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COOPERATIVE LOCALIZATION BETWEEN AIR AND GROUND ROBOTS

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Abstract

This paper studies the cooperative aspect of air and ground multi-robot system which focuses on the localization of an unmanned ground vehicle (UGV) using the information from an unmanned aerial vehicle (UAV). The main problem in the cooperative robotic system is how to acknowledge the position of each other which would affect the ability to localize each robot on the map. Therefore the FastSLAM algorithm is implemented in the UGV to estimate robot positions using the additional information from the UAV.

1. Instructions

Robots have been increasingly used for exploration in area that difficult or dangerous to access by human such as fire hazard area or mountains. In large area, there is also the need for using more than one robot. Different types of robot can also be used to increase the coverage area which requires different type of mobility.

In the system of air-ground multirobot, the unmanned ground vehicle (UGV) is used to cover the detail of the ground area while the unmanned aerial vehicle (UAV) provides larger aerial view of the explored space. Most researches use the GPS data to estimate the position of both robots in cooperative task [1]. However, the GPS data can be erroneous in bad weather condition and thick vegetation area. Some researchers [2] [3] suggested the used of shared image data between air and ground robot. The aerial view information from the air robot can improve the performance of position estimation of the ground robot than the local information from the ground robot alone.

This research proposed the method of cooperative localization between the air and ground robots which share the same explored space using image data from both robots (as show in Figure 1). The image data is processed in order to identify important features in the image such as landmarks and the robot. Standard image processing technique such as Blob analysis is used for feature identification. After the important features are identified in images from air and ground robot, the FastSLAM method is applied for position estimation. This paper will explain about the landmark detection using image data, the position estimation technique and the experiment that perform to validate the proposed method.

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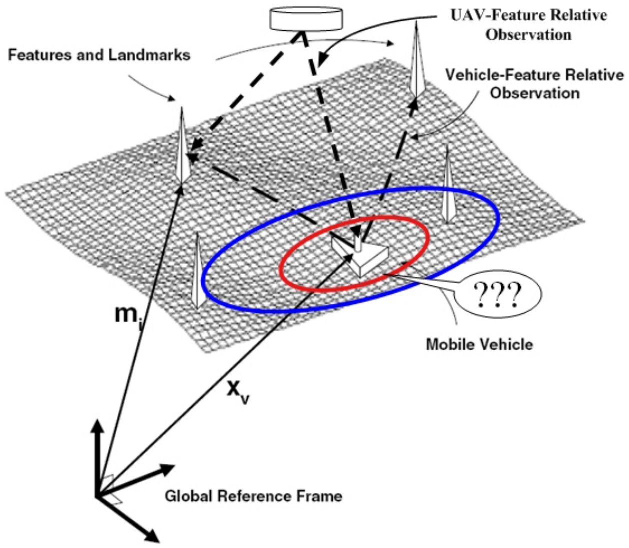

Figure 1. The conceptual diagram of air-ground cooperative localization

2. Landmark detection

In order to obtain the position information of the robot from an image data, features in an image has to be identified for landmark and robot detection.

Blob analysis technique (as shown in Figure 2) is used to separate the feature of interest from the background. The center, area and direction of objects are also obtained from the blob. When the blob is identified as landmark, the position of landmark is used as a reference for robot localization as will be explained in the next section.

Figure 3 shows images from aerial view from the air robot and the front view from the ground robot before and after blob analysis is applied.

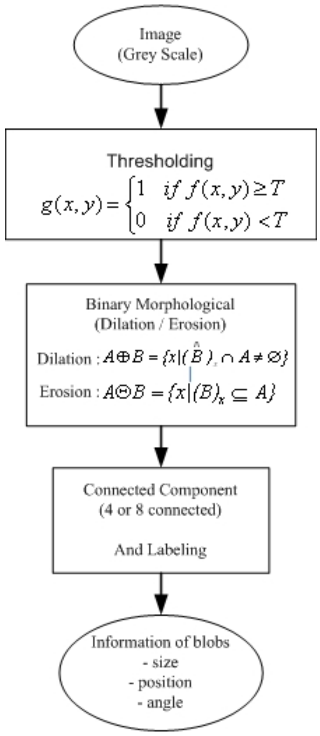

Figure 2. Diagram of blob analysis algorithm

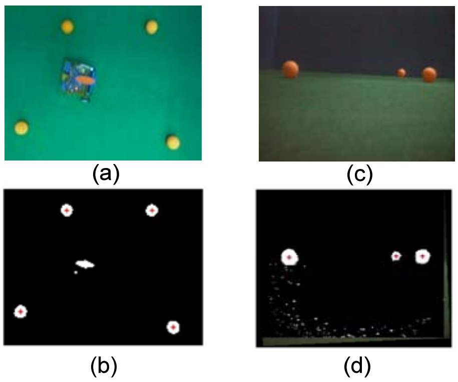

Figure 3. Raw Image: Top view (a) and Front view (c). Processed image by blob analysis: Top view (b) and Front view (d).

3. Position Estimation

After landmarks positions are identified from image data of both UAV and UGV, these information can be used to enhance accuracy of position estimation.

The proposed method for cooperative localization can be divided into two step processes: Geometric based position estimation and FastSLAM.

3.1 Geometric based position estimation

Position of the robot can be estimated from image data based on geometrical relationship between the robot and the surrounding landmarks. Stroupe et al. suggested the method of estimate the robot position from sensor measurement of multiple ground robots [4].

In this research, two different image viewpoints are used for calculating robot position. The aerial view (top view) image which is obtained from the UAV is used to estimate the position of the ground robot from its geometrical relationship with the known landmarks. The front view image which is obtained from the UGV is used to further refine the position estimation of the robot by referencing with its own surrounding landmarks.

From the top view image, distances between each observed landmarks position and the ground robot position can be found from equation (1). Angles between each observed landmarks and the ground robot can be calculated from equation (2).

$$D_i=\sqrt{(x_{UGV}-x_i)^2+(y_{UGV}-y_i)^2} \qquad (1)$$

Where i is number of landmark, x_i and y_i is position of i landmark (as show in Figure 4).

$$\theta_2=\arctan(\frac{y_o-y_r}{x_o-x_r}) \qquad (2)$$

In figure 4, θ_1 is the orientation of UGV and θ_2 is the angle between landmark *0* and axis x of global frame. The angle between the landmark *0* and the ground robot is the sum of θ_1 and θ_2.

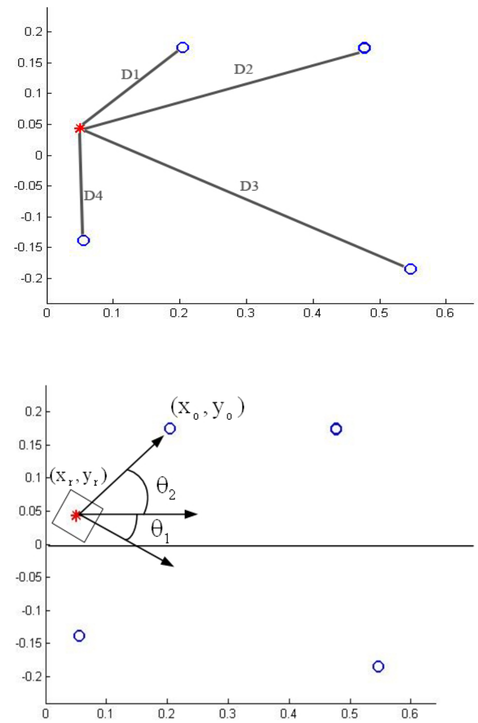

Figure 4. Estimation of distance and angle between the ground robot and the landmark from the top view.

From the front view image obtained from the UGV, the z-distance (z-depth) from the ground robot to the landmark is estimated from the size of the blob (as shown in Figure 5). From the estimate center pixel of the landmark blob, the angle between the robot and the landmark is calculated from equation (3). The camera viewing angle is defined as θ_{cam}.

$$\theta_{meas} = \frac{\left(\frac{col_{image}}{2} - x_{LM}\right) \times \theta_{cam}}{col_{image}} \quad (3)$$

The distance and angle between the ground robot and the landmark is then calculated from the z-distance and the measure angle (θ_{meas}), as shown in Figure 5.

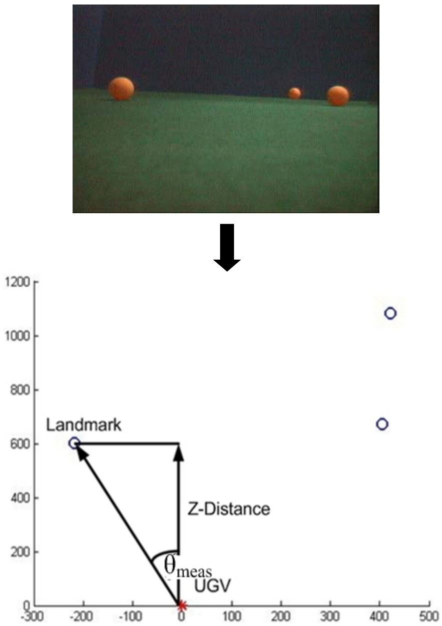

Figure 5. Estimation of distance and angle between the ground robot and the landmark from the front view image

3.2 FastSLAM

The position estimation based on image data alone does not provide enough accuracy for robot localization. FastSLAM technique [6] [7] can enhance the accuracy of position estimation using the statistical knowledge as shown by equation (4) in which the first term: the Robot path posterior $p\left(s^t \middle| z^t, u^t, n^t\right)$ and the second term: landmark estimators $p\left(\theta_n \middle| s^t, z^t, u^t, n^t\right)$ are combined to improve the accuracy of the estimated position.

$$p\left(s^t, \Theta \middle| z^t, u^t, n^t\right) = p\left(s^t \middle| z^t, u^t, n^t\right) \prod_{n=1}^{N} p\left(\theta_n \middle| s^t, z^t, u^t, n^t\right) \quad (4)$$

FastSLAM Library from Tim Bailey [5] was adapted for this research work. Figure 6 shows the flow chart of the position estimation computation using the observed data from section 3.1 as an input.

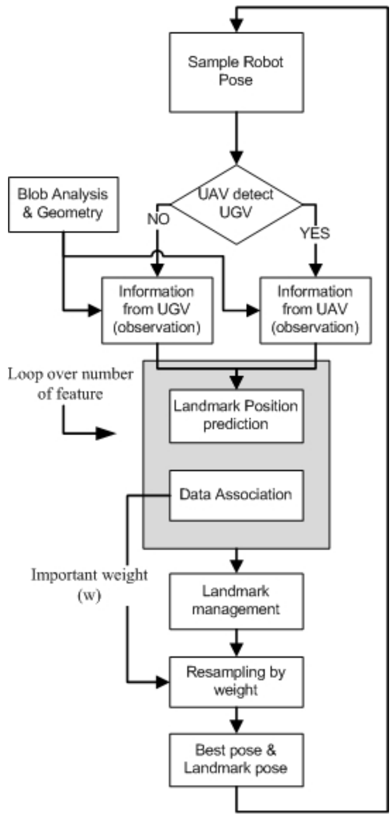

Figure 6. Flow chart of the proposed FastSLAM algorithm

4. Experimental System

In order to verify the performance of the proposed position estimation system, the experimental system was constructed as the simplified version of the cooperative air-ground multirobot system. The experimental system comprises of the 8x8 cm^2 differential drive robot equipped with a wireless camera to represent the UGV. The low level speed control is implemented on the Phillips LPC2138 (ARM7) processor. The ARM7 controller receives the velocity command from the central processing unit via RS-232 serial communication (as show in Figure 7).

The UAV is represented by an overhead XY Cartesian type robot with 200x150 cm^2 workspace. The Logitech webcam is attached to the XY robot which is position controlled by PLC (as show in Figure 8). The robot also receives the position command from the central processing through RS-232. The position estimation of both robots is performed by the central processing computer as shown as the block diagram in Figure 9.

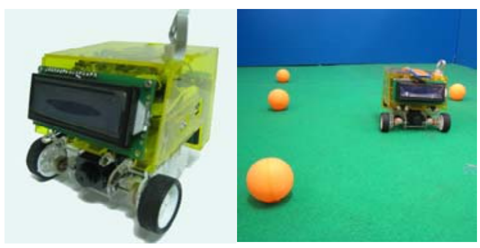

Figure 7. Mobile platform

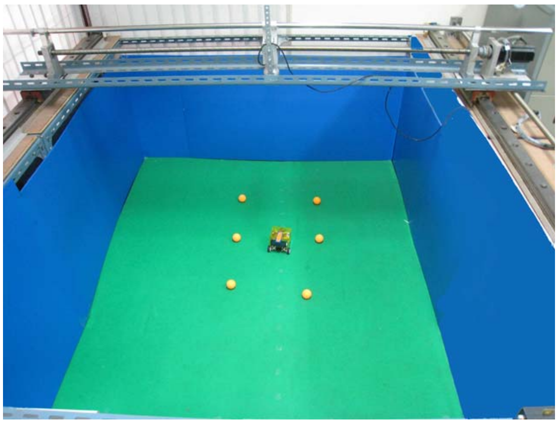

Figure 8. Experimental testbed

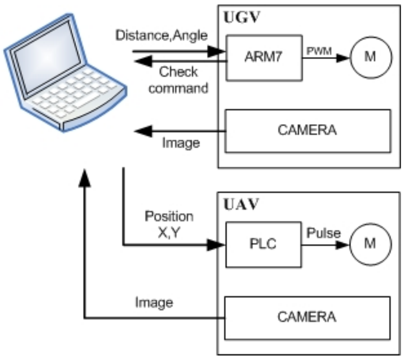

Figure 9. System block diagram

5. Experimental Results

In the experiment, way-points along the path are given to both UGV and UAV. When the UGV is moving, the new position estimation is performed using FastSLAM algorithm as explained in section 3. The distance and angle between the UGV and landmarks are estimated from the image data whenever the image is received.

Two methods are tested in this experiment; without infor-mation from UAV and with information from both UAV and UGV using the proposed method as explained in section 3.

5.1 Without information from UAV

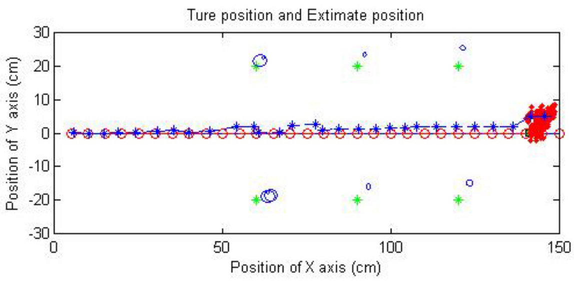

Figure 10. Estimated position of the UGV without information from the UAV: (o) is the way-points, (*) is the estimated position from FastSLAM.

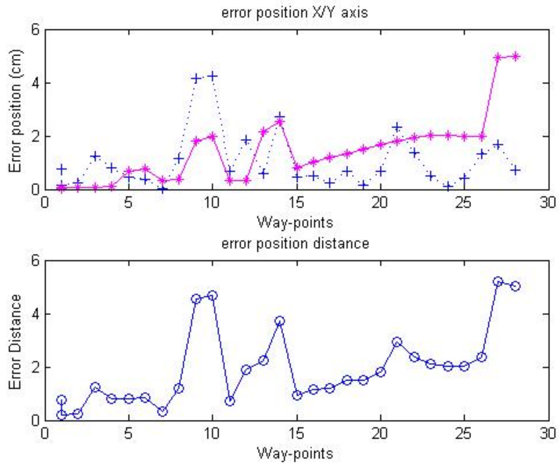

Figure 11. Position error between the way-points and the estimate position in X/Y axis: (+) is error X axis and (*) is error Y axis, and distance error between the way-points and the estimated position

5.2 With information from UAV

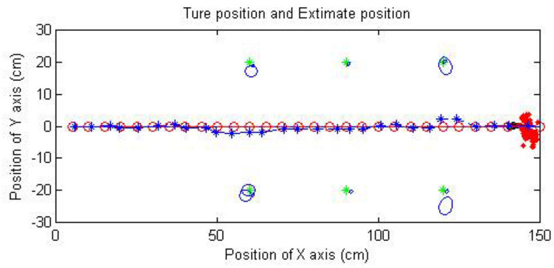

Figure 12. Estimated position of the UGV with the combined information from the UAV: (o) is the way-points, (*) is the estimated position from FastSLAM.

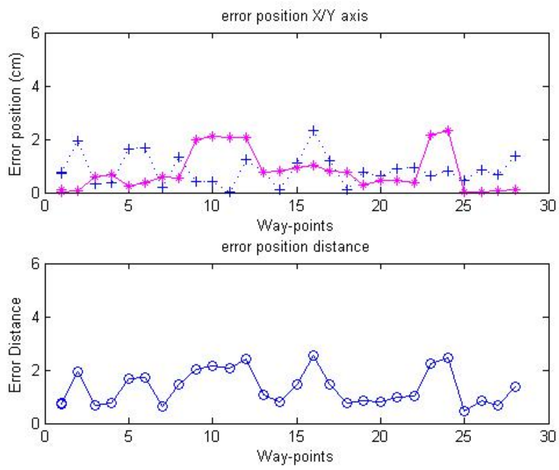

Figure 13. Position error between the way-points and the estimate position in X/Y axis: (+) is error X axis and (*) is error Y axis, and distance error between the way-points and the estimated position

Figure 10 shows the result of the estimated position and the way-points without information from UGV. From the result, the error between the way-points and the estimated position is high as shown in Figure 11. Therefore the position estimation by using of the information from UAV is used to reduce error in both position and angle thus increase the accuracy of position estimation by decreasing not less than 20%, approximately, of the error distances summation shown in Figure 12 and Figure 13.

From the experiment, the error distances are used to calculate the standard derivation (S.D.) of both position estimation methods with 100 200 and 300 particles in particle filter of FastSLAM (as show in Table 1, 2 and 3). The standard derivation from the proposed cooperative localization method is smaller than the first method about 15% with 100 200 and 300 particles.

Table 1
Standard derivative of position error with 100 particles

S.d.	Without UAV	With UAV
1	0.87	1.05
2	2.46	1.76
3	2.26	1.56
4	1.45	1.24
5	2.20	1.28

Table 2
Standard derivative of position error with 200 particles

S.d.	Without UAV	With UAV
1	2.01	0.93
2	1.55	1.01
3	2.38	1.17
4	2.52	1.20
5	2.21	1.06

Table 3
Standard derivative of position error with 300 particles

S.d.	Without UAV	With UAV
1	1.80	1.13
2	2.69	0.76
3	1.63	1.31
4	2.21	1.42
5	1.50	1.30

6. Conclusion

In this paper, the cooperative localization method between the multiple robots system comprises of UGV and UAV was proposed. First, the position of the robot is estimated using the location of landmarks which are identified from the image. The position information of the robot is acquired from the UGV and the UAV. These information are combined using FastSLAM algorithm to provide the more accurate position estimation of the robot. The proposed cooperative localization method is tested in the experimental testbed, compared with the localization method that used only information from UGV. The experimental result shown that the proposed cooperative localization method can improve the accuracy of position estimation by 15 percent in this experimental environment.

7. References

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