Kathmandu University
Journal of Science, Engineering and Technology
KUSET
Bezmen *et al.*, Vol.10, No.I, November, 2014, pp 55-72

ORIGINAL RESEARCH ARTICLE OPEN ACCESS

MOBILE WHEELED ROBOT MOTION CONTROL WITH USAGE OF GEOLOCATION SENSORS

[1]P. Bezmen*, [2]D. Tuladhar

[1]Department of Theoretical Mechanics and Mechatronics, Southwest State University, Russian Federation
[2]Department of Mechanical Engineering, School of Engineering, Kathmandu University, Nepal

*Corresponding author's e-mail: pbezmen@yahoo.com
Received 14 July, 2014; Revised 21 October, 2014

ABSTRACT
The authors state mobile robot motion control peculiarities which are induced by geolocation sensors operation. This paper specifies features of geolocation sensors – GPS receiver and electronic compass (magnetometer). Lay of land and man-made structures are obstacles for GPS signals. The paper describes precision of GPS receiver and offers a method that can reduce probable error of GPS signal. This method is a program digital filter based on finding of GPS data kernel – most likely mobile robot location which is expressed in terms of latitude and longitude. The paper formulates functioning principles of the six-wheeled robot movement automatic control system that uses geolocation sensors data.

Key words: mobile robot, control system, robotics, geolocation, GPS, magnetometer.

INTRODUCTION
During the last two decades, automatic control of wheeled mobile objects movement is actual objective due to a wheeled mover became the most widespread and this mover type has the greatest coefficient of efficiency. Many papers, written by authors: D.E. Ohocimsky, E.A. Devyanin, Ju. G. Martynenko, V.E. Pavlovsky, A.M. Formalsky, S.F. Yatsun, A.P. Krischenko, S.B. Tkachev, M.L. Zymbler, T. Bretl and their apprentices, describe methods of mobile wheeled robot control under determined and non-determined conditions of environment [1, 2]. In addition to previously mentioned, special attention is paid to control of robot powered with electrical motors. The wheel-motor unit is a device containing wheel, electrical drive, transmission, and braking system. Generally, this unit is mounted by underslung cantilever on chassis frame. Nowadays, such devices are used in electric car and mobile robot designs.

MATERIALS AND METHODS
The mobile six-wheeled robot "X6WD" (Fig. 1) was designed in Southwest State University for development and research of mobile object control methods with usage of geolocation. This robot design is based on chassis frame with six wheel-motors. The robot "X6WD" has onboard control system, autonomous power supply unit, geolocation sensors – GPS receiver "Seeed Studio GPS-Bee" (Fig. 2) and three-axis magnetometer "Devantech CMPS10" (Fig. 3), video camera, two manipulators with 5 degrees of freedom, and lighting equipment

[3]. The robot overall dimensions (with maximum elongate manipulators): 780 mm x 305 mm x 340 mm, its mass – 6 kg, its maximum linear velocity at movement on even surface – 14 km/h. The robot control system based on client-server model: the robot is a server controlled by client – remote computer via Internet or wireless LAN [4] (Fig. 4).

Figure 1 The X6WD mobile six-wheeled robot

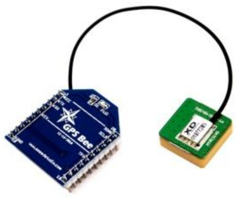

Figure 2 The Seeed Studio GPS-Bee GPS receiver

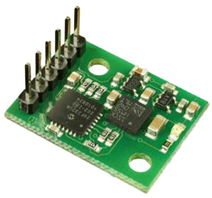

Figure 3 The Devantech CMPS10 magnetometer

Kathmandu University Journal of Science, Engineering and Technology KUSET
Bezmen *et al.*, Vol.10, No.I, November, 2014, pp 55-72

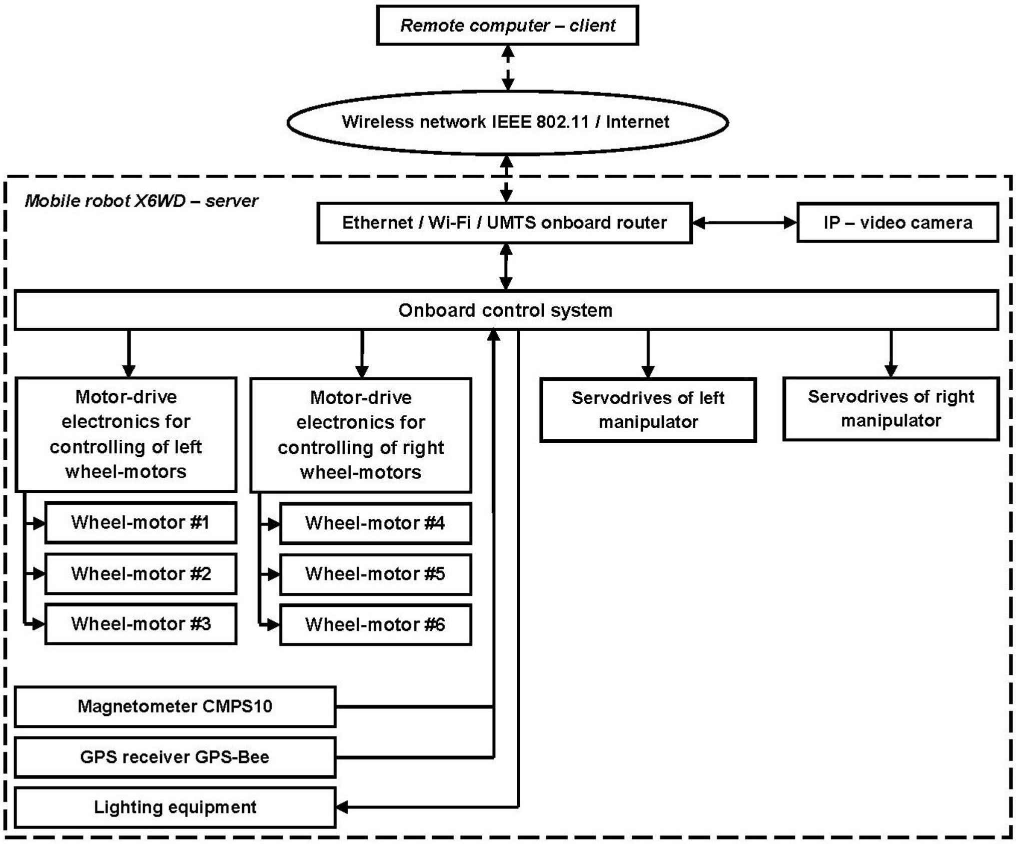

Figure 4 Chart of the robot control system

The CMPS10 module determines the bearing – the angle φ between the robot body forward direction and the direction from robot body to magnetic north (Fig. 5). The CMPS10 produces the bearing in the range from –179 to +180 degrees. The CMPS10 includes three-axis magnetometer and three-axis accelerometer that allows compensating the bearing error induced by tilting of the CMPS10 module. In addition to previously mentioned, built-in accelerometer gives information about roll and trim angles of robot body. The minimal determined bearing value by CMPS10 module is 0.1 degree. The roll and trim values range from –60 to +60 degrees. Communication between the CMPS10 module and the onboard control system of robot is carried out by serial interface I^2C.

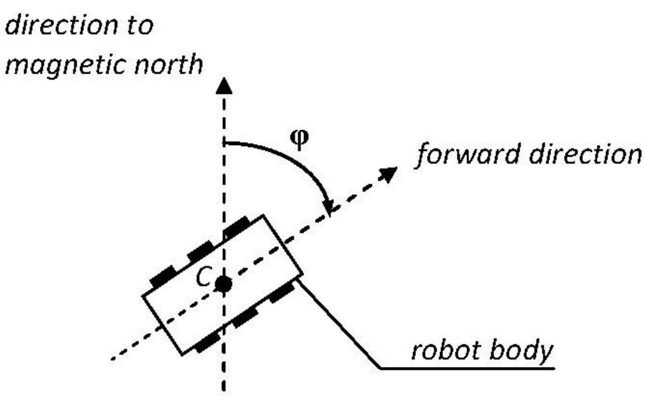

Figure 5 The bearing φ

The GPS receiver "Seeed Studio GPS-Bee" is based on U-Blox Neo-5 microcircuit. It has following parameters: maximum number of channels (GPS satellites) – 50, inaccuracy of position determination – ±1.017 m…±30.33 m, position updating duration – less than 1 sec, communication bus between the GPS receiver and the onboard control system of robot – serial interface UART.

To provide the robot movement control process we need to convert spherical coordinates of the Earth (longitude and latitude) into rectangular coordinates – x and y (Fig. 6):

$$x = \Lambda \cdot R_1, \quad (1)$$

$$y = \Phi \cdot R_2, \quad (2)$$

where: Λ – longitude ($-\pi \le \Lambda \le \pi$ rad), Φ – latitude ($-\pi/2 \le \Phi \le \pi/2$ rad), R_1 = 6378.16 km (Equatorial radius), R_2 = 6356.77 km (Polar radius).

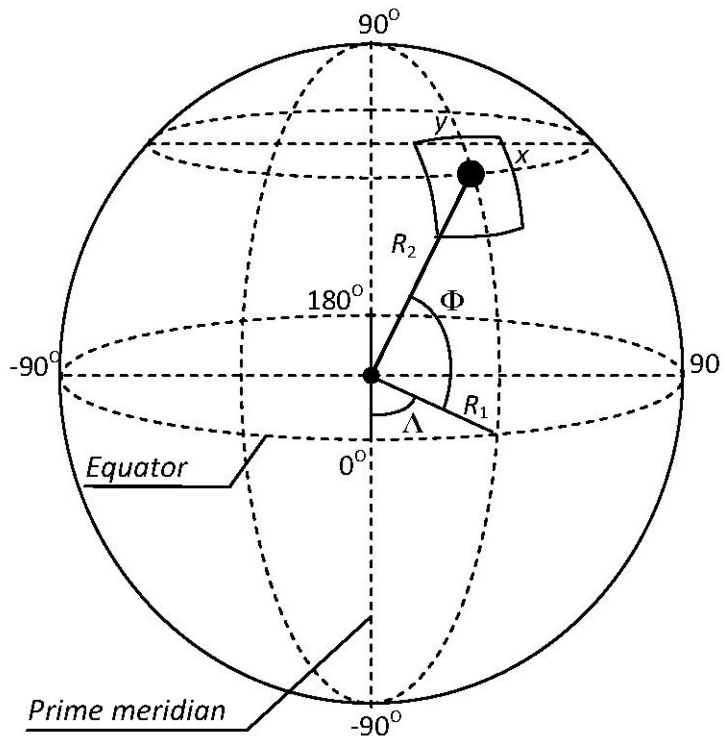

Figure 6 Spherical coordinates of the Earth

The inaccuracy of bearing φ_i determination can be denoted by $\Delta\varphi$. Thus, during robot movement to a destination point the robot body executes process of rotation so that the bearing value could be $\varphi_i \pm \Delta\varphi$, where φ_i is calculated on the basis of current coordinates (x_C and y_C) of the robot body and coordinates (x_i and y_i) of a destination point [5]:

Bezmen *et al.*, Vol.10, No.I, November, 2014, pp 55-72

$$\varphi_i = \begin{cases} \left[\dfrac{\pi}{2} - \left[\arccos\left[\dfrac{x_i - x_C}{\left[\sqrt{(x_i - x_C)^2 + (y_i - y_C)^2}\right]}\right]\right]\right], & if \quad (y_i - y_C) \geq 0, \\ \left[\left[\pi \cdot \mathrm{sign}(x_i - x_C) + \left[\dfrac{\pi}{2} - \left[\arccos\left[\dfrac{x_i - x_C}{\left[\sqrt{(x_i - x_C)^2 + (y_i - y_C)^2}\right] \cdot \mathrm{sign}(x_i - x_C)}\right]\right]\right]\right] \cdot (-\mathrm{sign}(x_i - x_C))\right], & if \quad (y_i - y_C) < 0, \end{cases} \tag{3}$$

where sign is the signum function:

$$\mathrm{sign}\,(x) = \begin{cases} 1, & if \quad x \geq 0, \\ -1, & if \quad x < 0. \end{cases} \tag{4}$$

Thereby, $\varphi_i \in (-\pi, \pi]$. Sign of the bearing φ_i means a destination point location: at $\varphi_i < 0$ destination point is located in the west, at $\varphi_i > 0$ – it is located in the east.

The course deviation is a difference between the specified bearing φ_i and the current bearing φ_C:

$$\Theta = \varphi_i - \varphi_C, \tag{5}$$

in this connection:

$$\begin{gathered} \text{if } \Theta > \pi, \text{ then } \Theta = -(2\pi - \Theta), \\ \text{if } \Theta \leq -\pi, \text{ then } \Theta = 2\pi + \Theta, \\ \Theta \in (-\pi, \pi]. \end{gathered} \tag{6}$$

After course deviation calculation there are possible the following variants of robot movement:

– if $|\Theta| > \Delta\varphi$ and $\Theta > 0$, then the robot body turns to right (clockwise rotation);
– if $|\Theta| > \Delta\varphi$ and $\Theta < 0$, then the robot body turns to left (contraclockwise rotation);
– if $|\Theta| \leq \Delta\varphi$, then the robot body does not turn, i.e. there is possible straightforward movement of the robot.

The criterion of robot movement completion can be denoted by following equations:

$$\begin{gathered} |x_i - x_C| = \Delta x, \\ |y_i - y_C| = \Delta y, \\ |\varphi_i - \varphi_C| = \Delta\varphi, \end{gathered} \tag{7}$$

where:

– x_i, y_i and φ_i are destination point coordinates and specified bearing;
– x_C, y_C and φ_C are current robot body coordinates and bearing;
– Δx, Δy, and $\Delta\varphi$ are determination inaccuracies of coordinates x, y (induced by GPS receiver bias and obstacles for GPS signals), and bearing φ (induced by magnetometer and intense magnetic fields), respectively.

Generally, the Δx and Δy values are induced by lay of land and man-made structures which are obstacles for GPS signals. In many cases the Δx and Δy inaccuracies are independent and different values (Fig. 7).

Kathmandu University Journal of Science, Engineering and Technology KUSET
Bezmen *et al.*, Vol.10, No.I, November, 2014, pp 55-72

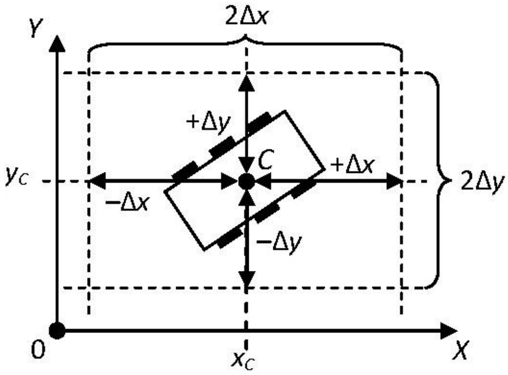

Figure 7 The Δx and Δy inaccuracies

The program digital filter “Constellation” is the method that can reduce probable error of GPS signal and help to decrease the Δx and Δy values. This program filter is based on finding of the GPS data kernel – most likely mobile robot location which is expressed in terms of latitude and longitude. The GPS data kernel is formed from two neighboring points of latitude or longitude. First of all the main advantage of the filter “Constellation” is its algorithm simplicity and high calculating speed. Moreover, the filter does its function in consideration of previous filtered values. The filter can be realized on basis of a personal computer or a microcontroller, such as Atmel ATmega32U4 or NXP Semiconductors LPC2880. The filter “Constellation” is a program class written in C++ language.

The filter class has following members – member functions (methods) and member variables:

```
class TConstellation
{
private:                                   // keyword "private" sets accessibility of
                                           // the class members only for the same class;
        double        Buf[N];              // the buffer for storage of
                                           // latitude or longitude samples;
        unsigned int  BufCounter;          // the counter for calculation of buffer filling;
        double        Mean;                // the variable stores filtered value of
                                           // latitude/longitude;
        double        ED[(N – 1) * N][3];  // the array for data kernel search;
public:                                    // keyword "public" sets accessibility of
                                           // the class members for all program objects;
        double        Buffer(int index);   // the method returns one latitude/longitude
                                           // sample that is conformable to its index;
        int           MaxIndex(void);      // the method returns maximum value of
                                           // sample index within buffer size;
        double        Filter(void);        // the method allows to filter
                                           // latitude/longitude samples;
        double        Average(void);       // the method returns arithmetic mean value of
                                           // latitude/longitude samples;
        void          Add(double S);       // the method allows to add one
                                           // latitude/longitude sample to the buffer;
                      TConstellation(void); // the constructor method allows to initialize
                                           // the class member variables.
};
```

The value of N is a maximum amount of latitude or longitude samples which are stored in the buffer "Buf". In many cases the value of $N = 20$ is sufficient ($N \geq 3$). If the class methods "Buffer", "Filter", and "Average" fail, they return –1. The buffer "Buf" must be filled by the method "Add" before using the method "Filter".

The text of program module "Constel.cpp" with implementation of the class methods is presented below.

```
#pragma hdrstop
#include <math.h>
#include "Constel.h"

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

double TConstellation::Buffer(int index)
{
if (index < BufCounter) return Buf[index]; else return -1;
}

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

int TConstellation::MaxIndex(void)
{
if (BufCounter < N) return (BufCounter - 1); else
return (N - 1);
}

////////////////////////////////////////////////////////////////////////////////
```

Bezmen *et al.*, Vol.10, No.I, November, 2014, pp 55-72

```
double TConstellation::Filter(void)
{
unsigned int h      = 0;
unsigned int k      = 0;
unsigned int d      = 0;
unsigned int m      = 0;
unsigned int minED  = 0;
unsigned int proxE1 = 0;
unsigned int proxE2 = 0;

  if (BufCounter > 2)
  {
    for (h = 0; h <= BufCounter - 1; h++)
    {
      for (k = 0; k <= BufCounter - 1; k++)
      {
        if (h != k)
        {
          ED[d][0] = fabs(Buf[h] - Buf[k]);
          ED[d][1] = h;
          ED[d][2] = k;
          d++;
        }
      }
    }

    for (m = 1; m <= d - 1; m++)
    {
       if (ED[minED][0] >= ED[m][0]) minED = m;    //GPS data kernel search
    }

    d = 0;

    proxE1 = ED[minED][1];
    proxE2 = ED[minED][2];

    minED = 0;

    if (BufCounter <= N) Mean = (Buf[proxE1] + Buf[proxE2]) / 2;
    else
    {
      if (fabs(Mean - ((Buf[proxE1] + Buf[proxE2]) / 2)) >= fabs(Buf[proxE1] –
      - Buf[proxE2]))
      Mean = (Buf[proxE1] + Buf[proxE2]) / 2;
    }
  }
  else
  {
    if (BufCounter > 1) Mean = (Buf[0] + Buf[1]) / 2; else
    if (BufCounter > 0) Mean = Buf[0]; else Mean = -1;
  }

return Mean;
}

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

double TConstellation::Average(void)
{
double A = 0;

  if (BufCounter > 0)
  {
    for (int i = 0; i < BufCounter; i++) A = A + Buf[i];
    return A / BufCounter;
  }
  else return -1;

}

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

void TConstellation::Add(double S)
{
```

```
if (BufCounter < N)
  {
     Buf[BufCounter] = S;
     BufCounter++;
  }
  else
  {
     for (int i = 0; i < N - 1; i++) Buf[i] = Buf[i + 1];
     Buf[N - 1] = S;
  }

}

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

TConstellation::TConstellation(void)
{
BufCounter = 0;
for (int i = 0; i < N; i++)           { Buf[i] = 0; }
for (int i = 0; i < (N - 1) * N; i++) { ED[i][0] = 0; ED[i][1] = 0; ED[i][2] = 0; }
Mean = 0;
}

/////////////////////////////////////////////////////////////////////////////////
```

RESULTS AND DISCUSSION

The series of GPS measurements was carried out using the Seeed Studio GPS-Bee receiver mounted on the X6WD robot. The measurements results give the information about the lay of land and man-made structures influences on the Δx and Δy inaccuracies. Also, the results allow estimating the dispersion of latitude/longitude samples under certain environmental conditions. To obtain the precise latitude/longitude, the value the GPS data samples is filtered by the program digital filter "Constellation", and then filtered GPS data is used in the calculation of latitude/longitude arithmetic mean value. This method gives maximum accurate measurements results. Therefore it is possible to evaluate the probability of certain latitude/longitude sample occurrence. This probability can be evaluated in relation to the latitude/longitude arithmetic mean. Thus, a perfect or partial coincidence between the maximum probability value and the arithmetic mean is possible at the robot location without any obstacles for GPS signals.

The results of four experiments are presented in the figures 8 – 23 and the tables 1 – 2:
– 1. The robot is in the building (Fig. 8 – 11) – this location is characterized as the worst to receive the GPS signals (the signals can penetrate through windows of the building);
– 2. The robot is situated in open territory (Fig. 12 – 15) – the GPS signals reach the robot easily;
– 3. The robot is in the wreck of the old factory (Fig. 16 – 19) – this location is bad to receive the GPS signals (the signals can penetrate through breaches of the old factory roof);
– 4. The robot is situated in open territory (Fig. 20 – 23) – the GPS signals reach the robot easily.
The figures 8, 12, 16, and 20 show the dispersion of GPS data samples and their arithmetic mean values. All latitude and longitude values are represented in degrees. The figures 9, 13, 17, and 21 display the probabilities of certain longitude samples occurrence. The figures 10, 14, 18, and 22 show the probabilities of certain latitude samples occurrence. The figures 11, 15, 19, and 23 display the Google Maps fragments with the marked points of the robot location. Latitude and longitude values (in degrees) must be calculated with an accuracy of seven decimal places.

Bezmen *et al.*, Vol.10, No.I, November, 2014, pp 55-72

Table 1 – The arithmetic mean values and the most probable values of GPS data samples

Experiment number	Arithmetic mean of latitude (in degrees)	Arithmetic mean of longitude (in degrees)	Latitude value with maximum probability of occurrence (in degrees)	Longitude value with maximum probability of occurrence (in degrees)
1	51.73906727	36.1479643	51.73901333	36.14763667
2	51.75576472	36.1249951	51.7558	36.12497667 / 36.12498833
3	51.73137722	36.27089615	51.73135833 / 51.7314	36.27093333
4	51.73167356	36.27092638	51.731675	36.270925

Table 2 – The maximum dispersions and the inaccuracies of GPS data

Experiment number	Maximum dispersion of latitude samples (in degrees)	Maximum dispersion of longitude samples (in degrees)	Maximum inaccuracy Δy (in metres)	Maximum inaccuracy Δx (in metres)
1	0.00022167	0.000545	±12.29657776	±30.33467063
2	0.00019	0.000065	±10.5399238	±3.6178965
3	0.00015167	0.0002	±8.41344794	±11.13198922
4	0.00001833	0.00001833	±1.01701019	±1.02043235

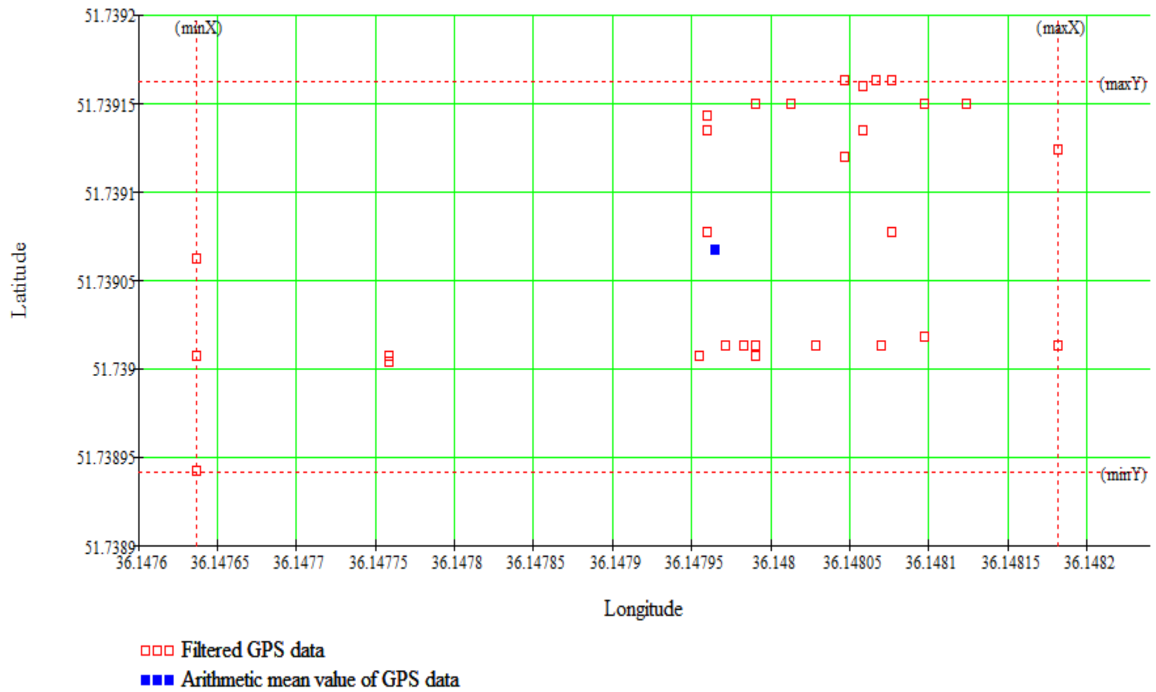

Figure 8 The dispersion of GPS data samples and their arithmetic mean value

Bezmen *et al.*, Vol.10, No.I, November, 2014, pp 55-72

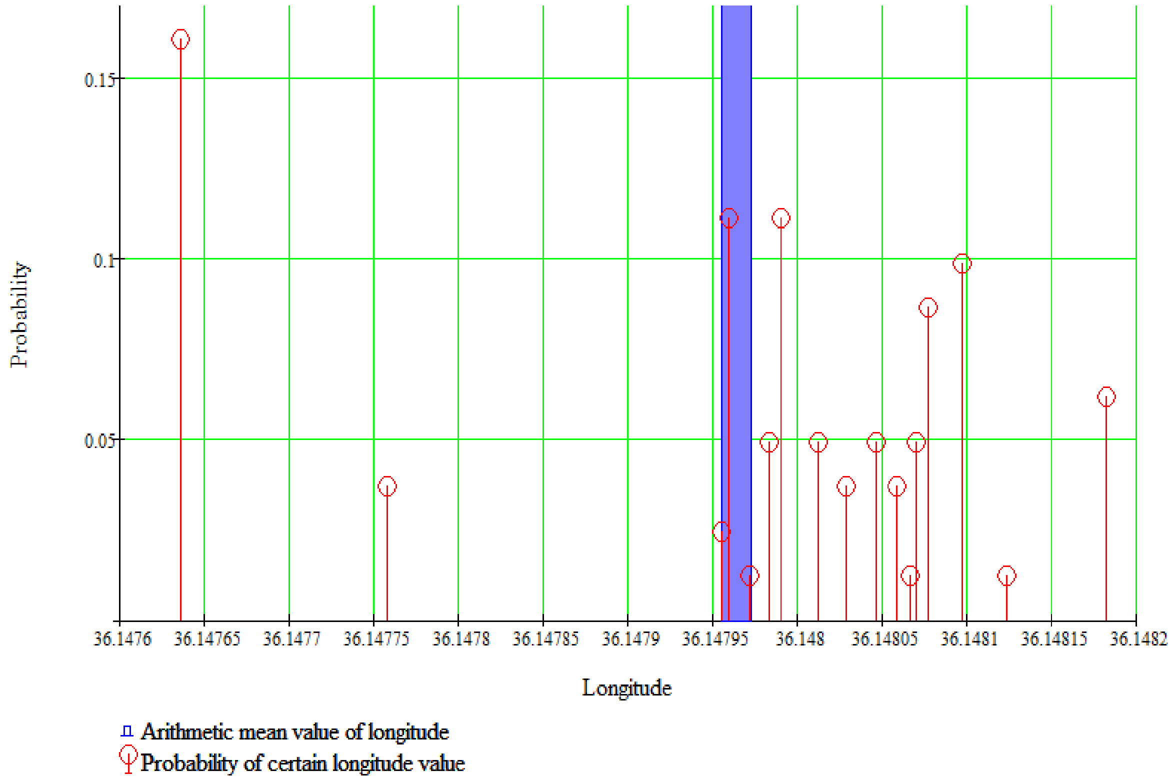

Figure 9 The probabilities of certain longitude samples occurrence

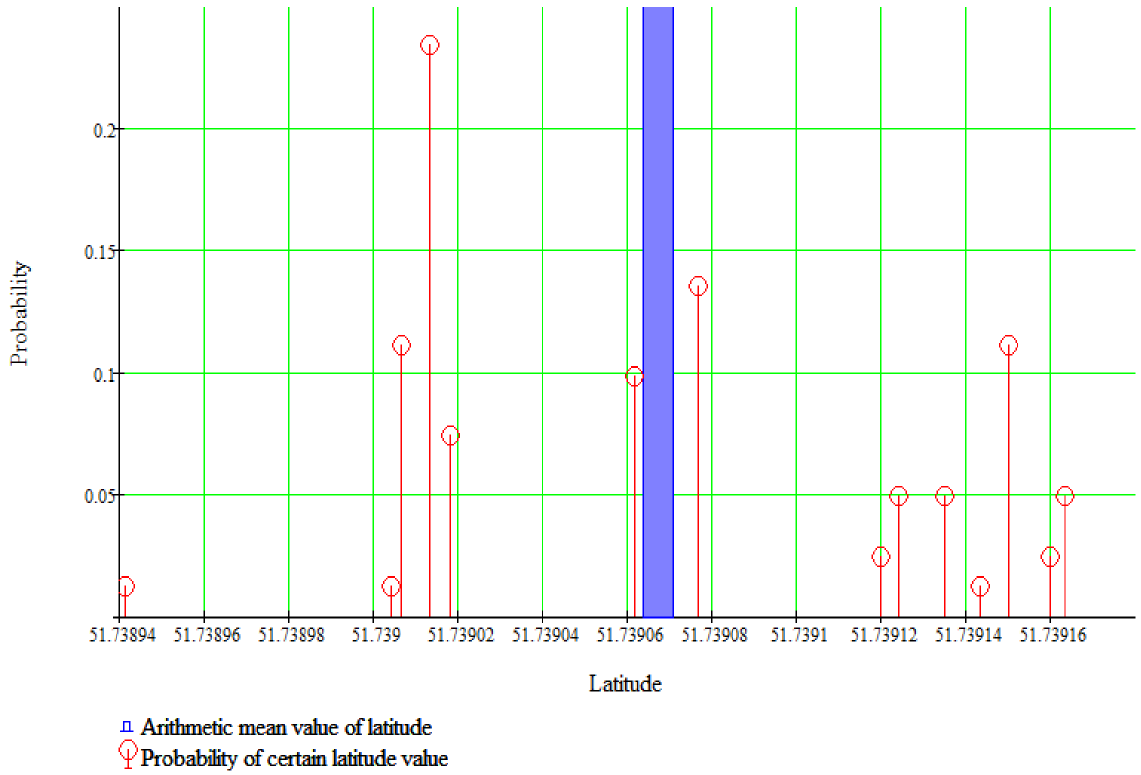

Figure 10 The probabilities of certain latitude samples occurrence

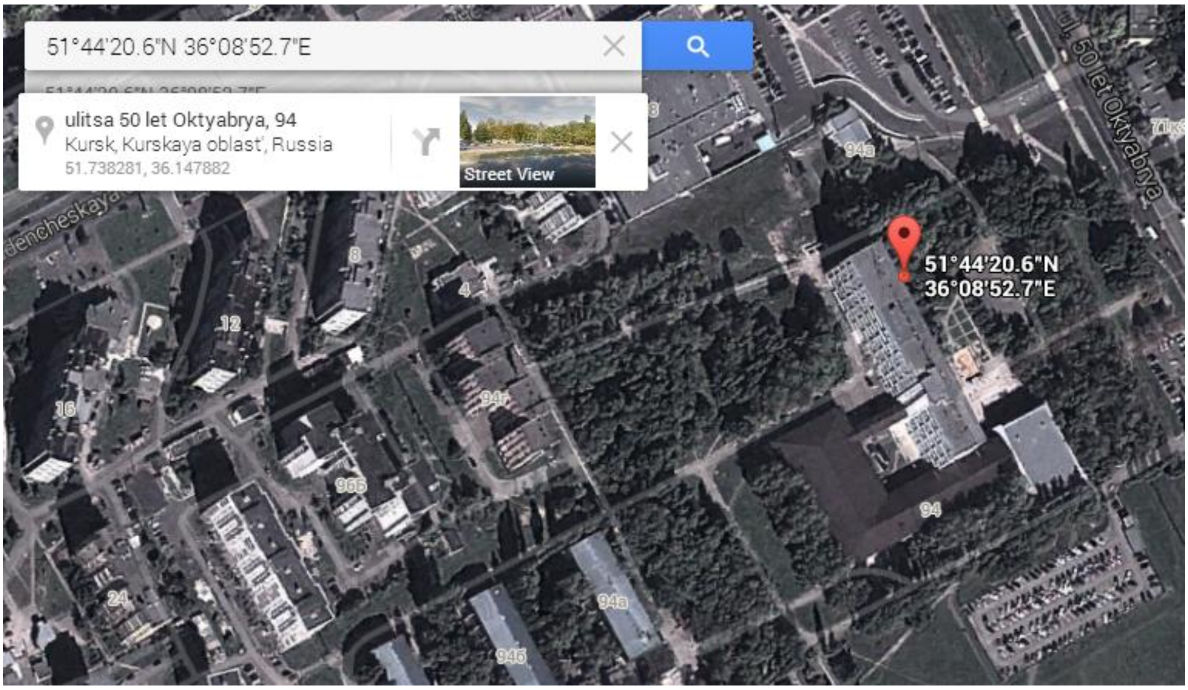

Figure 11 The Google Maps fragment with the marked point of the robot location – the robot is situated by a window of the building

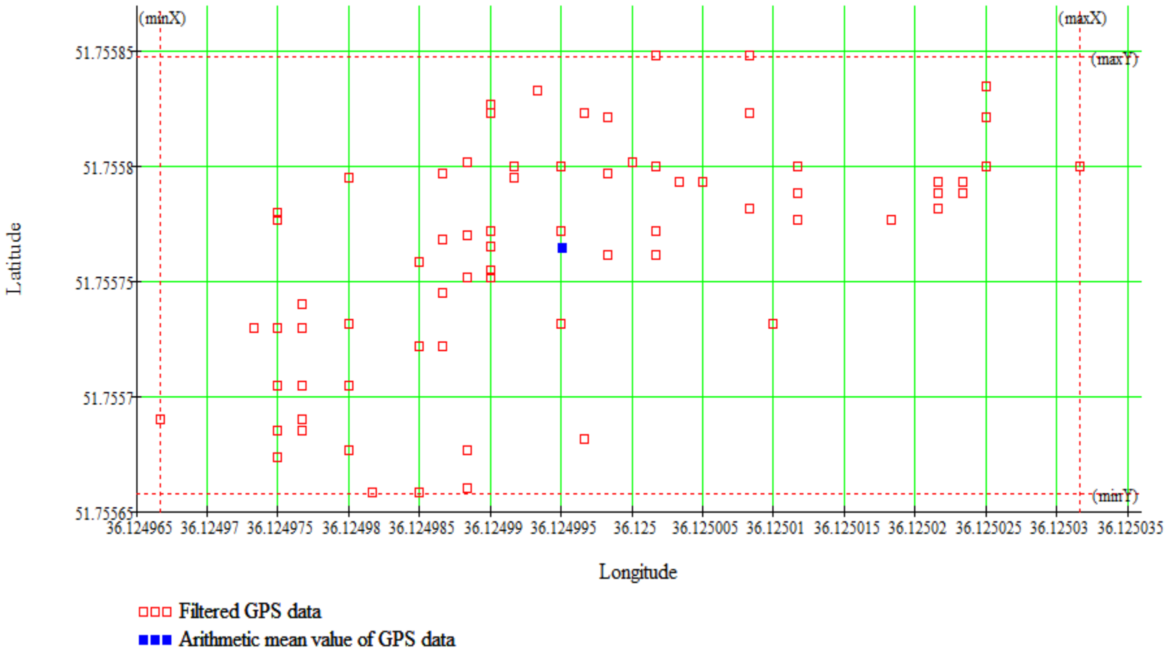

Figure 12 The dispersion of GPS data samples and their arithmetic mean value

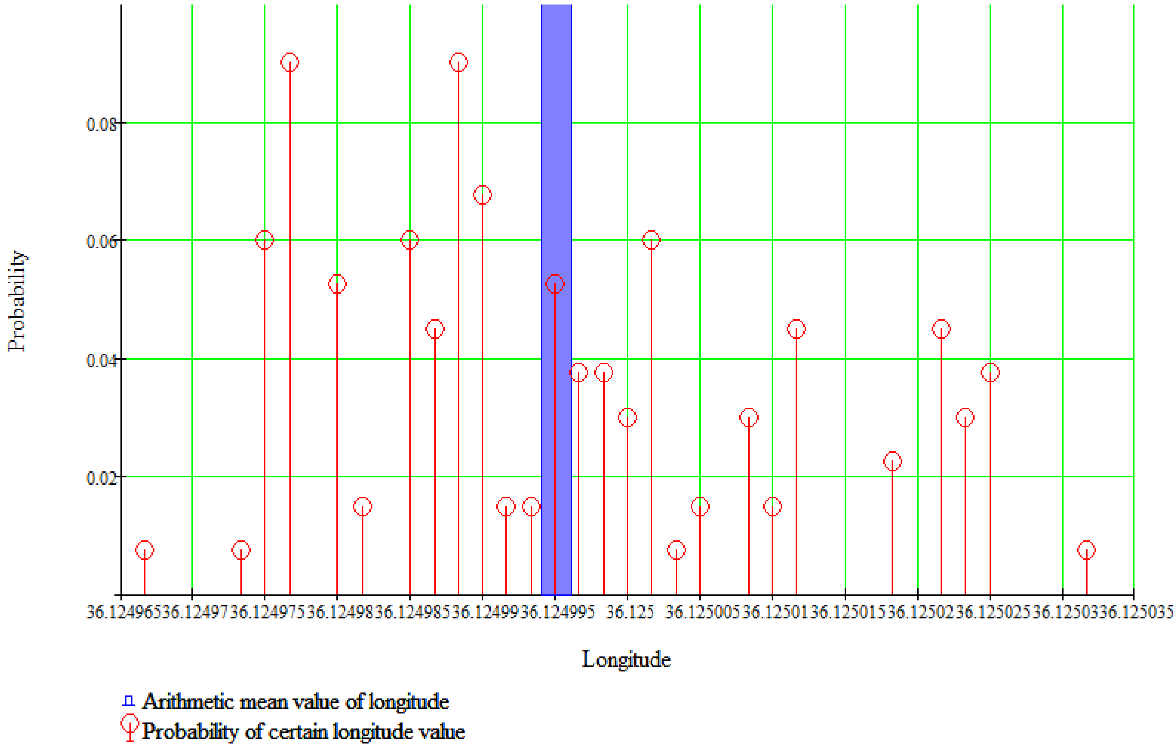

Figure 13 The probabilities of certain longitude samples occurrence

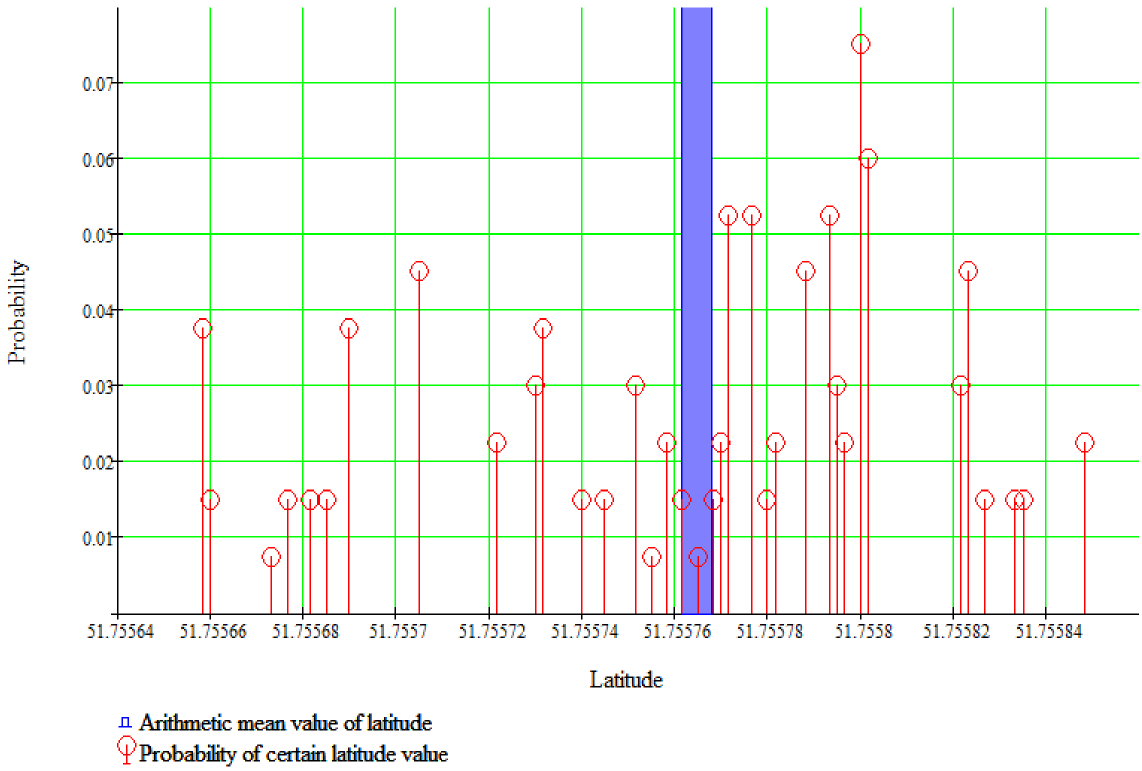

Figure 14 The probabilities of certain latitude samples occurrence

Kathmandu University Journal of Science, Engineering and Technology KUSET
Bezmen *et al.*, Vol.10, No.I, November, 2014, pp 55-72

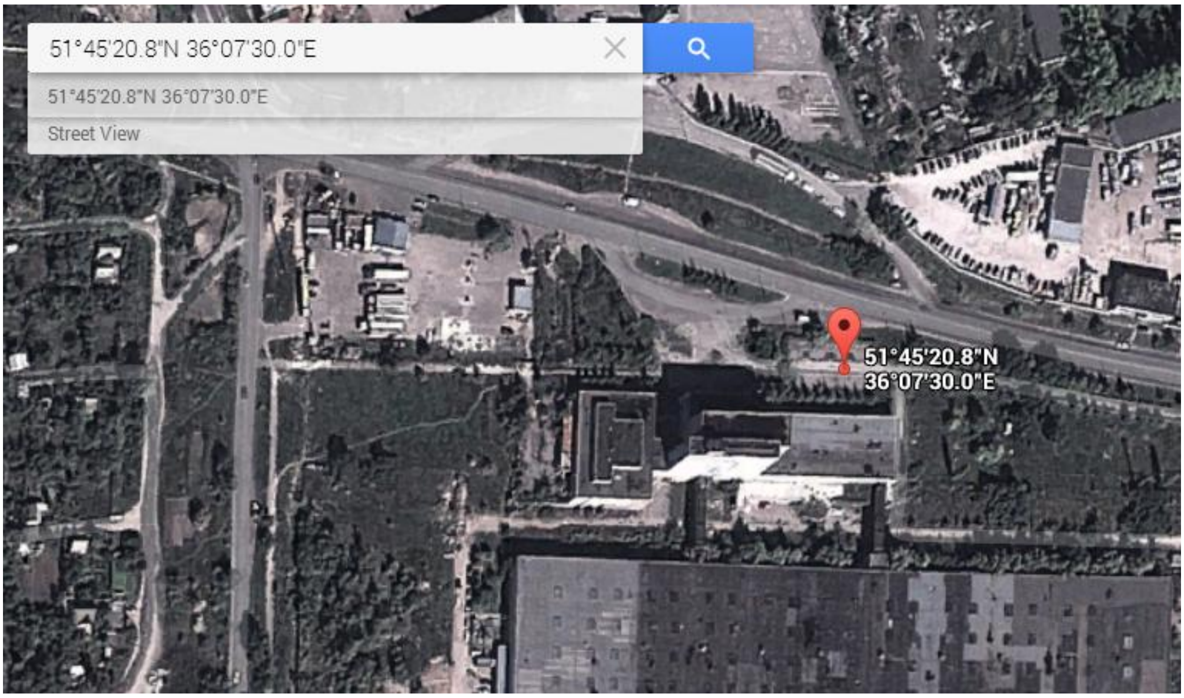

Figure 15 The Google Maps fragment with the marked point of the robot location – the robot is situated in open territory

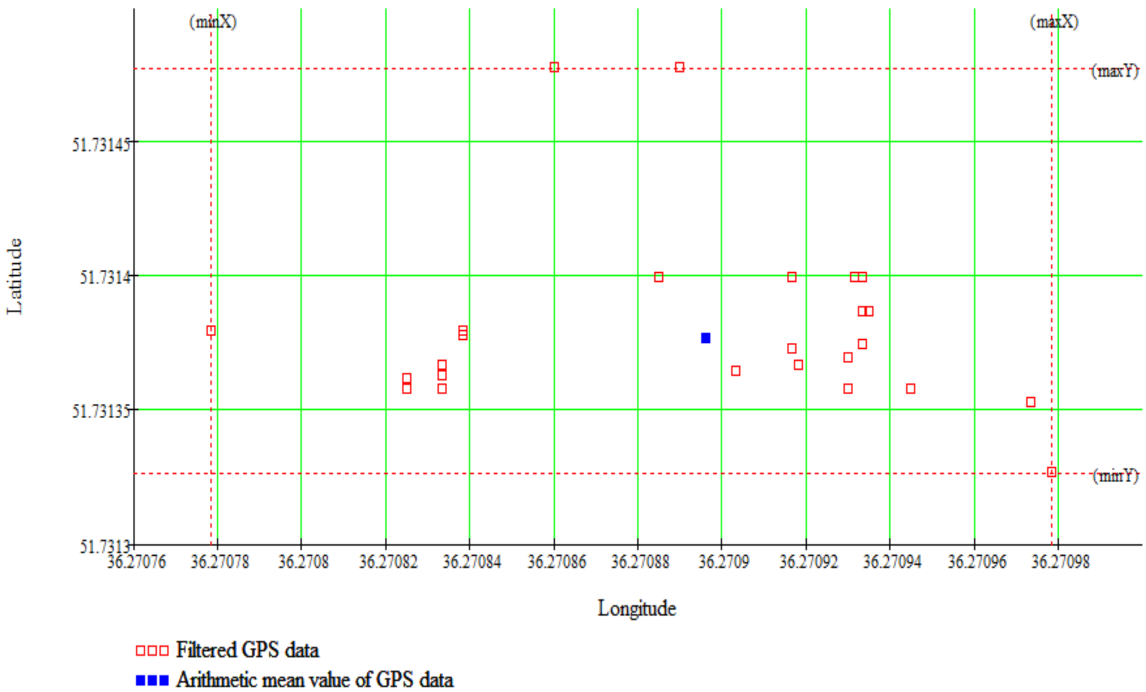

Figure 16 The dispersion of GPS data samples and their arithmetic mean value

Bezmen *et al.*, Vol.10, No.I, November, 2014, pp 55-72

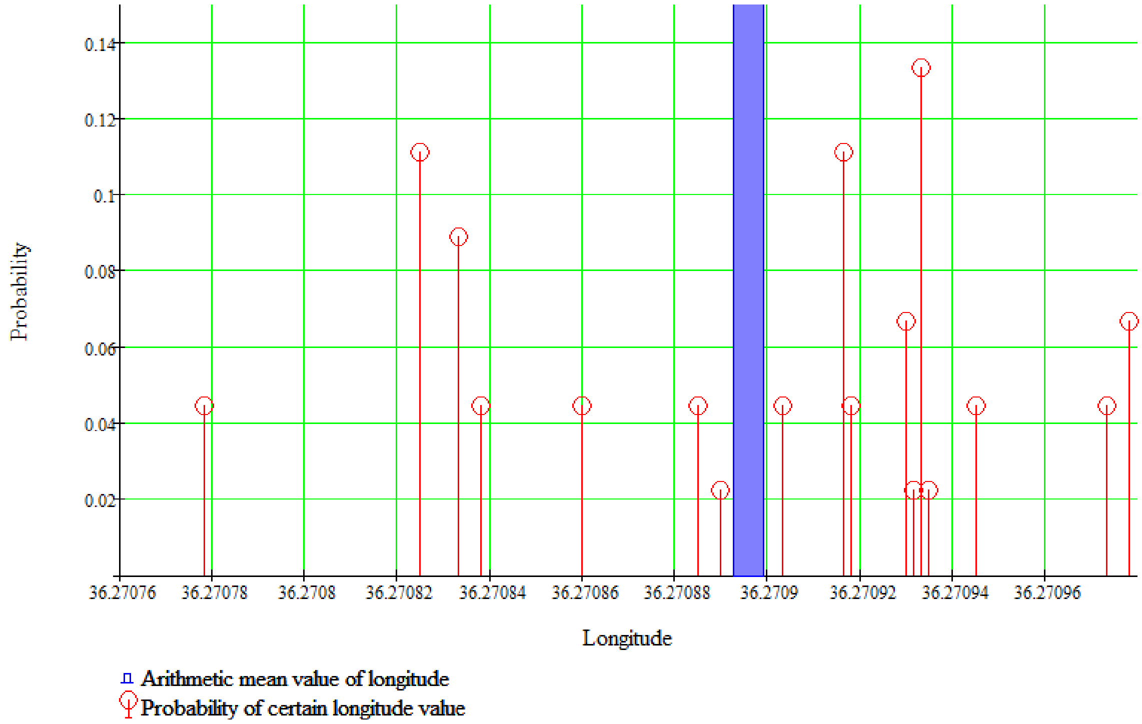

Figure 17 The probabilities of certain longitude samples occurrence

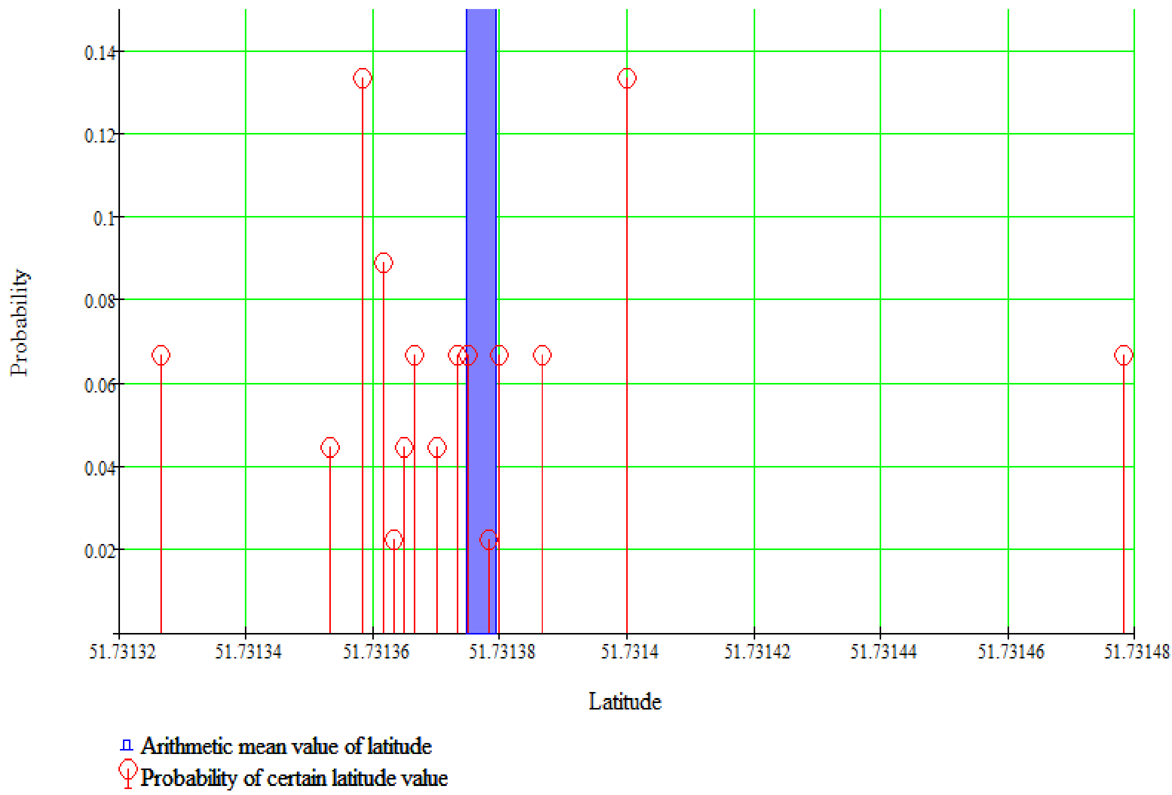

Figure 18 The probabilities of certain latitude samples occurrence

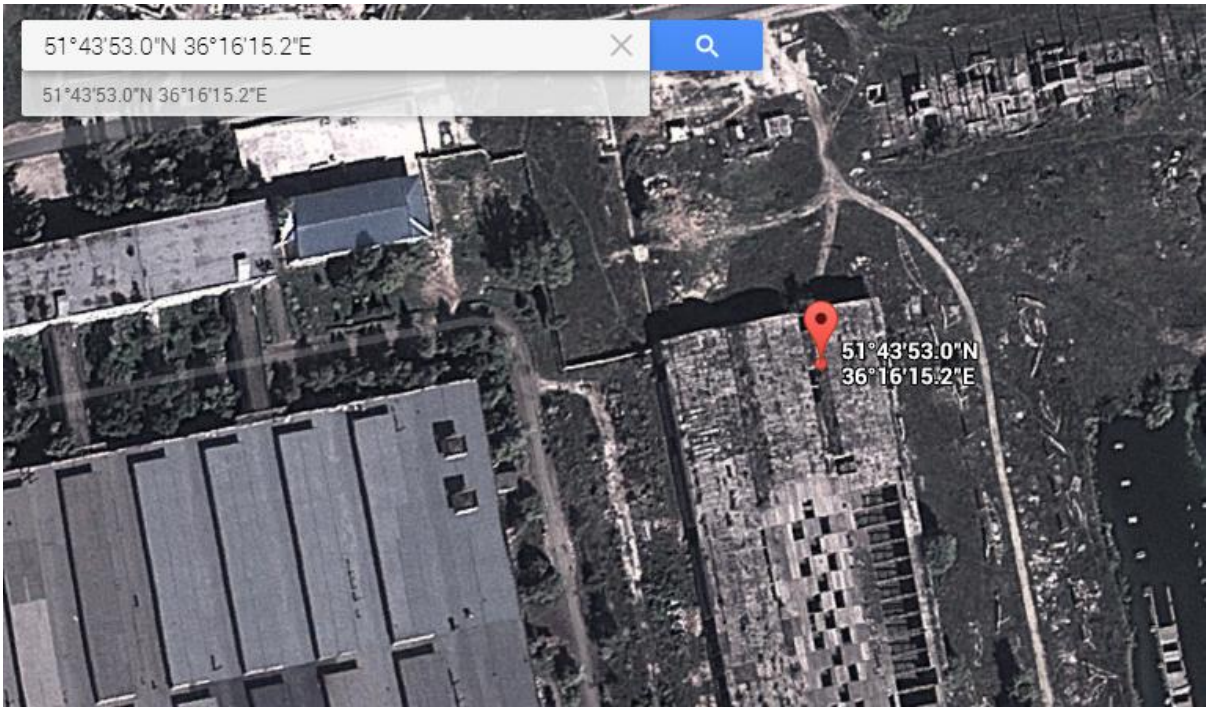

Figure 19 The Google Maps fragment with the marked point of the robot location – the robot is situated under a breach of the old factory roof

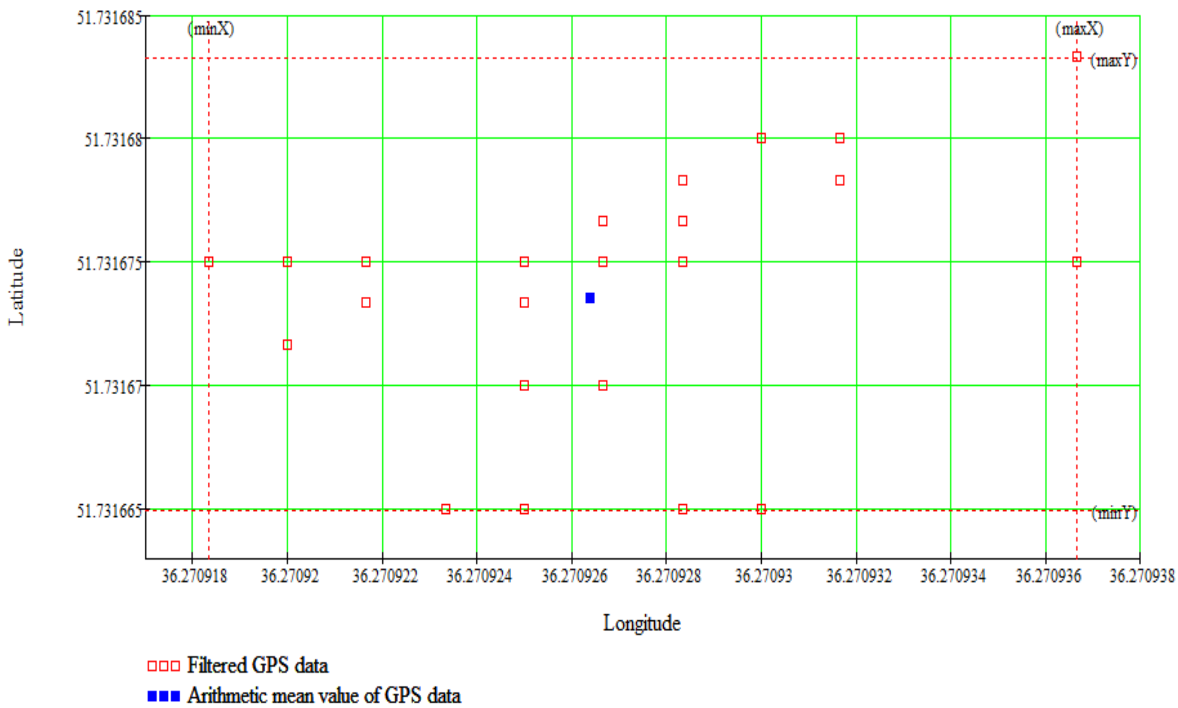

Figure 20 The dispersion of GPS data samples and their arithmetic mean value

Kathmandu University Journal of Science, Engineering and Technology KUSET
Bezmen *et al.*, Vol.10, No.I, November, 2014, pp 55-72

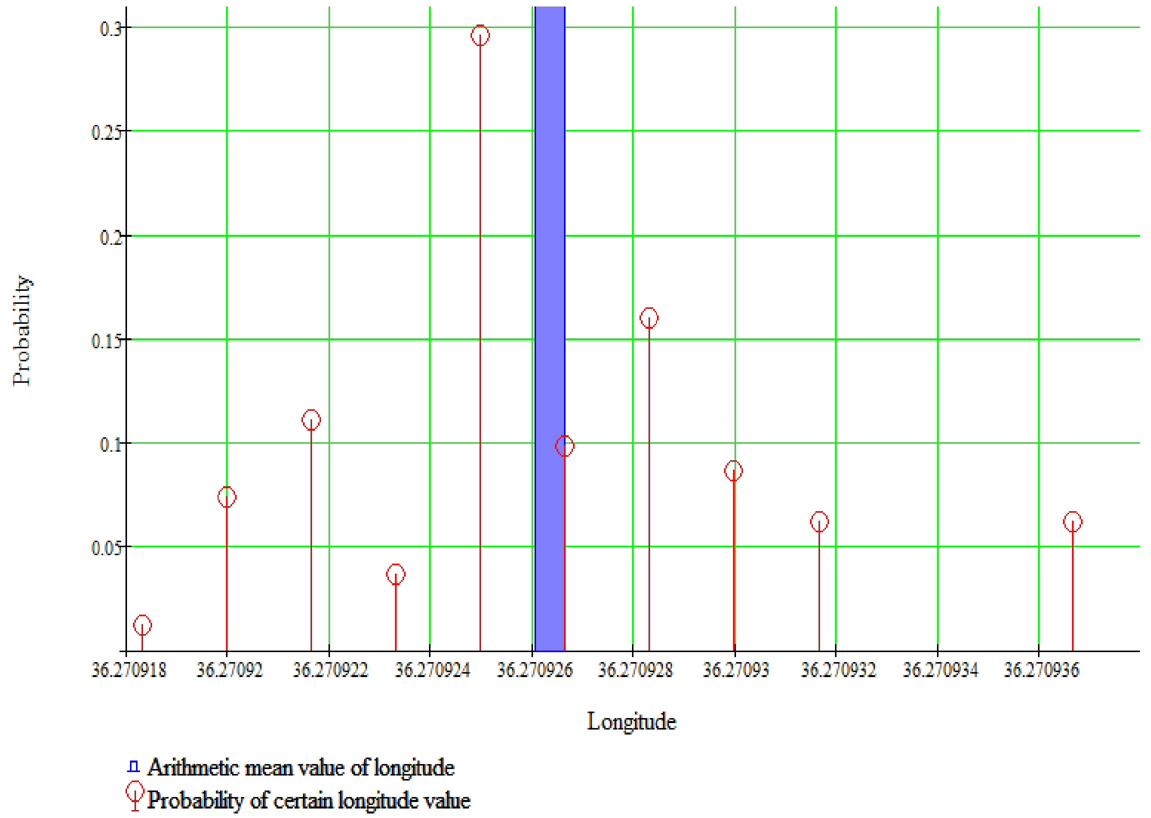

Figure 21 The probabilities of certain longitude samples occurrence

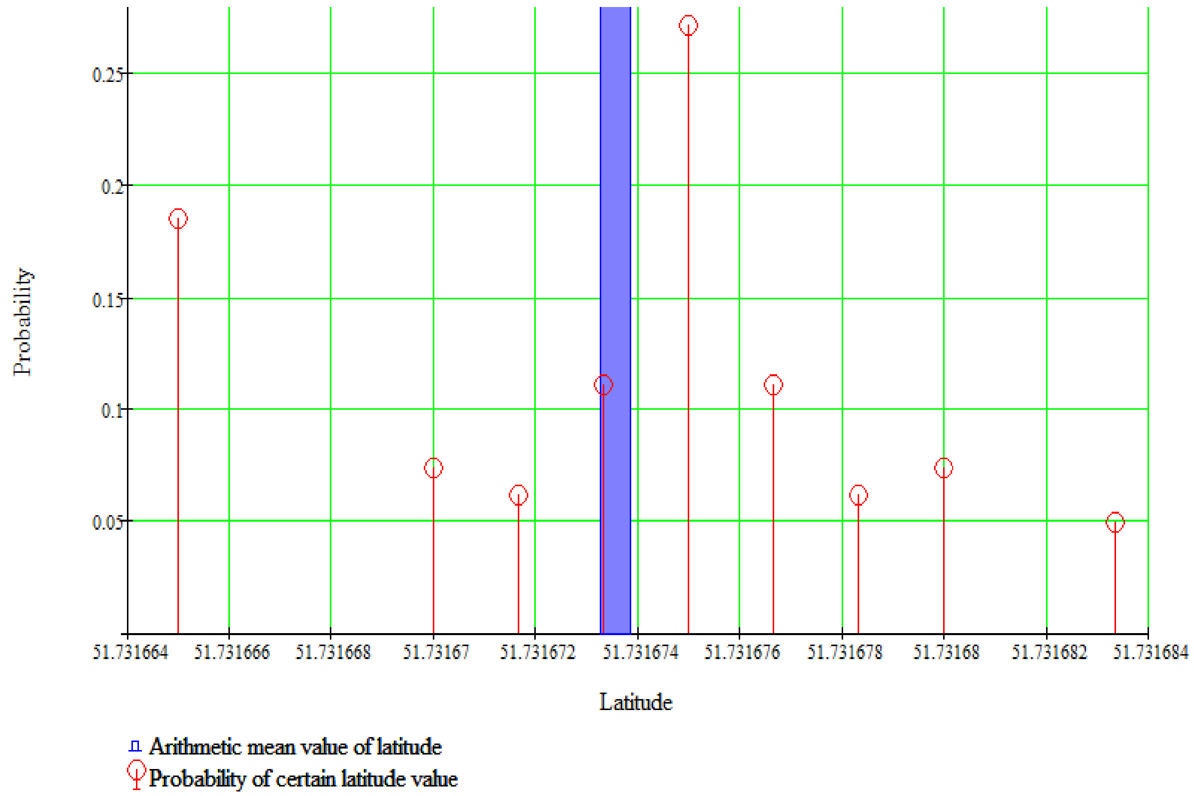

Figure 22 The probabilities of certain latitude samples occurrence

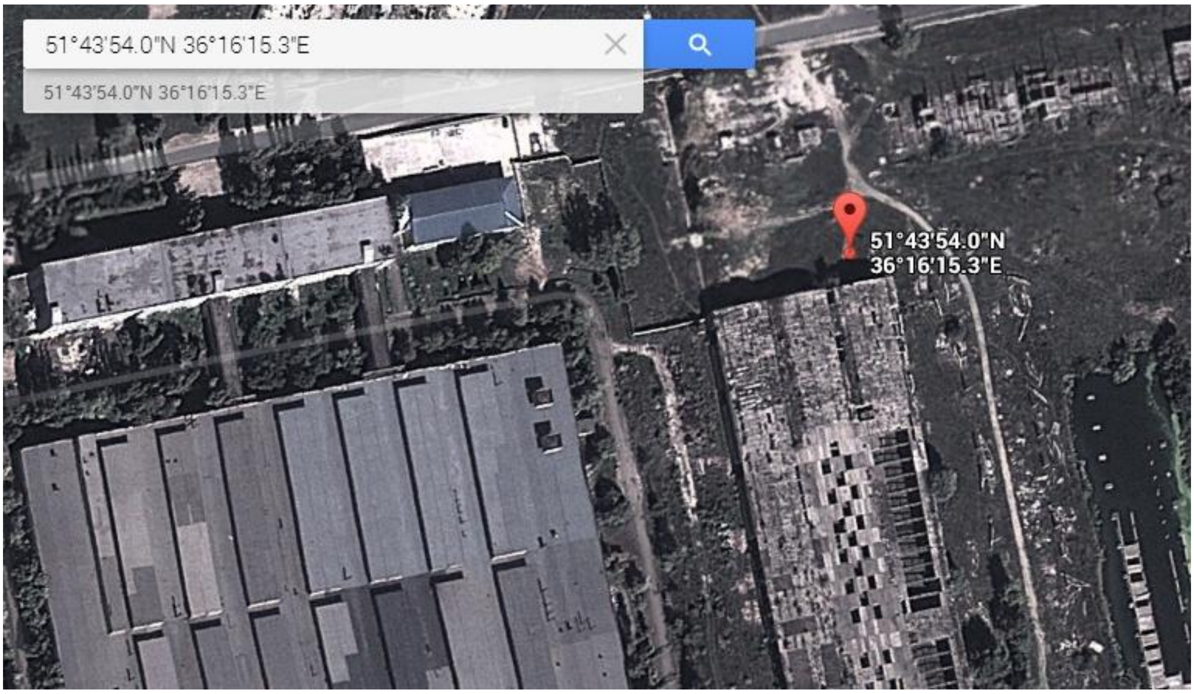

Figure 23 The Google Maps fragment with the marked point of the robot location – the robot is situated in open territory

ACKNOWLEDGEMENT
This research was supported by the research facilities of the Southwest State University, Russian Federation.

REFERENCES
[1] Martynenko Ju G, Motion control of mobile wheeled robots / Ju.G. Martynenko // *Fundamental and Applied Mathematics*. 11(no. 8)(2005) 29-80, ISSN 1560-5159.
[2] Aliseichik A P, The method of a multiwheeled mobile robot movement dynamic comfortability analysis / A.P. Aliseichik, V.E. Pavlovsky // *The preprints of the Keldysh Institute of Applied Mathematics*, No. 84.(2010) 1-27, ISSN 2071-2898.
[3] Bezmen P A, Manipulator system equipped mobile wheeled robot "X6WD" / P.A. Bezmen, K.G. Kazaryan // *Vibration technology, mechatronics and controlled machines – Kursk, Southwest State University*. **2** (2014) 152-161, ISBN 978-5-7681-0925-7.
[4] Bezmen P A, Movement control system of mobile six-wheeled robot / P.A. Bezmen // *Natural and engineering sciences*. No 1 (2014) 126-127, ISSN 1684-2626.
[5] Yatsun S F, Functioning principles of the six-wheeled robot movement automatic control system / S.F. Yatsun, P.A. Bezmen, K.G. Kazaryan // *Natural and engineering sciences*. No 2 (2014) 167-171, ISSN 1684-2626.