Mobile sensor device in Intelligent Space

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Abstract

In this research, we propose mobile sensor device in Intelligent Space. Intelligent Space, that is our recent research topic, is the system consistituted of distributed sensor devices and robots agents. We focuse on the capabiility of sensor devices which are mainly CCD cameras for acquisition of position information of the object in Intelligent Space.

In this paper, we tried to the estimation of position and posture of mobile distributed sensor device in Intelligent Space. This mobile sensors are for extension of technologies for Intelligent Space in scalability and so on. The estimation method is solving Perspective n Points problem on camera device on the device. Then, we describe the measuring experiments of the objects in Intelligent Space briefly.

Keyword

Intelligent Space, position estimation, camera calibration, Perspective n Points Problem

1 Introduction

This research is about mobile sensors in Intelligent Space[1][2]. Intelligent Space is a kind of platform that serves users through the robots connected the space based on the information from distributed sensor devices. In the recent research, these sensor devices have been realized with general CCD cameras and computers as vision processing system. This is mainly because we assume the services that Intelligent Space will offer are based on the users' and the robots' (received the directions from the space) position information and vision sensors system is very useful and reasonable for this purpose. We note this point, and so purpose mobile sensor device as a technique for acquiring more detailed position information of the objects in Intelligent Space.

To achieve mobile sensor device, first, we will purpose the method of estimation of the position and posture of mobile sensor device. To provide position information of the objects, it is necessary to obtain the sensor's own position and posture information. In this research, in order to construct simple system, we estimate the status of the device by solving Perspective n Points (PnP) problem of camera on the device. This is an appreciate approach is for employing the advantage of Intelligent Space that the information of the space is given as world coordination. In this reserach, we try the methods whose perspective points is 3 and 4. But in this paper, we will describe the metod using P4P problem solution only. Then, we will describe position measurement method of the objects. This is the method in the past researches.

2 Mobile Sensor

As we mentioned above, disributed sensor device in Intelligent Space acts for localization. Since our system uses CCD camera, to provide accurate position information of the object, camera position is necesary. We have researched on evaluation of camera arrangement [2], but we have treated simple environment. To intellectualize more complicated environment, we need to consider more dynamic system. Then, we propose mobile sensor device in Intelligent Space.

The proposal will bring other some merits. For example, since we consider that tracking or trace of the object is basic action of the robots in Intelligent Space, mobility of the sensor will make those task more easily. and, mobile sensor device may make the task which needs more accuracy, such as face or gesture recognition, more easier.

To realize mobile sensor device, we consider the camera self-localization. This is neccesary to cooperate with other distributed sensor device that is basis of Intelligent Space.

3 Self-position estimation of the mobile sensor using its camera system

3.1 Estimation method

In this research, in order to construct the simplest system, we estimate the status of the device by solving Perspective n Points (PnP) problem of camera on the device by numerical method. PnP problem is the problem to solve the position and posture of camera using the pixel value of n points whose position in world coordinate system.

There are some reasons for using PnP Problem following;

1. The amount and time of computation is stable
2. Estimation error is predictable
3. Easy to realize

1. is fulfilled by taking numerical method and using a small number of landmarks as perspective points. The number of landmarks is related to 3., . The least number for solving PnP Problem is three, but in case using P3P problem the estimation error is too large. Then, in this paper, we abridge the approach using P3P Problem solution and discribe the approach of Perspective 4 Points Problem (P4P Problem). 2. is the one of the merits of this approach.

3.2 P4P Problem of on-board camera

In this paragraph, we describe the simplified P4P problem solution as the sensor device position estimation. To simplify the solution, we assume that;

- Distortion of CCD camera can be ignored.
- Internal parameters of the system (focus length, center of vision, etc) is known.
- Position and posture of sensor device are determined unique if the exteranal camaera paremeters are determined.

The transfer equation from world coordinate system $[x_c \; y_c \; z_c]^T$ to camera coordinate syetem $[x_w \; y_w \; z_w]^T$ is as followed[3](Fig:1);

$$\tilde{c} = M\tilde{w} \tag{1}$$

where M is

$$M = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} & R & & T \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where R is 3×3 rotation matrix

$$R = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \tag{2}$$

and T is translation vector

$$T = \begin{bmatrix} m_{14} & m_{24} & m_{34} \end{bmatrix}^T \tag{3}$$

and $\tilde{c}$, $\tilde{w}$

$$\tilde{c} = \begin{bmatrix} x_c & y_c & z_c & 1 \end{bmatrix}^T, \; \tilde{w} = \begin{bmatrix} x_w & y_w & z_w & 1 \end{bmatrix}^T$$

Using orthogonal property of R, the following equation;

$$\sum_{k=1}^{3} m_{km}^2 = 1 \tag{4}$$

$$\sum_{k=1}^{3} m_{km} m_{kn} = 0 \tag{5}$$

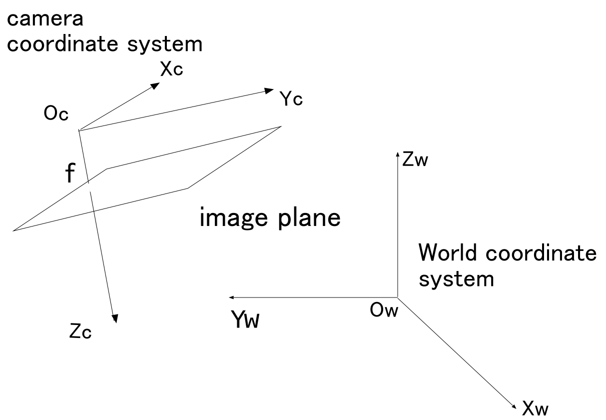

Figure 1: Coordinate system

Transformation from camera coordinate system to vision coordinate system is as followed[3];

$$\begin{bmatrix} x_p \\ y_p \end{bmatrix} = \frac{f}{z_c} \begin{bmatrix} x_c \\ y_c \end{bmatrix} \tag{6}$$

Since we have assumued that the internal parameters of the camera is known, we could easily obtain the transformation from vision coordinate to pixel value in vision. This transformation is depend on the value of internal and external parameters of camera, then landmarks whose position is known in world coordinates system and vision coordinates system will determine the unknown parameters.

Four landmarks used for self position estimation shall arranged on the same plane. At this time, conversion that is made the plane into $z_w = 0$ exitsts, then generality is not lost as $z_w = 0$.

Since equation(1) and equation(6),

$$x_{ip} = f\frac{m_{11}x_{iw} + m_{12}y_{iw} + m_{14}}{m_{31}x_{iw} + m_{32}y_{iw} + m_{34}} \quad (7)$$

normalized with m_{34}, the previous equation is equal to;

$$x_p = fm'_{11}x_w + fm'_{12}y_w + fm'_{14} - m'_{31}x_w x_p - m'_{32}y_w x_p$$

and through the same procrdure about y_p,

$$y_p = fm'_{21}x_w + fm'_{22}y_w + fm'_{24} - m'_{31}x_w y_p - m'_{32}y_w y_p$$

Then, that two equations for four landmarks $[x_{iw}\ y_{iw}\ 0]^T$ $(i = 1, 2, 3, 4)$ are shown as;

$$\begin{bmatrix} x_{1w} & y_{1w} & 1 & 0 & 0 & 0 & -x_{1p}x_{1w} & -x_{1p}y_{1w} \\ x_{2w} & y_{2w} & 1 & 0 & 0 & 0 & -x_{2p}x_{2w} & -x_{2p}y_{2w} \\ x_{3w} & y_{3w} & 1 & 0 & 0 & 0 & -x_{3p}x_{3w} & -x_{3p}y_{3w} \\ x_{4w} & y_{4w} & 1 & 0 & 0 & 0 & -x_{4p}x_{4w} & -x_{4p}y_{4w} \\ 0 & 0 & 0 & x_{1w} & y_{1w} & 1 & -y_{1p}x_{1w} & -y_{1p}y_{1w} \\ 0 & 0 & 0 & x_{2w} & y_{2w} & 1 & -y_{2p}x_{2w} & -y_{2p}y_{2w} \\ 0 & 0 & 0 & x_{3w} & y_{3w} & 1 & -y_{3p}x_{3w} & -y_{3p}y_{3w} \\ 0 & 0 & 0 & x_{4w} & y_{4w} & 1 & -y_{4p}x_{4w} & -y_{4p}y_{4w} \end{bmatrix} \begin{bmatrix} fm'_{11} \\ fm'_{12} \\ fm'_{14} \\ fm'_{21} \\ fm'_{22} \\ fm'_{24} \\ m'_{31} \\ m'_{32} \end{bmatrix} = \begin{bmatrix} x_{1p} & x_{2p} & x_{3p} & x_{4p} & y_{1p} & y_{2p} & y_{3p} & y_{4p} \end{bmatrix} \quad (8)$$

Since this equation and focus length f, m'_{11}, m'_{12}, m'_{14}, m'_{21}, m'_{22}, m'_{24}, m'_{31}, m'_{32} can be calulated.

On the other hand, since equation(5),

$$\sum_{k=1}^{3} m'_{km}m'_{kn} = 0 \quad (9)$$

then, m'_{13}, m'_{23}, m'_{33} are determined. Next, Since equation(4), m_{34} can be calculated. Then, the parameter of R and T is determined.

3.3 Computer simulation

We experimented the validity of the approach shown in the previous clause by computer simulation. The procedure of the experimetnt is following. We operated virtual mobile sensor device so that a spiral was drawn in the world coordinate system, and then, we obtained virtual picture from camera model. Next, based on the picture information, we apply the self-position estimation of the camera inthe preceding clauses.

Table1 is landmarks pattern used in this experience.

Table 1: Landmarks Pattern

landmark no.	1	2
position	(0.30 -1.0 0.0)	(-1.0 0.60 0.0)
landmark no.	3	4
position	(0.70 0.40 0.0)	(0.0 0.0 0.0)

The result of the experiment is shown Fig:2. Mean estimation error at eacch step was 10.2 cm.

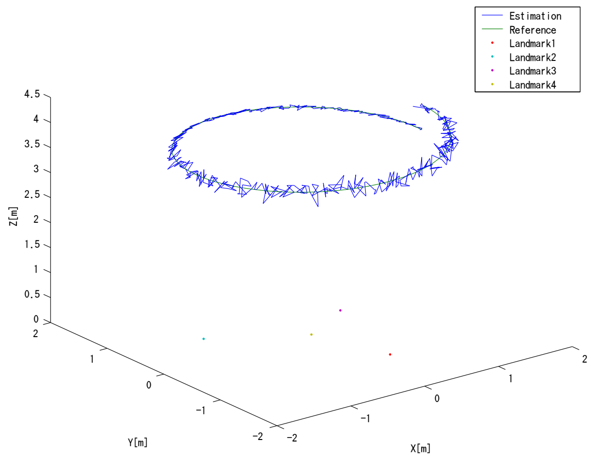

Figure 2: Self position estimation

4 Position mesurement of the object using the mobile sensor

The self-position estimation we described in the previous paragraph is for position measurement of some object (mobile robots or users) in intelligent space. In this paragraph, we show the position measurement experience of the robot whose height is known. Fig:3 is the result of computer simulation based on the self-positionestimation of the sensor in the previous paragraph.

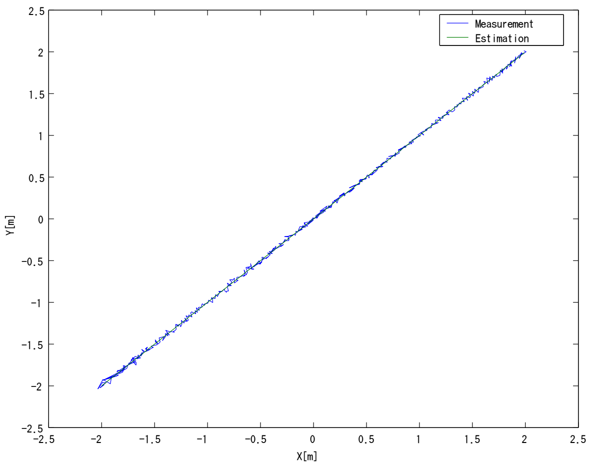

Figure 3: Measurement of the object position

In this case, mean measurement error at each step was 2.44 cm. The figure show this results is sufficient accurate for almost application we consider.

5 Summary

In this paper, we proposed the mobile sensor device in Intelligent Space, and described about self-position estimation of the mobile sensor required for the sensor to measure the position of the object. And we introduced the meaurement experiment of the object in Intelligent Space.

References

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