid_i_mem_roll > pid_max_roll)pid_i_mem_roll = pid_max_roll;
  else if(pid_i_mem_roll < pid_max_roll * -1)pid_i_mem_roll = pid_max_roll * -1;

  pid_output_roll = pid_p_gain_roll * pid_error_temp + pid_i_mem_roll + pid_d_gain_roll * (pid_error_temp
- pid_last_roll_d_error);
  if(pid_output_roll > pid_max_roll)pid_output_roll = pid_max_roll;
  else if(pid_output_roll < pid_max_roll * -1)pid_output_roll = pid_max_roll * -1;

  pid_last_roll_d_error = pid_error_temp;

  //Pitch calculations
  pid_error_temp = gyro_pitch_input - pid_pitch_setpoint;
  pid_i_mem_pitch += pid_i_gain_pitch * pid_error_temp;
  if(pid_i_mem_pitch > pid_max_pitch)pid_i_mem_pitch = pid_max_pitch;
  else if(pid_i_mem_pitch < pid_max_pitch * -1)pid_i_mem_pitch = pid_max_pitch * -1;

  pid_output_pitch = pid_p_gain_pitch * pid_error_temp + pid_i_mem_pitch + pid_d_gain_pitch *
(pid_error_temp - pid_last_pitch_d_error);
  if(pid_output_pitch > pid_max_pitch)pid_output_pitch = pid_max_pitch;
  else if(pid_output_pitch < pid_max_pitch * -1)pid_output_pitch = pid_max_pitch * -1;

  pid_last_pitch_d_error = pid_error_temp;

  //Yaw calculations
  pid_error_temp = gyro_yaw_input - pid_yaw_setpoint;
  pid_i_mem_yaw += pid_i_gain_yaw * pid_error_temp;
  if(pid_i_mem_yaw > pid_max_yaw)pid_i_mem_yaw = pid_max_yaw;
  else if(pid_i_mem_yaw < pid_max_yaw * -1)pid_i_mem_yaw = pid_max_yaw * -1;

  pid_output_yaw = pid_p_gain_yaw * pid_error_temp + pid_i_mem_yaw + pid_d_gain_yaw *
(pid_error_temp - pid_last_yaw_d_error);
  if(pid_output_yaw > pid_max_yaw)pid_output_yaw = pid_max_yaw;
  else if(pid_output_yaw < pid_max_yaw * -1)pid_output_yaw = pid_max_yaw * -1;

  pid_last_yaw_d_error = pid_error_temp;
}
```

```
//This part converts the actual receiver signals to a standardized 1000 – 1500 – 2000 microsecond value.
//The stored data in the EEPROM is used.
int convert_receiver_channel(byte function){
  byte channel, reverse;                                            //First we declare some local variables
  int low, center, high, actual;
  int difference;

  channel = eeprom_data[function + 23] & 0b00000111;                //What channel corresponds with the
specific function
  if(eeprom_data[function + 23] & 0b10000000)reverse  = 1;          //Reverse channel when most
significant bit is set
  else reverse = 0;                                                 //If the most significant is not set there is no reverse

  actual = receiver_input[channel];                                 //Read the actual receiver value for the
corresponding function
  low = (eeprom_data[channel * 2 + 15] << 8) | eeprom_data[channel * 2 + 14];  //Store the low value for the
specific receiver input channel
  center = (eeprom_data[channel * 2 - 1] << 8) | eeprom_data[channel * 2 - 2]; //Store the center value for the
specific receiver input channel
  high = (eeprom_data[channel * 2 + 7] << 8) | eeprom_data[channel * 2 + 6];   //Store the high value for the
specific receiver input channel

  if(actual < center){                                              //The actual receiver value is lower than the center
value
    if(actual < low)actual = low;                                   //Limit the lowest value to the value that was
detected during setup
    difference = ((long)(center - actual) * (long)500)  / (center - low);       //Calculate and scale the actual value
to a 1000 - 2000us value
    if(reverse == 1)return 1500 + difference;                       //If the channel is reversed
    else return 1500 - difference;                                  //If the channel is not reversed
  }
  else if(actual > center){                                         //The actual receiver value is higher
than the center value
    if(actual > high)actual = high;                                 //Limit the lowest value to the value that was
detected during setup
    difference = ((long)(actual - center) * (long)500)  / (high - center);      //Calculate and scale the actual value
to a 1000 - 2000us value
    if(reverse == 1)return 1500 - difference;                       //If the channel is reversed
    else return 1500 + difference;                                  //If the channel is not reversed
  }
  else return 1500;
}

void set_gyro_registers(){
  //Setup the MPU-6050
  if(eeprom_data[31] == 1){
    Wire.beginTransmission(gyro_address);                           //Start communication with the address
found during search.
    Wire.write(0x6B);                                               //We want to write to the PWR_MGMT_1 register
(6B hex)
    Wire.write(0x00);                                               //Set the register bits as 00000000 to activate the
gyro
    Wire.endTransmission();                                         //End the transmission with the gyro.

    Wire.beginTransmission(gyro_address);                           //Start communication with the address
found during search.
    Wire.write(0x1B);                                               //We want to write to the GYRO_CONFIG register
(1B hex)
    Wire.write(0x08);                                               //Set the register bits as 00001000 (500dps full
scale)
```

```
  Wire.endTransmission();                    //End the transmission with the gyro

  Wire.beginTransmission(gyro_address);      //Start communication with the address
found during search.
  Wire.write(0x1C);                          //We want to write to the ACCEL_CONFIG register
(1A hex)
  Wire.write(0x10);                          //Set the register bits as 00010000 (+/- 8g full scale
range)
  Wire.endTransmission();                    //End the transmission with the gyro

  //Let's perform a random register check to see if the values are written correct
  Wire.beginTransmission(gyro_address);      //Start communication with the address
found during search
  Wire.write(0x1B);                          //Start reading @ register 0x1B
  Wire.endTransmission();                    //End the transmission
  Wire.requestFrom(gyro_address, 1);         //Request 1 bytes from the gyro
  while(Wire.available() < 1);               //Wait until the 6 bytes are received
  if(Wire.read() != 0x08){                   //Check if the value is 0x08
   digitalWrite(12,HIGH);                    //Turn on the warning led
   while(1)delay(10);                        //Stay in this loop for ever
  }

  Wire.beginTransmission(gyro_address);      //Start communication with the address
found during search
  Wire.write(0x1A);                          //We want to write to the CONFIG register (1A
hex)
  Wire.write(0x03);                          //Set the register bits as 00000011 (Set Digital Low
Pass Filter to ~43Hz)
  Wire.endTransmission();                    //End the transmission with the gyro

 }
}
```

LAMPIRAN IV
DATASHEET

repository.ub.ac.id
UNIVERSITAS BRAWIJAYA