Magnetometer based Navigation Algorithm for a four-wheel Omni drive using concepts of Machine Learning

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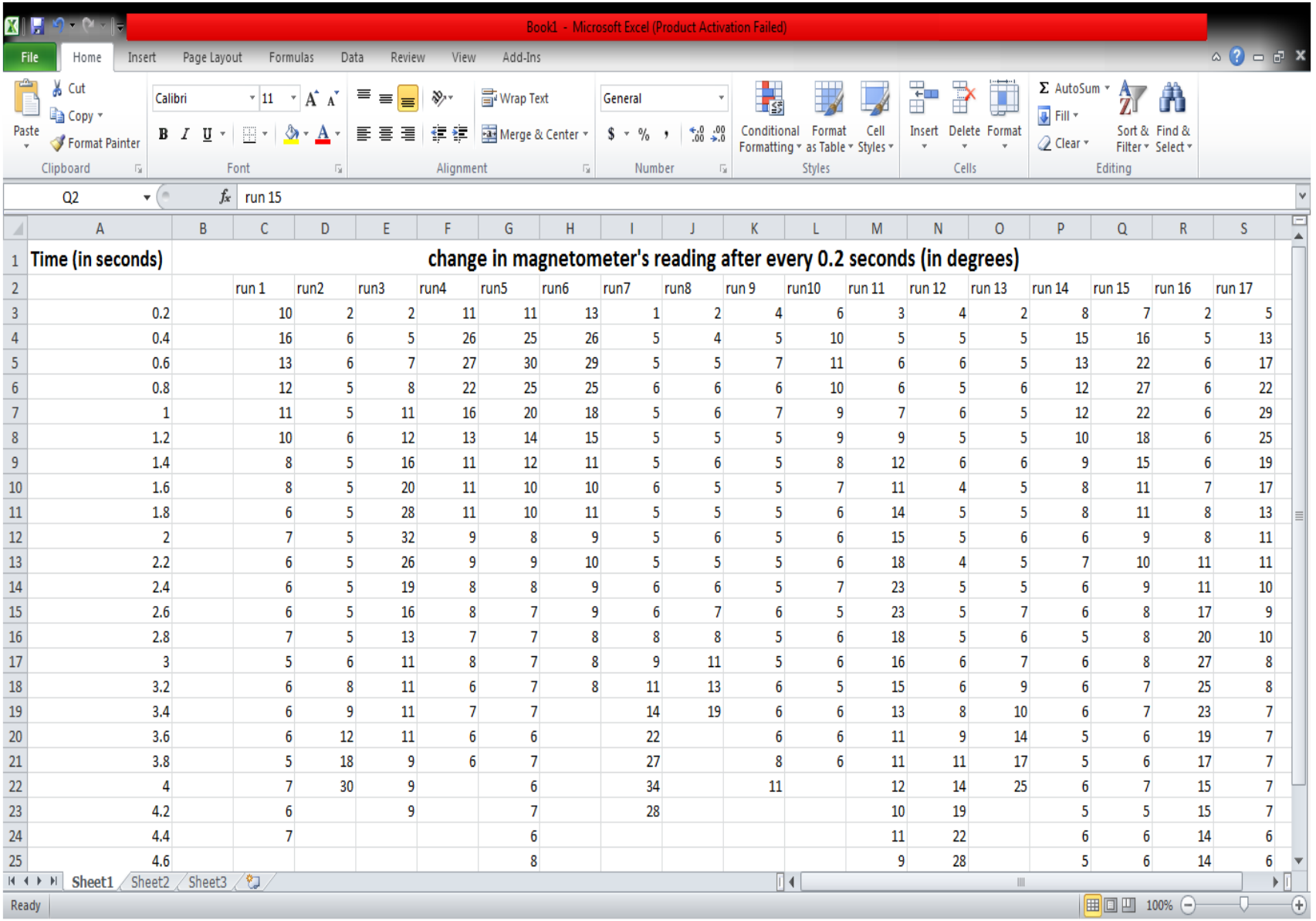
Objective:

Autonomously moving a four-wheel Omni drive on a defined trajectory using magnetometer.

Approach:

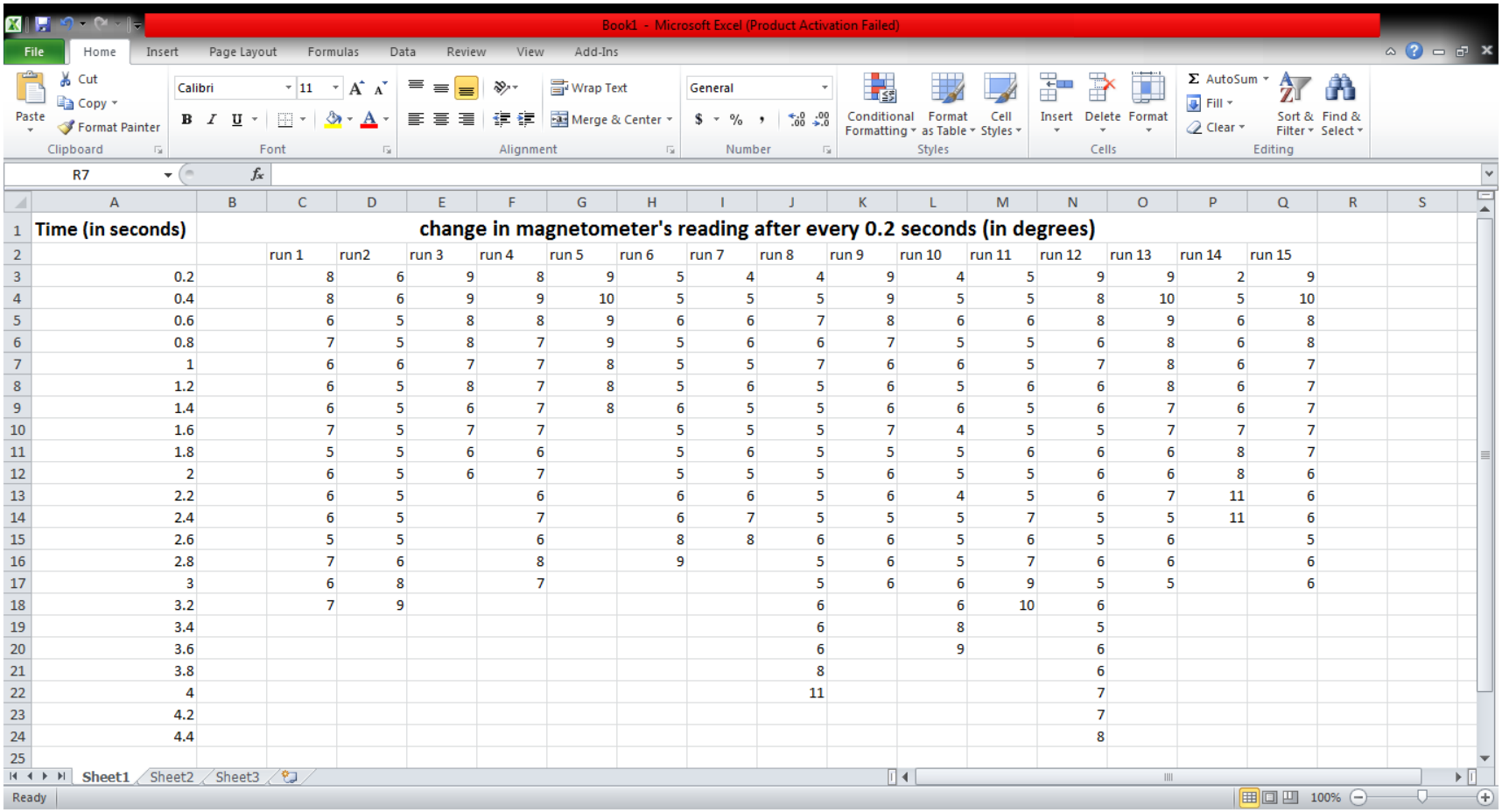
Machine Learning is used to get an equation of the desired trajectory by training the dataset (magnetometer's readings) obtained by moving the bot on the desired path manually.

1. **Obtaining the dataset (magnetometer readings):**
    - First, the bot was made to move on a circle of defined radius manually.
    - Readings of magnetometer were taken after every 0.2 seconds.
    - Every run consists of 15-20 readings, I.e. the bot was made to move manually for about 3-4 seconds.
    - Around 18 such runs were taken and data collected is shown below.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Time (in seconds)		change in magnetometer's reading after every 0.2 seconds (in degrees)																
2			run 1	run2	run3	run4	run5	run6	run7	run8	run 9	run10	run 11	run 12	run 13	run 14	run 15	run 16	run 17
3	0.2		10	2	2	11	11	13	1	2	4	6	3	4	2	8	7	2	5
4	0.4		16	6	5	26	25	26	5	4	5	10	5	5	5	15	16	5	13
5	0.6		13	6	7	27	30	29	5	5	7	11	6	6	5	13	22	6	17
6	0.8		12	5	8	22	25	25	6	6	6	10	6	5	6	12	27	6	22
7	1		11	5	11	16	20	18	5	6	7	9	7	6	5	12	22	6	29
8	1.2		10	6	12	13	14	15	5	5	5	9	9	5	5	10	18	6	25
9	1.4		8	5	16	11	12	11	5	6	5	8	12	6	6	9	15	6	19
10	1.6		8	5	20	11	10	10	6	5	5	7	11	4	5	8	11	7	17
11	1.8		6	5	28	11	10	11	5	5	5	6	14	5	5	8	11	8	13
12	2		7	5	32	9	8	9	5	6	5	6	15	5	6	6	9	8	11
13	2.2		6	5	26	9	9	10	5	5	5	6	18	4	5	7	10	11	11
14	2.4		6	5	19	8	8	9	6	6	5	7	23	5	5	6	9	11	10
15	2.6		6	5	16	8	7	9	6	7	6	5	23	5	7	6	8	17	9
16	2.8		7	5	13	7	7	8	8	8	5	6	18	5	6	5	8	20	10
17	3		5	6	11	8	7	8	9	11	5	6	16	6	7	6	8	27	8
18	3.2		6	8	11	6	7	8	11	13	6	5	15	6	9	6	7	25	8
19	3.4		6	9	11	7	7		14	19	6	6	13	8	10	6	7	23	7
20	3.6		6	12	11	6	6		22		6	6	11	9	14	5	6	19	7
21	3.8		5	18	9	6	7		27		8	6	11	11	17	5	6	17	7
22	4		7	30	9		6		34		11		12	14	25	6	7	15	7
23	4.2		6		9		7		28				10	19		5	5	15	7
24	4.4		7				6						11	22		6	6	14	6
25	4.6						8						9	28		5	6	14	6

- The above data contains certain spikes at the beginning of the run because the motors doesn't respond to the given PWM instantaneously.
- So, a modified dataset was created as shown below.



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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Time (in seconds)		change in magnetometer's reading after every 0.2 seconds (in degrees)																
2			run 1	run2	run 3	run 4	run 5	run 6	run 7	run 8	run 9	run 10	run 11	run 12	run 13	run 14	run 15		
3	0.2		8	6	9	8	9	5	4	4	9	4	5	9	9	2	9		
4	0.4		8	6	9	9	10	5	5	5	9	5	5	8	10	5	10		
5	0.6		6	5	8	8	9	6	6	7	8	6	6	8	9	6	8		
6	0.8		7	5	8	7	9	5	6	6	7	5	5	6	8	6	8		
7	1		6	6	7	7	8	5	5	7	6	6	5	7	8	6	7		
8	1.2		6	5	8	7	8	5	6	5	6	5	6	6	8	6	7		
9	1.4		6	5	6	7	8	6	5	5	6	6	5	6	7	6	7		
10	1.6		7	5	7	7		5	5	5	7	4	5	5	7	7	7		
11	1.8		5	5	6	6		5	6	5	5	5	6	6	6	8	7		
12	2		6	5	6	7		5	5	5	6	5	5	6	6	8	6		
13	2.2		6	5		6		6	6	5	6	4	5	6	7	11	6		
14	2.4		6	5		7		6	7	5	5	5	7	5	5	11	6		
15	2.6		5	5		6		8	8	6	6	5	6	5	6		5		
16	2.8		7	6		8		9		5	6	5	7	6	6		6		
17	3		6	8		7				5	6	6	9	5	5		6		
18	3.2		7	9						6		6	10	6					
19	3.4									6		8		5					
20	3.6									6		9		6					
21	3.8									8				6					
22	4									11				7					
23	4.2													7					
24	4.4													8					
25																			

Sheet1 Sheet2 Sheet3

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- Graphs/plots of these dataset were made using Matlab and are shown below.

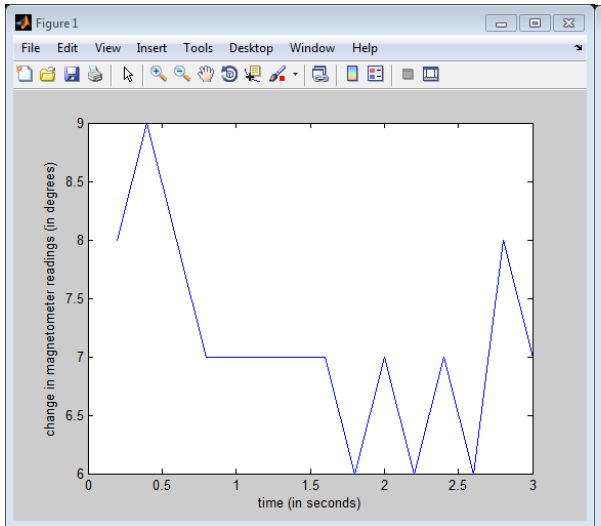
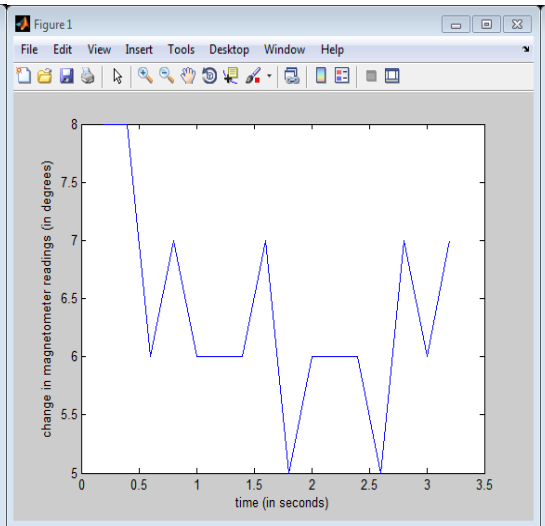


Figure 1
File Edit View Insert Tools Desktop Window Help
change in magnetometer readings (in degrees)
time (in seconds)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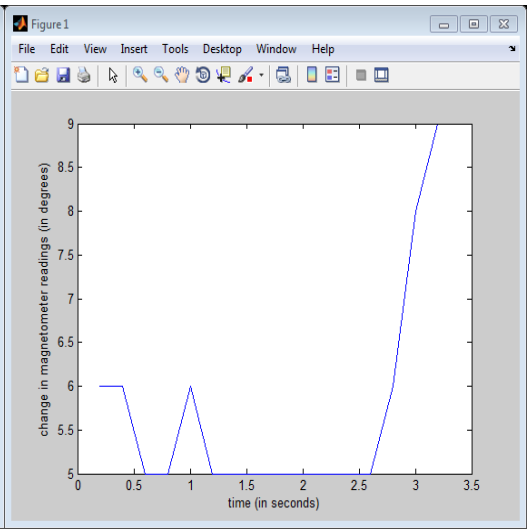
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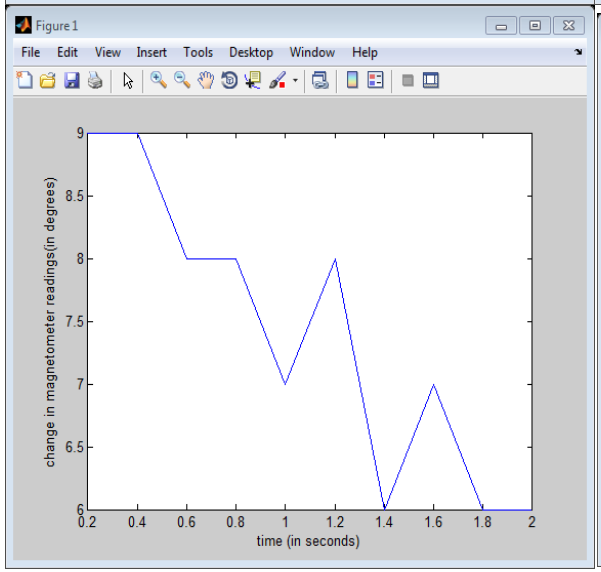
Figure 1
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change in magnetometer readings(in degrees)
time (in seconds)

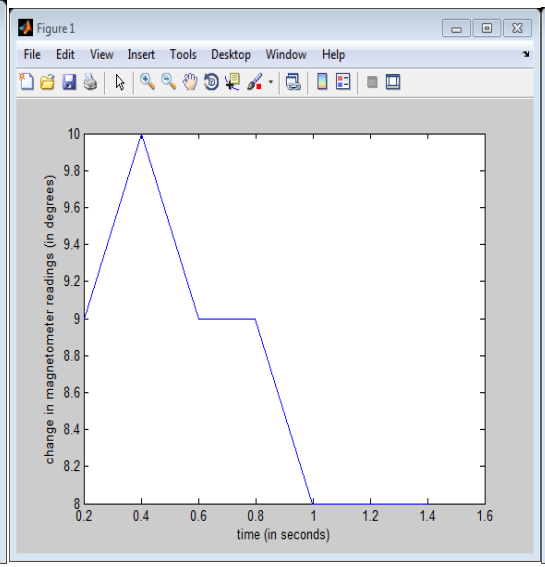
Figure 1
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change in magnetometer readings (in degrees)
time (in seconds)

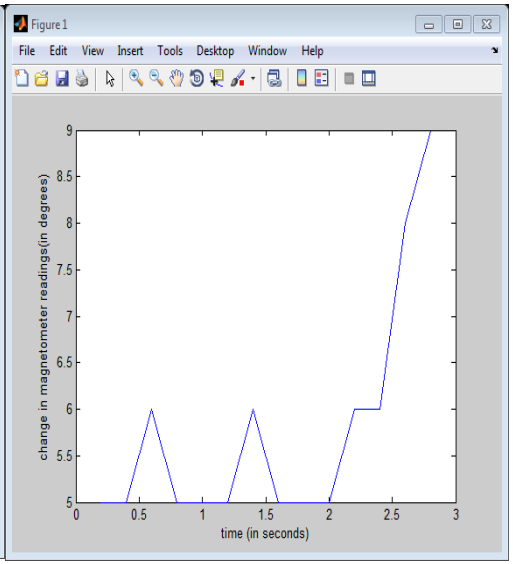
Figure 1
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change in magnetometer readings(in degrees)
time (in seconds)

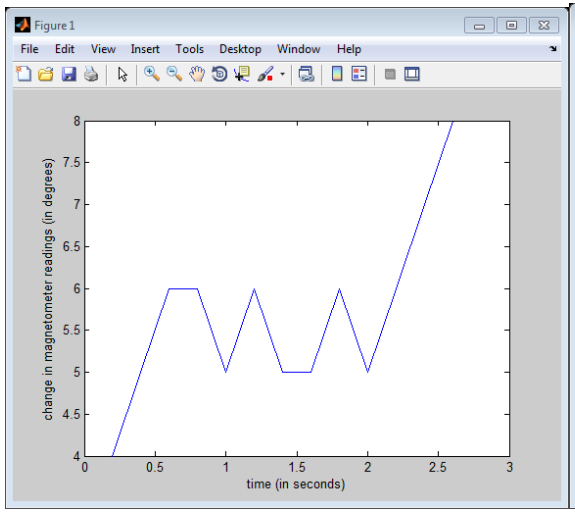
Figure 1
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change in magnetometer readings (in degrees)
time (in seconds)

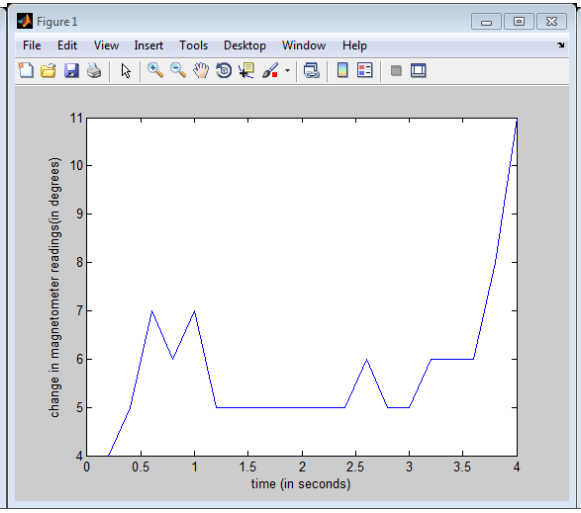
Figure 1
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change in magnetometer readings(in degrees)
time (in seconds)

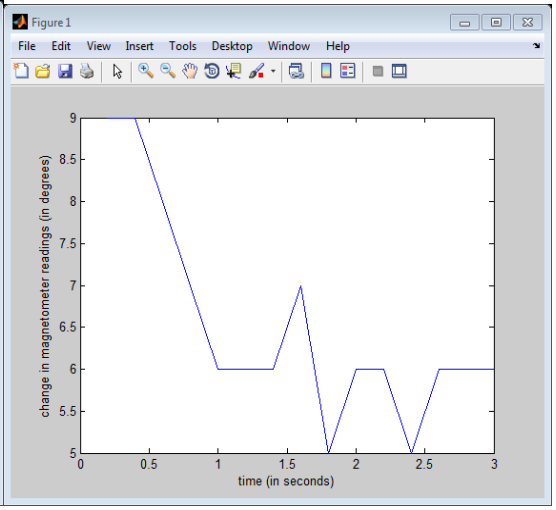
Figure 1
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change in magnetometer readings (in degrees)
time (in seconds)

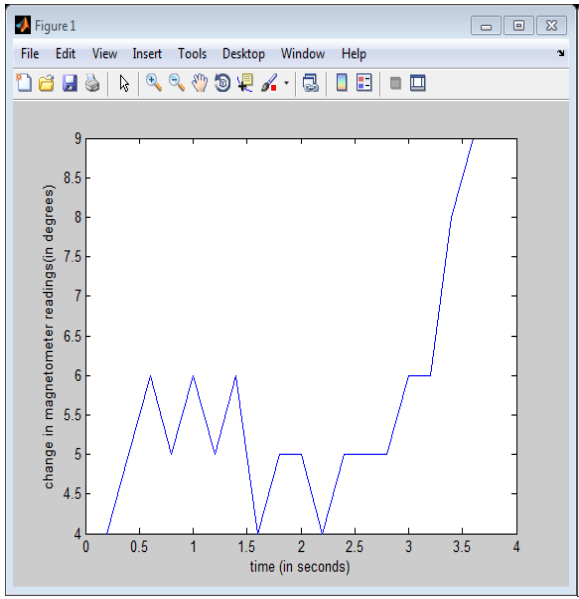
Figure 1
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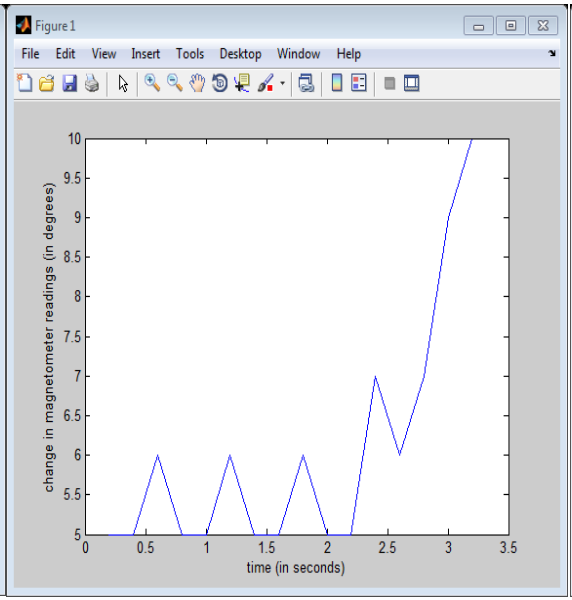
change in magnetometer readings(in degrees)
time (in seconds)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change in magnetometer readings (in degrees)
time (in seconds)

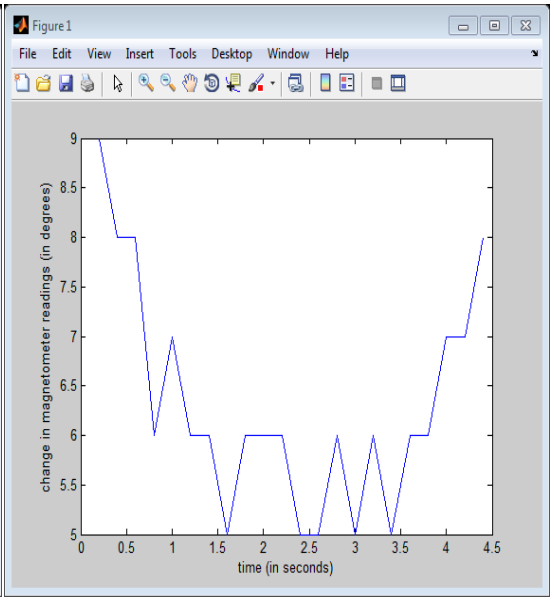
Figure 1
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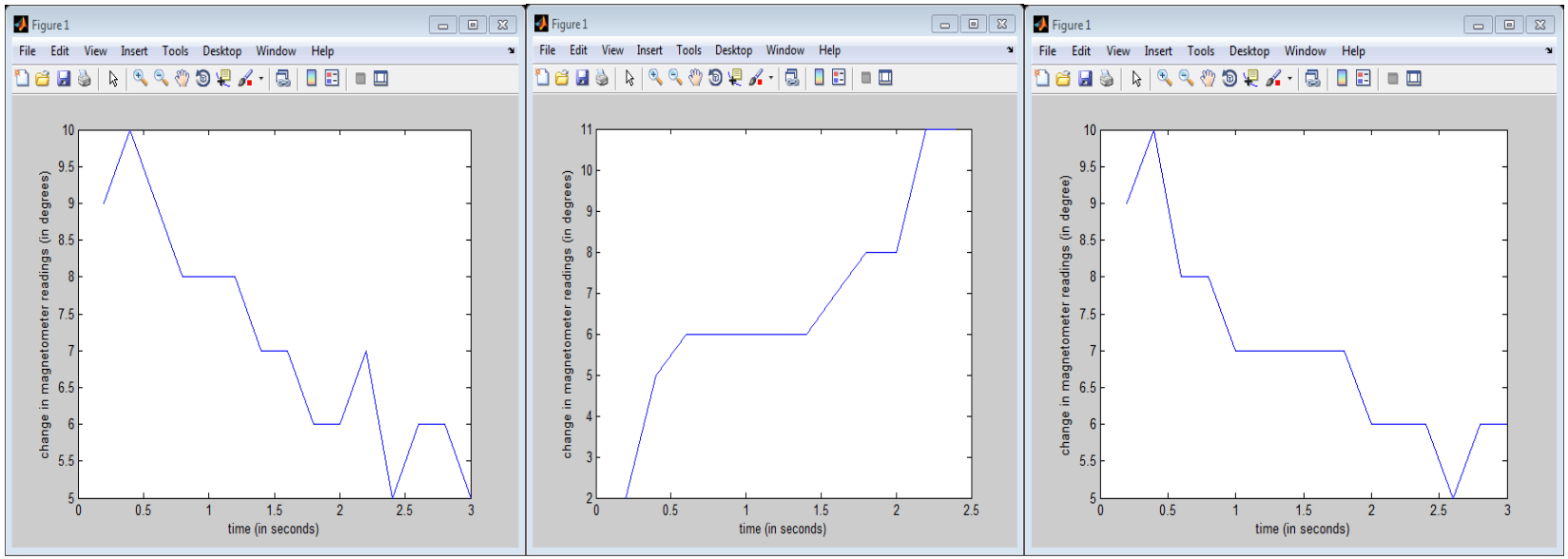
change in magnetometer readings (in degrees)
time (in seconds)



2. **Curve fitting using machine learning**
    - Regression algorithm is used to find the best fit to the above plotted graphs.
    - Code is written in c++ to find which degree polynomial is most close to the above drawn plots and find its equation.
    - Code for linear fit, quadratic fit and cubic fit is written in c++ and is shown below. (**No inbuilt libraries are used for regression algorithm)**

Code for linear fit:

```
#include<iostream>
using namespace std;
int main()
{
   double x_1[]={16.0,8.0,8.0,6.0,7.0,6.0,6.0,6.0,7.0,5.0,6.0,6.0,6.0,5.0,7.0,6.0,7.0};
   double x_2[]={16.0,6.0,6.0,5.0,5.0,6.0,5.0,5.0,5.0,5.0,5.0,5.0,5.0,5.0,6.0,8.0,9.0};
```

```
double x_3[]={10.0,9.0,9.0,8.0,8.0,7.0,8.0,6.0,7.0,6.0,6.0};
double x_4[]={15.0,8.0,9.0,8.0,7.0,7.0,7.0,7.0,7.0,6.0,7.0,6.0,7.0,6.0,8.0,7.0};
double x_5[]={7.0,9.0,10.0,9.0,9.0,8.0,8.0,8.0};
double x_6[]={14.0,5.0,5.0,6.0,5.0,5.0,5.0,6.0,5.0,5.0,5.0,6.0,6.0,8.0,9.0};
double x_7[]={13.0,4.0,5.0,6.0,6.0,5.0,6.0,5.0,5.0,6.0,5.0,6.0,7.0,8.0};
double x_8[]={20.0,4.0,5.0,7.0,6.0,7.0,5.0,5.0,5.0,5.0,5.0,5.0,5.0,6.0,5.0,5.0,6.0,6.0,6.0,8.0,11.0};
double x_9[]={15.0,9.0,9.0,8.0,7.0,6.0,6.0,6.0,7.0,5.0,6.0,6.0,5.0,6.0,6.0,6.0};
double x_10[]={18.0,4.0,5.0,6.0,5.0,6.0,5.0,6.0,4.0,5.0,5.0,4.0,5.0,5.0,5.0,6.0,6.0,8.0,9.0};
double x_11[]={16.0,5.0,5.0,6.0,5.0,5.0,6.0,5.0,5.0,6.0,5.0,5.0,7.0,6.0,7.0,9.0,10.0};
double x_12[]={22.0,9.0,8.0,8.0,6.0,7.0,6.0,6.0,5.0,6.0,6.0,6.0,5.0,5.0,6.0,5.0,6.0,5.0,6.0,6.0,7.0,7.0,8.0};
double x_13[]={15.0,9.0,10.0,9.0,8.0,8.0,8.0,7.0,7.0,6.0,6.0,7.0,5.0,6.0,6.0,5.0};
double x_14[]={12.0,2.0,5.0,6.0,6.0,6.0,6.0,6.0,7.0,8.0,8.0,11.0,11.0};
double x_15[]={15.0,9.0,10.0,8.0,8.0,7.0,7.0,7.0,7.0,7.0,6.0,6.0,6.0,5.0,6.0,6.0};

double theta_1=1;
double theta_0=1;
double alpha=0.1;
int iterations=5000;
double sum1=0,sum2=0;
for(int i1=1;i1<=iterations;i1++)
{
   sum1=0;sum2=0;
   for(int i=1;i<=int(x_1[0]);i++)
   {
      sum1=sum1+(theta_1*0.2*i+theta_0-x_1[i])*0.2*i;
      sum2=sum2+(theta_1*0.2*i+theta_0-x_1[i]);
   }
   for(int i=1;i<=int(x_2[0]);i++)
   {
      sum1=sum1+(theta_1*0.2*i+theta_0-x_2[i])*0.2*i;
```

```
    sum2=sum2+(theta_1*0.2*i+theta_0-x_2[i]);
}
for(int i=1;i<=int(x_3[0]);i++)
{
    sum1=sum1+(theta_1*0.2*i+theta_0-x_3[i])*0.2*i;
    sum2=sum2+(theta_1*0.2*i+theta_0-x_3[i]);
}
for(int i=1;i<=int(x_4[0]);i++)
{
    sum1=sum1+(theta_1*0.2*i+theta_0-x_4[i])*0.2*i;
    sum2=sum2+(theta_1*0.2*i+theta_0-x_4[i]);
}
for(int i=1;i<=int(x_5[0]);i++)
{
    sum1=sum1+(theta_1*0.2*i+theta_0-x_5[i])*0.2*i;
    sum2=sum2+(theta_1*0.2*i+theta_0-x_5[i]);
}
for(int i=1;i<=int(x_6[0]);i++)
{
    sum1=sum1+(theta_1*0.2*i+theta_0-x_6[i])*0.2*i;
    sum2=sum2+(theta_1*0.2*i+theta_0-x_6[i]);
}
for(int i=1;i<=int(x_7[0]);i++)
{
    sum1=sum1+(theta_1*0.2*i+theta_0-x_7[i])*0.2*i;
    sum2=sum2+(theta_1*0.2*i+theta_0-x_7[i]);
}
for(int i=1;i<=int(x_8[0]);i++)
{
    sum1=sum1+(theta_1*0.2*i+theta_0-x_8[i])*0.2*i;
```

```
    sum2=sum2+(theta_1*0.2*i+theta_0-x_8[i]);
  }
  for(int i=1;i<=int(x_9[0]);i++)
  {
    sum1=sum1+(theta_1*0.2*i+theta_0-x_9[i])*0.2*i;
    sum2=sum2+(theta_1*0.2*i+theta_0-x_9[i]);
  }
  for(int i=1;i<=int(x_10[0]);i++)
  {
    sum1=sum1+(theta_1*0.2*i+theta_0-x_10[i])*0.2*i;
    sum2=sum2+(theta_1*0.2*i+theta_0-x_10[i]);
  }
  for(int i=1;i<=int(x_11[0]);i++)
  {
    sum1=sum1+(theta_1*0.2*i+theta_0-x_11[i])*0.2*i;
    sum2=sum2+(theta_1*0.2*i+theta_0-x_11[i]);
  }
  for(int i=1;i<=int(x_12[0]);i++)
  {
    sum1=sum1+(theta_1*0.2*i+theta_0-x_12[i])*0.2*i;
    sum2=sum2+(theta_1*0.2*i+theta_0-x_12[i]);
  }
  sum2=sum2+theta_0;
  theta_1=theta_1-2*alpha/224.0*sum1;
  theta_0=theta_0-2*alpha/224.0*sum2;


}
cout<<"predicted values...."<<endl;
for(int i=1;i<20;i++)
```

```
   {
      cout<<int(theta_1*0.2*i+theta_0+0.5)<<endl;
   }
  /* cout<<theta_1<<endl;
   cout<<theta_0<<endl; */
   system("pause");
   return 0;
}
```

Code for quadratic fit:

```
#include<iostream>
using namespace std;
int main()
{
   double x_1[]={16.0,8.0,8.0,6.0,7.0,6.0,6.0,6.0,7.0,5.0,6.0,6.0,6.0,5.0,7.0,6.0,7.0};
   double x_2[]={16.0,6.0,6.0,5.0,5.0,6.0,5.0,5.0,5.0,5.0,5.0,5.0,5.0,5.0,6.0,8.0,9.0};
   double x_3[]={10.0,9.0,9.0,8.0,8.0,7.0,8.0,6.0,7.0,6.0,6.0};
   double x_4[]={15.0,8.0,9.0,8.0,7.0,7.0,7.0,7.0,7.0,6.0,7.0,6.0,7.0,6.0,8.0,7.0};
   double x_5[]={7.0,9.0,10.0,9.0,9.0,8.0,8.0,8.0};
   double x_6[]={14.0,5.0,5.0,6.0,5.0,5.0,5.0,6.0,5.0,5.0,5.0,6.0,6.0,8.0,9.0};
   double x_7[]={13.0,4.0,5.0,6.0,6.0,5.0,6.0,5.0,5.0,6.0,5.0,6.0,7.0,8.0};
   double x_8[]={20.0,4.0,5.0,7.0,6.0,7.0,5.0,5.0,5.0,5.0,5.0,5.0,5.0,6.0,5.0,5.0,6.0,6.0,6.0,8.0,11.0};
   double x_9[]={15.0,9.0,9.0,8.0,7.0,6.0,6.0,6.0,7.0,5.0,6.0,6.0,5.0,6.0,6.0,6.0};
   double x_10[]={18.0,4.0,5.0,6.0,5.0,6.0,5.0,6.0,4.0,5.0,5.0,4.0,5.0,5.0,5.0,6.0,6.0,8.0,9.0};
   double x_11[]={16.0,5.0,5.0,6.0,5.0,5.0,6.0,5.0,5.0,6.0,5.0,5.0,7.0,6.0,7.0,9.0,10.0};
   double x_12[]={22.0,9.0,8.0,8.0,6.0,7.0,6.0,6.0,5.0,6.0,6.0,6.0,5.0,5.0,6.0,5.0,6.0,5.0,6.0,6.0,7.0,7.0,8.0};
   double x_13[]={15.0,9.0,10.0,9.0,8.0,8.0,8.0,7.0,7.0,6.0,6.0,7.0,5.0,6.0,6.0,5.0};
   double x_14[]={12.0,2.0,5.0,6.0,6.0,6.0,6.0,6.0,7.0,8.0,8.0,11.0,11.0};
   double x_15[]={15.0,9.0,10.0,8.0,8.0,7.0,7.0,7.0,7.0,7.0,6.0,6.0,6.0,5.0,6.0,6.0};
   double theta_2=1.0;
```

```
double theta_1=1;
double theta_0=1;
double alpha=0.007;
int iterations=500000;
double sum1=0,sum2=0,sum3=0;
for(int i1=1;i1<=iterations;i1++)
{
   sum1=0;sum2=0;sum3=0;
   for(int i=1;i<=int(x_1[0]);i++)
   {
      sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_1[i])*0.2*i*0.2*i;
      sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_1[i])*0.2*i;
      sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_1[i]);
   }
   for(int i=1;i<=int(x_2[0]);i++)
   {
      sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_2[i])*0.2*i*0.2*i;
      sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_2[i])*0.2*i;
      sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_2[i]);
   }
   for(int i=1;i<=int(x_3[0]);i++)
   {
      sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_3[i])*0.2*i*0.2*i;
      sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_3[i])*0.2*i;
      sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_3[i]);
   }
   for(int i=1;i<=int(x_4[0]);i++)
   {
      sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_4[i])*0.2*i*0.2*i;
      sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_4[i])*0.2*i;
```

```
   sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_4[i]);
}
for(int i=1;i<=int(x_5[0]);i++)
{
   sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_5[i])*0.2*i*0.2*i;
   sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_5[i])*0.2*i;
   sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_5[i]);
}
for(int i=1;i<=int(x_6[0]);i++)
{
   sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_6[i])*0.2*i*0.2*i;
   sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_6[i])*0.2*i;
   sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_6[i]);
}
for(int i=1;i<=int(x_7[0]);i++)
{
   sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_7[i])*0.2*i*0.2*i;
   sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_7[i])*0.2*i;
   sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_7[i]);
}
for(int i=1;i<=int(x_8[0]);i++)
{
   sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_8[i])*0.2*i*0.2*i;
   sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_8[i])*0.2*i;
   sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_8[i]);
}
for(int i=1;i<=int(x_9[0]);i++)
{
   sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_9[i])*0.2*i*0.2*i;
   sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_9[i])*0.2*i;
```

```
    sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_9[i]);
  }
  for(int i=1;i<=int(x_10[0]);i++)
  {
    sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_10[i])*0.2*i*0.2*i;
    sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_10[i])*0.2*i;
    sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_10[i]);
  }
  for(int i=1;i<=int(x_11[0]);i++)
  {
    sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_11[i])*0.2*i*0.2*i;
    sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_11[i])*0.2*i;
    sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_11[i]);
  }
  for(int i=1;i<=int(x_12[0]);i++)
  {
   sum3=sum3+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_12[i])*0.2*i*0.2*i;
    sum1=sum1+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_12[i])*0.2*i;
    sum2=sum2+(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_12[i]);
  }
  sum2=sum2+theta_0;
  theta_2=theta_2-2*alpha/224.0*sum3;
  theta_1=theta_1-2*alpha/224.0*sum1;
  theta_0=theta_0-2*alpha/224.0*sum2;


}
cout<<"predicted values...."<<endl;
for(int i=1;i<20;i++)
{
```

```
      cout<<int(theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0+0.5)<<endl;
   }
   cout<<" "<<endl;
   cout<<theta_2<<endl;
   cout<<theta_1<<endl;
   cout<<theta_0<<endl;
   system("pause");
   return 0;
}
```

Code for cubic fit:

```
#include<iostream>
using namespace std;
int main()
{
   double x_1[]={16.0,8.0,8.0,6.0,7.0,6.0,6.0,6.0,7.0,5.0,6.0,6.0,6.0,5.0,7.0,6.0,7.0};
   double x_2[]={16.0,6.0,6.0,5.0,5.0,6.0,5.0,5.0,5.0,5.0,5.0,5.0,5.0,5.0,5.0,6.0,8.0,9.0};
   double x_3[]={10.0,9.0,9.0,8.0,8.0,7.0,8.0,6.0,7.0,6.0,6.0};
   double x_4[]={15.0,8.0,9.0,8.0,7.0,7.0,7.0,7.0,7.0,6.0,7.0,6.0,7.0,6.0,8.0,7.0};
   double x_5[]={7.0,9.0,10.0,9.0,9.0,8.0,8.0,8.0};
   double x_6[]={14.0,5.0,5.0,6.0,5.0,5.0,5.0,6.0,5.0,5.0,5.0,6.0,6.0,8.0,9.0};
   double x_7[]={13.0,4.0,5.0,6.0,6.0,5.0,6.0,5.0,5.0,6.0,5.0,6.0,7.0,8.0};
   double x_8[]={20.0,4.0,5.0,7.0,6.0,7.0,5.0,5.0,5.0,5.0,5.0,5.0,5.0,6.0,5.0,5.0,6.0,6.0,6.0,8.0,11.0};
   double x_9[]={15.0,9.0,9.0,8.0,7.0,6.0,6.0,6.0,7.0,5.0,6.0,6.0,5.0,6.0,6.0,6.0};
   double x_10[]={18.0,4.0,5.0,6.0,5.0,6.0,5.0,6.0,4.0,5.0,5.0,4.0,5.0,5.0,5.0,6.0,6.0,8.0,9.0};
   double x_11[]={16.0,5.0,5.0,6.0,5.0,5.0,6.0,5.0,5.0,6.0,5.0,5.0,7.0,6.0,7.0,9.0,10.0};
   double x_12[]={22.0,9.0,8.0,8.0,6.0,7.0,6.0,6.0,5.0,6.0,6.0,6.0,5.0,5.0,6.0,5.0,6.0,5.0,6.0,6.0,7.0,7.0,8.0};
   double x_13[]={15.0,9.0,10.0,9.0,8.0,8.0,8.0,7.0,7.0,6.0,6.0,7.0,5.0,6.0,6.0,5.0};
   double x_14[]={12.0,2.0,5.0,6.0,6.0,6.0,6.0,6.0,7.0,8.0,8.0,11.0,11.0};
   double x_15[]={15.0,9.0,10.0,8.0,8.0,7.0,7.0,7.0,7.0,7.0,6.0,6.0,6.0,5.0,6.0,6.0};
```

```
double theta_3=1;
double theta_2=1.0;
double theta_1=1;
double theta_0=1;
double alpha=0.00000007;
int iterations=500000;
double sum1=0,sum2=0,sum3=0,sum4=0;
for(int i1=1;i1<=iterations;i1++)
{
  sum1=0;sum2=0,sum3=0,sum4=0;
  for(int i=1;i<=int(x_1[0]);i++)
  {

     sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_1[i])*0.2*i*0.2*i*0.2*i;
    sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_1[i])*0.2*i*0.2*i;
    sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_1[i])*0.2*i;
    sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_1[i]);
  }
  for(int i=1;i<=int(x_2[0]);i++)
  {
     sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_2[i])*0.2*i*0.2*i*0.2*i;
    sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_2[i])*0.2*i*0.2*i;
    sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_2[i])*0.2*i;
    sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_2[i]);
  }
  for(int i=1;i<=int(x_3[0]);i++)
  {
     sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_3[i])*0.2*i*0.2*i*0.2*i;
    sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_3[i])*0.2*i*0.2*i;
    sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_3[i])*0.2*i;
```

```
  sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_3[i]);
}
for(int i=1;i<=int(x_4[0]);i++)
{
    sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_4[i])*0.2*i*0.2*i*0.2*i;
  sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_4[i])*0.2*i*0.2*i;
  sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_4[i])*0.2*i;
  sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_4[i]);
}
for(int i=1;i<=int(x_5[0]);i++)
{
    sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_5[i])*0.2*i*0.2*i*0.2*i;
  sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_5[i])*0.2*i*0.2*i;
  sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_5[i])*0.2*i;
  sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_5[i]);
}
for(int i=1;i<=int(x_6[0]);i++)
{
    sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_6[i])*0.2*i*0.2*i*0.2*i;
  sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_6[i])*0.2*i*0.2*i;
  sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_6[i])*0.2*i;
  sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_6[i]);
}
for(int i=1;i<=int(x_7[0]);i++)
{
    sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_7[i])*0.2*i*0.2*i*0.2*i;
  sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_7[i])*0.2*i*0.2*i;
  sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_7[i])*0.2*i;
  sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_7[i]);
}
```

```
for(int i=1;i<=int(x_8[0]);i++)
{
    sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_8[i])*0.2*i*0.2*i*0.2*i;
  sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_8[i])*0.2*i*0.2*i;
  sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_8[i])*0.2*i;
  sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_8[i]);
}
for(int i=1;i<=int(x_9[0]);i++)
{
   sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_9[i])*0.2*i*0.2*i*0.2*i;
  sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_9[i])*0.2*i*0.2*i;
  sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_9[i])*0.2*i;
  sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_9[i]);
}
for(int i=1;i<=int(x_10[0]);i++)
{
    sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_10[i])*0.2*i*0.2*i*0.2*i;
  sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_10[i])*0.2*i*0.2*i;
  sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_10[i])*0.2*i;
  sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_10[i]);
}
for(int i=1;i<=int(x_11[0]);i++)
{
    sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_11[i])*0.2*i*0.2*i*0.2*i;
  sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_11[i])*0.2*i*0.2*i;
  sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_11[i])*0.2*i;
  sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_11[i]);
}
for(int i=1;i<=int(x_12[0]);i++)
{
```

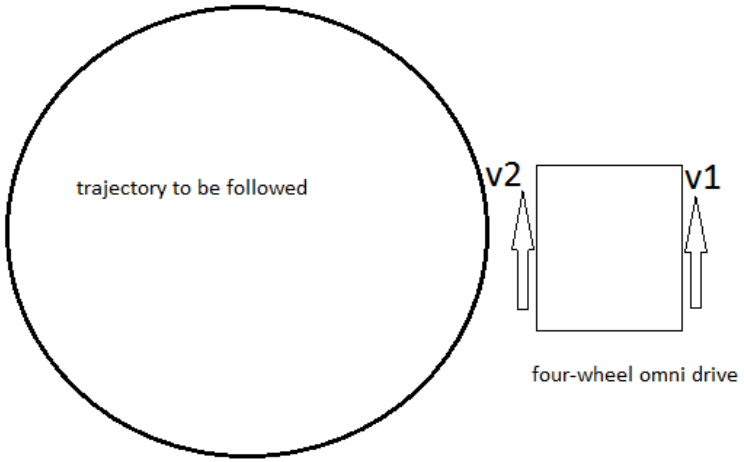
```
        sum4=sum4+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_12[i])*0.2*i*0.2*i*0.2*i;
        sum3=sum3+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_12[i])*0.2*i*0.2*i;
        sum2=sum2+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_12[i])*0.2*i;
        sum1=sum1+(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0-x_12[i]);
      }
      sum2=sum2+theta_0;
      theta_3=theta_3-2*alpha/224.0*sum4;
      theta_2=theta_2-2*alpha/224.0*sum3;
      theta_1=theta_1-2*alpha/224.0*sum1;
      theta_0=theta_0-2*alpha/224.0*sum2;


    }
    cout<<"predicted values...."<<endl;
    for(int i=1;i<20;i++)
    {
      cout<<int(theta_3*0.2*0.2*0.2*i*i*i+theta_2*(0.2*i)*(0.2*i)+theta_1*0.2*i+theta_0+0.5)<<endl;
    }
   /*  cout<<theta_2<<endl;
    cout<<theta_1<<endl;
    cout<<theta_0<<endl; */
    system("pause");
    return 0;
}
```

- Quadratic fit gave the closest approximation and its equation is f(t)=0.398979*t*t-1.42948*t+7.08966 where t=time in seconds and f(t) is the change in magnetometer reading at time=t.
- This equation is used by arduino to make the bot move in desired trajectory.

3. **Moving the bot on desired path using the equation obtained from above c++ code**
   - Rather than using the typical PID algorithm for navigation, new method is developed and is explained below:

     Derivation:



   - Omni chassis is made to follow the circle by keeping the two opposite facing wheels stall and moving the rest two wheels at velocity **v1 and v2.**
   - Let the length of bot be 'l' and radius of the trajectory is 'r'.

     v2/r=v1/(r+l) -1

     After a time interval of t=0.2 seconds:

     V2*t=r*(change in magnetometer reading)/2/pi -2

     From equation '1':

     r=v2*l/(v1-v2)

from equation ‘2’:
v2*t=v2*l/(v1-v2)*(change in magnetometer reading)/2/pi
dividing the entire equation by v2:
v1/v2=1+(change in magnetometer reading)*c where c=l/t/2/pi is a constant

v1/v2=1+c*(change in magnetometer reading) is the equation we are using for moving the bot on a circle.

- At every time step, value of c is updated by the equation :
  C(present)=c(past)*(value of the quadratic equation at time=t)/(present magnetometer reading-past magnetometer reading)

  And this time step is chosen to be 0.2 seconds.
- If (present magnetometer reading-past magnetometer reading) > desired change in magnetometer reading given by the quadratic equation, then value of v1 is decreased keeping v2 constant.
- If (present magnetometer reading-past magnetometer reading) < desired change in magnetometer reading given by the quadratic equation, then value of v1 is increased keeping v2 constant.
- If (present magnetometer reading-past magnetometer reading) = desired change in magnetometer reading given by the quadratic equation, then value of v1 and v2 is kept constant.
- This equation gives the bot an auto-correct feature which helps it during the motion

4. **Conclusion**

This approach is successfully implemented for navigation on a circular track but could be used for moving on any desired trajectory.

END