# AN ALGORITHM FOR AUTOMATIC LOCATION AND ORIENTATION IN PATTERN DESIGNED ENVIRONMENT

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## ABSTRACT

Special designed patterns, e.g. several parallel lines with black and white tones, are used for automatic location and orientation of a three dimensional movable object in the room environment, in which the special designed patterns are painted on the walls of the room. Three CCD cameras or at least one mounted on the object are used to take the images from the wall patterns, which are transferred to the computer via radio. The features of such patterns can be extracted full automatically. Then the shifting parameters ( $H_X, H_Y, H_Z$ ) and the rotation parameters (φ, ω, κ) can be automatically calculated without any manual operation.
The algorithm is based on traditional photogrammetrical theory , But special new formulas are derived for the designed patterns, and some simplifying processing are proposed.

## 1. INTRODUCTION

Automatic location and orientation for movable robot and free movable object are one of the unresolved technical problems in the area of robot and intelligent automation. Although much progress has been made in the field of computer vision (CV) and artificial intelligent (AI), it is still an unresolved issues for fully automation. In order to overcome this difficulty, much efforts have been made in CV which try to integrate knowledge into inference algorithms so far, alternatively, this paper put forward an new method which integrate knowledge into signals, that is , special patterns are designed to simplify the algorithm so as to realize the fully automatic location and orientation.

The new proposed method can be used in the following limited environments:

a)The robot and movable object are moved in the room consists of horizontal ceilings and vertical walls.

b)Special designed patterns, i. e. Fig.1, can be painted on the walls and ceilings.

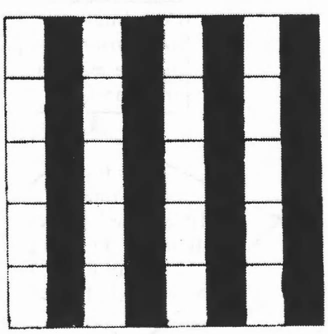

Fig.1 Special Designed Patterns

c) Three CCD cameras can be mounted on the robot or object to take images from the painted patterns, the images are transferred to the fixed (or specialized) computer via radio for calculation, after automatic calculation of shifting parameters and rotation parameters, the calculated control information is returned to the robot or object via radio again so as to realize automatic control of its motion (Fig. 2).

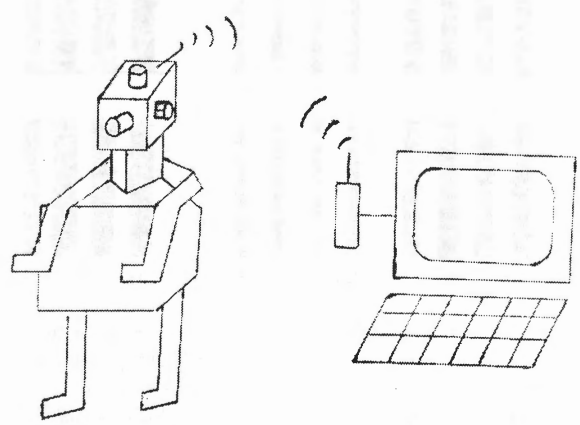

Fig.2 Taking images and transferring

The special patterns in Fig.1 are designed according to following principles:

a) The features of such patterns can be extracted full automatically .
Binarization of the taken CCD images is easy, through edge detection and Hough transformation, we can get the parameter of all lines and calculate the coordinates of all grid points.

b) Shifting and orientation parameters of the movable object can be determined automatically.
According to the theory of photogrammetry , in the photograph plane, image of every straight line in object plane is a straight line and vice versa. However, since there exist some rotation of the camera, we may get the deformed image, such as in Fig.3. Deformation of the image may be: (1) a whole rotation angle, (2)

no longer parallel among our parallel straight lines (caused by the slanting of partial angle), and (3) variation of the interval between our parallel straight line patterns. In term of these deformation characteristics and the intervals of our parallel patterns in image plane, we can determine the parameters of location and orientation automatically, algorithms of which will be given later.

c) Any kind of orientation parameter can be calculated.
In order to satisfy all needs of position and orientation for free shifting object in 3 dimensional space, it is necessary to consider the ability of discrimination of all six walls in the room while designing our special patterns. This can be easy realized through the difference of stripe with black and white, and the difference of interval between the parallel lines on the walls (see Fig.4).

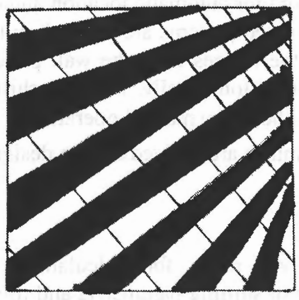

Fig.3 Image of our parallel patterns

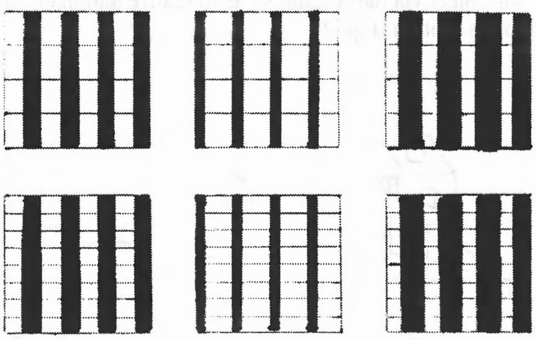

Fig.4 Special designed patterns on different walls

In the case when the taken image is composed of patterns on one more walls, since different kind of patterns are painted on different wall, it is easy to automatic extract the common boundary of the walls, and the position and location parameters can be calculated from the image with boundary (Fig.5).

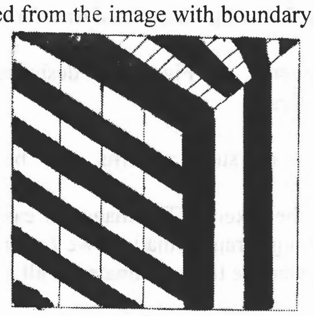

Fig.5 Image composed of patterns on one more walls

The special designed patterns make the calculation of our location and orientation parameters full automatically, indicate the advantage of our new method that integrate knowledge into signals.

Fig.6 gives the coordinate system used in this paper, in which we define the three vertical distances $H_x, H_y, H_z$ between the center of camera lens to the three walls as our position parameter, and the three angle φ, ω, κ, which are rotation angles of camera about axis $X, Y, Z$ respectively, as our orientation or rotation parameter.

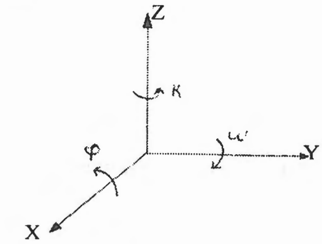


Fig6. Coordinate system used in this paper

## 2. PRINCPILE AND ALGORITHMS

The key issues of our new method are the calculation of shifting parameters and rotation parameters from grid points of the special patterns detected from their images automatically.

### 2.1 Calculation Procedure

Fig.7 gives the main principle and calculation steps of our new method. In this procedure, automatic extraction of grid

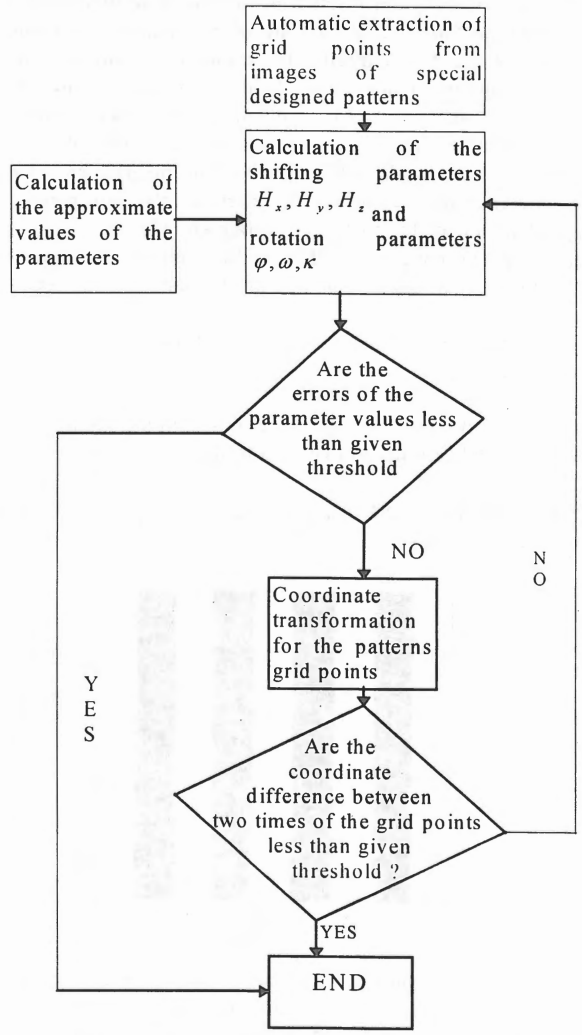


Fig.7 Block diagram of the resolving procedure

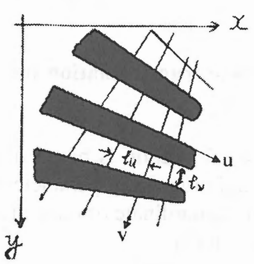


Fig.8 Image coordinate

points from the image of painted patterns gives their image coordinates ( $x, y$ ) of the cross points among stripes and lines. Since the coordinate values of the cross points are aligned in terms of the structure of our designed patterns (Fig.8), it is easy to detect grid points along every stripe edge or line. Moreover, the side length ( $L_u, L_v$ ) of the grids in object space are known, and the side length ( $l_u, l_v$ ) of that in image space is measurable, that is, we calculate the ( $l_u, l_v$ ) through the automatic extracted coordinate values of the grid points.

## 2.2 Approximate value calculation of the shifting parameter ( $H_X, H_y, H_Z$ ) and rotation parameter ( $\varphi, \omega, \kappa$ )

Approximate value $H_Z^0$ of $H_Z$ can be calculated from the patterns in XY plane, given the value ( $l_u, l_v$ ) of all grids, we have

$$H_Z^0 = \frac{f}{n}\left[\sum_i \left(\frac{L_u}{l_{u_i}} + \frac{L_v}{l_{v_i}}\right)\right] \qquad (1)$$

where f is the principle distance of the photograph, and $n$ is the total amount of $l_u$ and $l_v$ used for the calculation.

Similar to the computational formula (1), approximate values $H_X^0, H_Y^0$ of $H_X, H_Y$ are determined from the patterns in YZ planes and ZX planes respectively.

Approximate value $\kappa^0$ of $\kappa$ is calculated from the patterns stripe direction in XY plane. Let $\alpha_i$ be the included angle between x axis and stripe $u_i$, then

$$\kappa^0 = \frac{1}{n}\sum_i \alpha_i$$

where n is the amount of stripe border used for the calculation.

Similarly, we compute approximate value $\varphi^0, \omega^0$ of $\varphi, \omega$ from the patterns stripe direction in ZX planes and YZ planes separately.

## 2.3 Computational equations of shifting parameters and orientation parameters

Fig.9 gives the stripes of object space corresponding to their image in Fig.8, Fig.10 gives an plane consists of three elements: the camera center point, a stripe edge line in direction $u$ from Fig.9, and its corresponding image in Fig.8. We can find some influence of the grid interval $l_u$ along a stripe edge direction caused by the angle of deflection $\varphi$, from this we can establish the computational equation of $l_u$ expressed in formula (2)

$$l_{u_i} = f\left[\frac{H_Z tg\varphi + U_1 + iL_u}{H_Z - (U_1 + iL_u)tg\varphi} - \frac{H_Z tg\varphi + U_1 + (i-1)L_u}{H_Z - (U_1 + iL_u - L_u)tg\varphi}\right] \qquad (2)$$

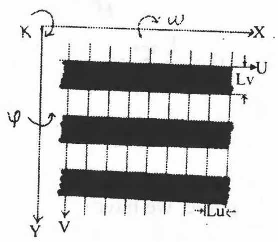


Fig.9 patterns in object plane

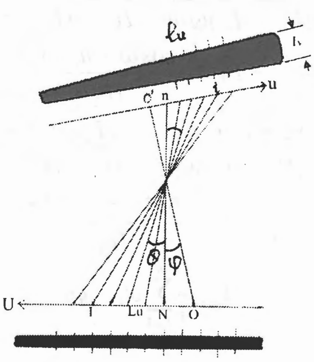


Fig.10 Influence of $lu$ through angle $\varphi$

In equation (2), $i = 1, 2, \cdots, n_1$, $n_1$ is the amount of grid side in direction $u$ within the image, so we have $n_1$ equations for every stripe line. $\varphi, H_Z$ and $U_1$ are unknown number need to be resolved.

Also, we can establish the computation equation of $l_v$, which indicates the variation of stripe width in taken image

$$l_{v_i} = L_v \cdot \frac{f \cdot \cos\varphi + u_i \sin\varphi}{H_Z} \qquad (3)$$

where, $i = 1, 2, \cdots, n_1 + 1$, (for simplification, when $n_1$ is greater, we can let $i = 1, 2, \cdots, n_1$ ), $u_i$ is the $u$ coordinate value of the image. Origin of the $u$ axis locates at the cross point $O'$ between the grid line through the photograph principle point and that stripe pattern. In equation (3), there are two unknown number, i.e. $\varphi$ and $H_Z$.

To sum up above mentioned principle, the computational equations of shifting parameters and orientation parameters are listed as following formula (4), (5) and (6).

For the patterns in XY plane, we have:

$$
\begin{cases}
l_{u_i} = f\left[\dfrac{H_Z tg\varphi + U_1 + iL_u}{H_Z - (U_1 + iL_u)tg\varphi} - \dfrac{H_Z tg\varphi + U_1 + (i-1)L_u}{H_Z - (U_1 + iL_u - L_u)tg\varphi}\right] \\
l_{v_i} = Lv \cdot \dfrac{f\cos\varphi + u_i \sin\varphi}{H_Z} \\
l_{v_j} = f\left[\dfrac{H_Z tg\omega + V_1 + jL_v}{H_Z - (V_1 + jLv)tg\omega} - \dfrac{H_Z tg\omega + V_1 + (j-1)L_v}{H_Z - (V_1 + jL_v - L_v)tg\omega}\right] \\
l_{u_j} = L_u \dfrac{f\cos\omega + v_j \sin\omega}{H_Z} \\
0 = \dfrac{1}{n}\sum_{k=1}^{n}\alpha_k - \kappa
\end{cases}
\tag{4}
$$

For the patterns in YZ plane, we have

$$
\begin{cases}
l_{u_i} = f\left[\dfrac{H_X tg\omega + U_1 + iL_u}{H_X - (U_1 + iL_u)tg\omega} - \dfrac{H_X tg\omega + U_1 + (i-1)L_u}{H_X - (U_1 + iL_u - L_u)tg\omega}\right] \\
l_{v_i} = Lv \cdot \dfrac{f\cos\omega + u_i \sin\omega}{H_X} \\
l_{v_j} = f\left[\dfrac{H_X tg\kappa + V_1 + jL_v}{H_X - (V_1 + jLv)tg\kappa} - \dfrac{H_X tg\kappa + V_1 + (j-1)L_v}{H_X - (V_1 + jL_v - L_v)tg\kappa}\right] \\
l_{u_j} = L_u \dfrac{f\cos\kappa + v_j \sin\kappa}{H_X} \\
0 = \dfrac{1}{n}\sum_{k=1}^{n}\alpha_k - \varphi
\end{cases}
\tag{5}
$$

For the patterns in ZX plane, we have

$$
\begin{cases}
l_{u_i} = f\left[\dfrac{H_Y tg\kappa + U_1 + iL_u}{H_Y - (U_1 + iL_u)tg\kappa} - \dfrac{H_Y tg\kappa + U_1 + (i-1)L_u}{H_Y - (U_1 + iL_u - L_u)tg\kappa}\right] \\
l_{v_i} = Lv \cdot \dfrac{f\cos\kappa + u_i \sin\kappa}{H_Y} \\
l_{v_j} = f\left[\dfrac{H_Y tg\varphi + V_1 + jL_v}{H_Y - (V_1 + jLv)tg\varphi} - \dfrac{H_Y tg\varphi + V_1 + (j-1)L_v}{H_Y - (V_1 + jL_v - L_v)tg\varphi}\right] \\
l_{u_j} = L_u \dfrac{f\cos\varphi + v_j \sin\varphi}{H_Y} \\
0 = \dfrac{1}{n}\sum_{k=1}^{n}\alpha_k - \omega
\end{cases}
\tag{6}
$$

Respectively, the number of equations in above formula (4), (5), (6) is

$$
\begin{gathered}
n_1 \times m_1 + 1 \\
n_2 \times m_2 + 1 \\
n_3 \times m_3 + 1
\end{gathered}
$$

and least square method is needed for the solution of these equations.

### 2.4 Image coordinate transformation for the patterns grid points

Image coordinate transformation is based on the above solved shifting parameters and orientation parameters. For the image in XY plane, the rectified coordinate of the patterns grid points are expressed as in equation (7)

$$
\begin{cases}
\bar{x} = -f\dfrac{a_1 x + a_2 y - a_3 f}{c_1 x + c_2 y - c_3 f} \\
\bar{y} = -f\dfrac{b_1 x + b_2 y - b_3 f}{c_1 x + c_2 y - c_3 f}
\end{cases}
\tag{7}
$$

where

$$
\begin{cases}
a_1 = \cos\varphi\cos\kappa + \sin\varphi\sin\omega\sin\kappa \\
b_1 = \cos\varphi\sin\kappa - \sin\varphi\sin\omega\cos\kappa \\
c_1 = \sin\varphi\cos\omega \\
a_2 = -\cos\omega\sin\kappa \\
b_2 = \cos\omega\cos\kappa \\
c_2 = \sin\omega \\
a_3 = \sin\varphi\cos\kappa + \cos\varphi\sin\omega\sin\kappa \\
b_3 = -\sin\varphi\sin\kappa - \cos\varphi\sin\omega\cos\kappa \\
c_3 = \cos\varphi\cos\omega
\end{cases}
\tag{8}
$$

Recalculation of the patterns grid point coordinate in object space from the corresponding corrected coordinate in image space, we have

$$
\begin{cases}
\bar{U} = \bar{x} \cdot \dfrac{f}{H_Z} \\
\bar{V} = \bar{y} \cdot \dfrac{f}{H_Z}
\end{cases}
$$

If $\bar{U} = U$ and $\bar{V} = V$, that is, if $L_{\bar{u}}, L_{\bar{v}}$ have uniform interval and $L_{\bar{u}} = L_u, L_{\bar{v}} = L_v$, we can conclude that we have got right solution of the shifting parameters and orientation parameters. Otherwise, we need return to the previous steps and continue the iterative process .

Similarly, for the image in YZ plane, we have

$$
\begin{cases}
\bar{y} = -f\dfrac{-b_1 f + b_2 y + b_3 z}{-a_1 f + a_2 y + a_3 z} \\
\bar{z} = -f\dfrac{-c_1 f + c_2 y + c_3 z}{-a_1 f + a_2 y + a_3 z}
\end{cases}
\tag{10}
$$

$$
\begin{cases}
\bar{U} = \bar{y} \cdot \dfrac{f}{H_X} \\
\bar{V} = \bar{z} \cdot \dfrac{f}{H_Y}
\end{cases}
\tag{11}
$$

For the image in ZX plane, we have

$$\begin{cases} \bar{z} = -f\dfrac{c_1x - c_2f + c_3z}{b_1x - b_2f + b_3z} \\ \bar{x} = -f\dfrac{a_1x - a_2f + a_3z}{b_1x - b_2f + b_3z} \end{cases} \quad (12)$$

$$\begin{cases} \overline{U} = \bar{z} \cdot \dfrac{f}{H_Y} \\ \overline{V} = \bar{x} \cdot \dfrac{f}{H_Y} \end{cases} \quad (13)$$

## 3. HANDLING METHOD WHEN ARRIS FILLET APPEARS IN THE IMAGE

In the case when camera have a great angle of inclination, and there exist arris fillet of two or three walls in the image (see Fig.5), we can easy determine the coordinate of patterns grid point while defining the arris fillet as the start line. This means that we have several control points known of their three coordinates in object space, so we can calculate the shifting parameters and orientation parameters through the conventional space resection.

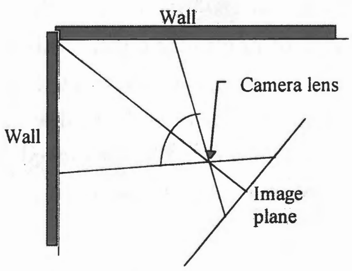


Fig.11 Wall corner image

## 4. SIMPLIFIED SITUATION

### 4.1 One camera for determining $H_Z$ and $\varphi, \omega, \kappa$

Following description comes from a practical application requirement. We need to determine its performance of hanging stability of a new kind of helicopter, that is, we are request to measure its vertical height $H_Z$ from ground and its tilting rotation angles $(\varphi, \omega, \kappa)$ at every time intervals. Under this situation, the above mentioned method can be simplified greatly, only one camera is demanded to mount on the helicopter to take picture from ground patterns, and we can calculate the parameters $H_Z$ and $(\varphi, \omega, \kappa)$ according to above equation team (4).

### 4.2 One camera for determining $H_X, H_Y, H_Z$ and $\varphi, \omega, \kappa$

If it is need to determining all the six parameters of location and rotation with one camera, the patterns on the plane to be imaging should designed in complete form, in which the coordinate of the point corresponded to the principle point of image can be automatically recognized and location made by the patterns. Fig.12 shows an example of such patterns.

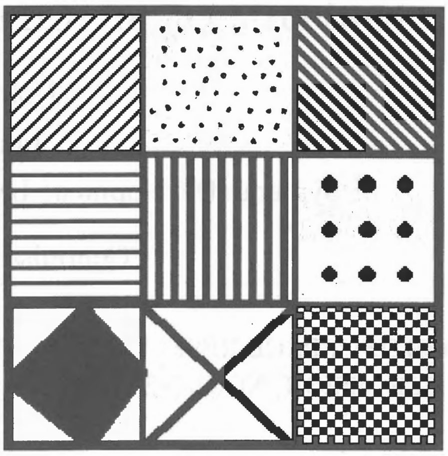

Fig.12 patterns for automatic location

## 5. CONCLUSION

The new method proposed above, may support not only to real-time determine its three coordinates $H_X, H_Y, H_Z$ and motion speed of movable robot or free movable object, automatic record its motion trajectory, but also, it can joint with the control system so as to guide the robot or movable object to designated position.

## REFERENCES

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