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An efficient circle detector not relying on edge detection

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Abstract

Accurate and efficient detection of circular modules fixed on non-cooperative target is a key technology for Tethered Space Robot. This paper presents an efficient circle detector based on region-growing of gradient and histogram distribution of Euclidean distance. Region-growing of gradient is applied to generate arc support regions from single point. And the corresponding square fitting areas are defined to accelerate the detection and decrease storage. A histogram is then used to count frequency of the distances that participates in the accumulator and the parameters of each circle are acquired. Finally, a verification strategy of circular integrity is designed to test the detection results. We have tested our algorithm on 35 images dealing with kinds of circles and ellipses. Experimental results demonstrate that our method is able to detect circular objects under occlusion, image noises and moderate shape deformations with a good precision.

Keywords: Hough transform; Circle detection; Region growing; Histogram; Machine vision

1. Introduction

1.1. Motivation

On-orbit service technologies have many potential applications such as on-orbit maintenance, on-orbit assembly, and space debris cleaning (Xu et al., 2011). Traditionally, a space robot has a rigid body structure and a manipulator for on-orbit service tasks, such as ETS-VII, Canada arm, and Orbital Express, which have less flexibility because of limitations of manipulator length. To overcome these shortcomings and unlike these rigid manipulator arms, the use of a Tethered Space Robot system (TSR) (Huang et al., 2016; Wang et al., 2014) for space manipulation, especially in case of non-cooperative capture is a promising technology. The TSR is a new type of space robot, as shown in Fig. 1, the architecture of which comprises a Robot Platform, Space Tether, and an Operational Robot.

Most of the on-orbit satellites are non-cooperative satellites, which have the following characteristics (Du et al., 2011) (1) without special interface installed for capture docking; (2) no cooperative retro reflectors or sensors for measurement; (3) the motion of target satellite is uncontrolled. Capturing non-cooperative satellite is a more challenging technology than ever before.

By comparison with some active sensors, such as radar, scanning laser or infrared range finder, vision-based measurements don't suffer from the shortcomings of expensiveness, large power consumption, and small work field. So it is considered as the main sensor of TSR.

As we described in Huang et al. (2013), the guidance and navigation scheme of the Operational Robot for far-range rendezvous has to detect, recognize, track the non-cooperative target and acquire azimuthal angles autonomously to ensure the safety of this mission (Kwon et al.,

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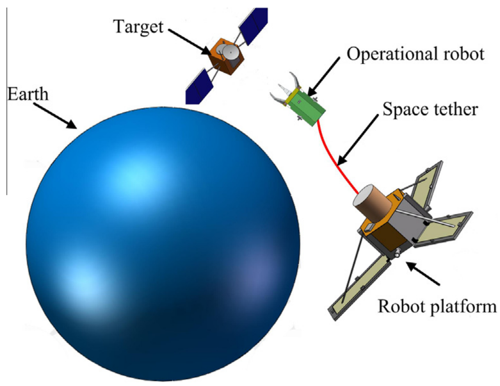

Fig. 1. Construction of the TSR system.

2013). Considering that the shape of target satellite's body and module is usually cubical, polyhedral, or cylindrical, such satellite can naturally be imaged by optical sensors. When the target satellite is coupled with advanced image processing and estimating algorithms, it achieves cost-effective and accurate sensing capability to capture and track the target.

The common parts mounted on the non-cooperative satellites are usually selected as the region of interest (ROI) for Operational Robot's manipulation (Sansone et al., 2014), including the bolts which can separate satellite from the rocket, the docking ring, the apogee rocket motor injector, the span of solar panels and so on, as shown in Fig. 2.

1.2. Related works

In Cai et al. (2016), we proposed a recognition algorithm of polygonal solar panel based on novel dynamic template matching. In practice, when Operational Robot captured the polygonal solar panel, it was hard for the 3-finger gripper hand to lock this polygonal module. We can use only a priori knowledge for recognition is that the target has circular modules since it is non-cooperative. Hence, we consider guiding Operational Robot to capture the circular bolts, docking ring or motor injector, in expect to lock the combination system for delicate manipulation. So how to detect and recognize the target's circular modules accurately and stably is a crucial link in the whole project. This problem can be viewed as a circle detection problem. The task is far from trivial and many research works addressed it over the decades (De Marco et al., 2015; Akinlar and Topal, 2013; Chung et al., 2010). Existing circular feature detectors can be roughly classified into two categories (Pan et al., 2011): voting-based and maximum likelihood estimation (MLE). The MLE based methods directly estimate the parameters of a circle as a least square estimation problem. In order to prove detection accuracy, Zelniker et al. extended Gander et al. (1994) with convolution-based MLE to estimate the parameter of circular object in Zelniker (2006). Frosio and Borghese (2008) employed prior knowledge of foreground and background statistics to estimate the likelihood of circular object parameter. Despite substantial improvements, these approaches are still sensitive to noise, partial occlusion and background clutter. Moreover, it is unclear how to extend these approaches to detect multiple circles.

Unlike MLE based methods, voting based methods are more robust against noise and occlusion. The most commonly used voting based algorithm is the Circular Hough Transform (CHT) (Hough, 1962). A major drawback of the method is the need to build a 3-D accumulator array of circle parameter (i.e., center and radius), resulting in high computational complexity and memory requirements. In Xu and Oja (1993), reduced computational complexity by randomly selecting a subset of edge points for voting. Another approach for reducing the computational expense of CHT is to leverage gradient information of every edge point. Yuan et al. conducted to recognize and extract the craters automatically based on mathematical morphology in Yuan et al. (2013). They separate the rims by mathematical morphology in binary image and extract the sizes and locations of craters by fitting rims with circles. The identification of mare craters is accurate, while of terra craters is a little worse, due to big grayscale variety. Liu presented the idea of point-lines distance distribution for shape detection named PLDD in Liu and Wang (2014). The method just votes on distance using the edge points included in a local neighborhood, which is more robust, and accurate. However, its time consumption is a little high. Zou designed a real time elliptical head contour detection method based on quadrant arcs are introduced in Zou et al. (2009). Based on the sub-image corresponding to

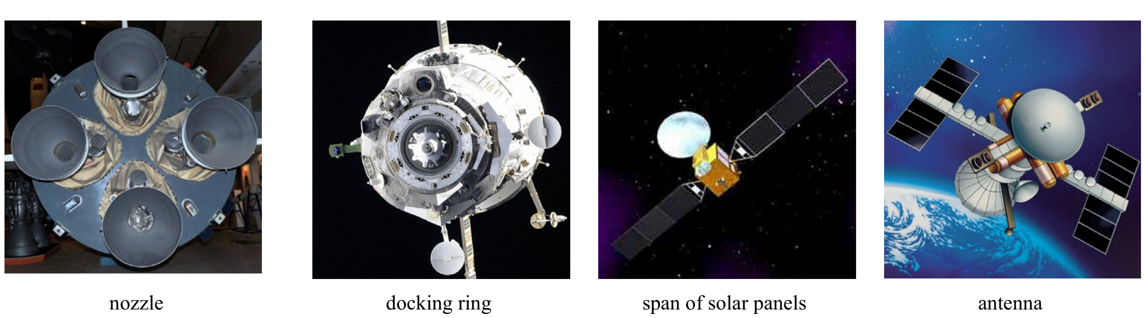

Fig. 2. Examples of ROI on spacecraft.