Recognition method of spacecraft docking ring based on monocular vision and laser range finder

Kun Zhai[1], Xi Qu[2], Zhi Li[3], Xinlong Chen[3]

（1. School of Astronautics and Aerospace，Tsinghua University，Beijing 100084，China；

2. Institute of Manned Space System Engineering, China Academy of Space Technology，Beijing 100094，China;

3. Qian Xuesen Laboratory of Space Technology, China Academy of Space Technology，Beijing 100094，China;）

Relative position and attitude measurements between spacecraft are the precondition of some kinds of on-orbit manipulations, such as flying around surveillance, tracking and approaching, rendezvous and docking, and on-board maintaining. Most in-orbit spacecraft have not equipped cooperative markers in advance, so determining the relative position and attitude between non-cooperative spacecraft is the key to realize the real on-orbit operations.

Docking ring is the connecting part of spacecraft and carrier rocket. After satellite-rocket separation, the docking ring is still remained on the spacecraft. Identified of the target spacecraft's docking ring can help to capture and track the non-cooperative target spacecraft, and be beneficial to on-orbit operations further.

Docking ring is a conical structure and usually located on the -X surface of spacecraft (see Fig.1). In this paper the docking ring recognition means to gain sizes of the docking ring end frame——radius $\boldsymbol{R}$ of docking ring and distance $\boldsymbol{D_f}$ of docking ring to the centroid. Docking ring mentioned below refer to the docking ring end frame. Looking from the -X direction docking ring is a circular. But because of the existence of relative attitude deviation, from the chasing spacecraft docking ring is an ellipse. Therefore the main content of docking ring recognition is ellipse detection, as well as obtaining the docking ring sizes from the ellipse.

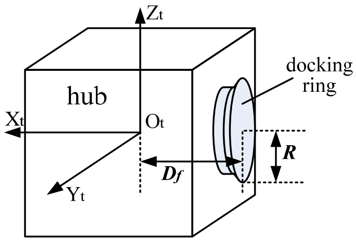

Fig.1 Sketch map of docking ring

In this paper, based on the measurement information of monocular vision and laser range finder, a certain number of dimensions are determined of non-cooperative spacecraft docking ring. Firstly, the relative position and attitude measurement algorithm is derived for the unknown sized space rectangular target (see Fig.2).

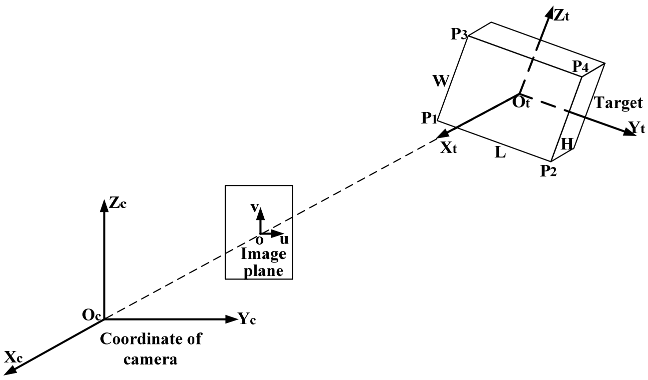

Fig.2 Coordinates of camera and target

The derivation process effectively avoids the singular points. The relative attitude is represented by the coordinate transformation matrix $\boldsymbol{R}_{ct}=\left[\boldsymbol{r}_1 \quad \boldsymbol{r}_2 \quad \boldsymbol{r}_3\right]$, and we have

$$\boldsymbol{r}_2=-\frac{1}{\sqrt{\left(k_1-1\right)^2+\frac{\left(u_1-u_2 \bullet k_1\right)^2}{f^2}+\frac{\left(v_1-v_2 \bullet k_1\right)^2}{f^2}}}\begin{bmatrix} k_1-1 \\ \left(u_1-u_2 \bullet k_1\right)/f \\ \left(v_1-v_2 \bullet k_1\right)/f \end{bmatrix} \tag{1}$$

$$\boldsymbol{r}_3=-\frac{1}{\sqrt{\left(k_2-1\right)^2+\frac{\left(u_1-u_3 \bullet k_2\right)^2}{f^2}+\frac{\left(v_1-v_3 \bullet k_2\right)^2}{f^2}}}\begin{bmatrix} k_2-1 \\ \left(u_1-u_3 \bullet k_2\right)/f \\ \left(v_1-v_3 \bullet k_2\right)/f \end{bmatrix} \tag{2}$$

$$\boldsymbol{r}_1=\boldsymbol{r}_2 \times \boldsymbol{r}_3 \tag{3}$$

Where k_1, k_2, u_1, u_2, u_3, v_1, v_2, v_3 and f can be calculated based on the camera's measurement information.

Then by using edge detection algorithm the elliptic image of docking ring is obtained, and based on the least square method the parameters of ellipse are calculated——u_0, v_0, a, b , and φ.

$$u_0=\frac{2BC-AD}{A^2-4B} \tag{4}$$

$$v_0=\frac{2D-AC}{A^2-4B} \tag{5}$$

$$a=\sqrt{\frac{2\left(ACD-BC^2-D^2+4BE-A^2E\right)}{\left(A^2-4B\right)\left(B-\sqrt{A^2+(1-B)^2}+1\right)}} \tag{6}$$

$$b=\sqrt{\frac{2\left(ACD-BC^2-D^2+4BE-A^2E\right)}{\left(A^2-4B\right)\left(B+\sqrt{A^2+(1-B)^2}+1\right)}} \tag{7}$$

$$\varphi=a\tan\sqrt{\frac{a^2-Bb^2}{Ba^2-b^2}} \tag{8}$$

Where A, B, C, D and E are optimized parameters according to the least square method.

Finally, according to parameters of detected ellipse and the known relative position and attitude information, the radius of docking ring and distance of docking ring to the centroid are determined.

$$R=\sqrt{y_{1t}^2+z_{1t}^2} \tag{9}$$

$$D_f=x_{1t} \tag{10}$$

$$\begin{aligned} x_{1t}&=x_{1c}f_x(u_1,v_1)-T_x \\ y_{1t}&=x_{1c}f_y(u_1,v_1)-T_y \\ z_{1t}&=x_{1c}f_z(u_1,v_1)-T_z \end{aligned} \tag{11}$$

Simulations of flying around in the orbit plane are performed. The results indicate that the proposed docking ring recognition method can determine sizes of the non-cooperative spacecraft docking ring using the monocular vision and laser range finder.