A Summary of Research on Model Identification and Target Tracking of Non-cooperative Target

Chun Xu, Linfang Yang, Songtao Fan and Jinzhe Jiang
Beijing Institute of Control Engineering
Zhongguancun South Third Street 16, Beijing 100190, P. R. China
Email: tuchtig@hotmail.com

ABSTRACT
This paper is a survey which mainly studies the model identification and target tracking of the non-cooperative target with no visual feature in space. In order to achieve a visual model for non-cooperative target recognition and attitude tracking, we introduce a compressed sensing and particle filter method, especially no prior knowledge of the visual target. Topics include: (1) research on image reconstruction of non-cooperative target based on compressed sensing; (2) research on visual model identification to non-cooperative targets; (3) research on attitude estimate and target tracking to non-cooperative target gesture based on multi-regional joint particle filter. The aims of this paper are: to give sparse reconstruction algorithms for the high dimension image, to give visual model identification method for the non-cooperative target with no visual feature, to solve the problems of attitude estimation and tracking of on-cooperative target based on identification model. Finally, a systematic solution will be given for the docking or capture mission to spacecraft especially the non-cooperative target in space.

KEYWORDS
non-cooperative target; model identification; target tracking; sparse reconstruction algorithms; compressed sensing.

1 INTRODUCTION
The technology of rendezvous and docking (Rendezvous and docking or berthing, RVD/B) in space is an important research, attracting more and more concerns in aerospace industry with high economic and strategic value. From a view of space mission, docking rendezvous and docking technology for cooperative target has become mature, from the 1960s to the present, have hundreds of practice, successfully docked to the space station, supplies, moon landing and planetary exploration[1] and so on. With the demand for space missions complex and diversified, non-cooperative space missions and space-related needs of the target in large numbers[2], such as fault satellite capture[3] and in-orbit repair[4], the failure to dispose of used spacecraft or space debris[5], as a deep space probe captured asteroid relay station[6]. These requirements for the development of space rendezvous and docking technology brings new challenges, the world has developed a variety of research projects related to the space program[7-11].

For approaching and capturing target, the spacecraft can accomplish its mission well, depending on whether it has a valid target detection, localization, tracking function. Active radar systems are generally used to determine the relative position of the target and the relative attitude determination of cooperation target, but not provide enough relative attitude information of non-cooperative target effectively, and have poor integrated performance, power consumption and hidden defects and poor performance; in contrast, passive imaging systems can provide a lot of high-resolution images for spatial objects, such as the relative position and relative attitude determination and low power consumption devices, these devices can be used in different types of spacecraft, without the special designing. For non-cooperative target space, the use of visual sensor and advanced image processing technology is an inevitable choice [12].
Non-cooperative targets in space include: failure of small satellites or space station, or the failure of the space-craft space debris, and other unknown asteroid or comet objects. Currently, there are the following models, such as OLEV[14-15], DEOS[13], EPOS[13], PHOENIX[16], ROGER[17], OMS[18] conducted experiments to non-cooperative targets. In these experiments, the non-cooperative target is defined as there is no cooperation with respect to attitude and orbit control of the client, and the client satellite does not have a special docking port or retro reflectors used for vision-based navigation[13]. In addition, the non-cooperative targets also include non-own spacecraft, space debris and asteroids, which not only have the characteristics of non-cooperation target above experiment, also have no prior knowledge of the external geometry and other visual characteristics. November 2014 Germany's "Philae" lander and "Rosetta" detector separation, comet 67P arrival, in order to find a suitable landing spot after a long time for analysis, culminating in the end of August for an initial A, I, B, J, C, located five candidates selected head of J-point [19], which is the only time mankind to explore such non-cooperative target, but this experiment is to obtain a suitable landing site (target acquisition) cost a long time. For this type of visual characteristics unknown target, it is urgent that we look for a more effective method to achieve its attitude estimation and tracking tasks.

2 MODEL IDENTIFICATION and TARGET TRACKING METHOD

For such non-cooperative target is unknown changes in attitude and orbit by visually sensitive and efficient algorithm for image tracking goals that attitude estimation and tracking; for such non-cooperative target does not have the visual characteristics, you must first use an advanced Model identification means to build awareness of the target, and then identify the target completion attitude estimation and tracking. Existing literatures are rarely known, in which the measurement information processing theory and algorithms of the non-cooperative space target. For other areas of target motion and attitude estimation, Moeslund in the literature[20] and [21], respectively, had analyzed and summarized in Gavrila[22] and Aggarwal[23] before 2000 and before 2006 on the basis of whether to use a priori model in accordance with the existing methods can be divided into three categories: (1) non-model-based approach; (2) indirect-method-based model; (3) direct method using the model. In the three methods, the method of non-model and the indirect use of model-based approach requires a large amount of sample data, the non-model-based learning need to use sample data to obtain a mapping function between image visual features and attitude; and indirect using a model approach requires the use of sample data and a priori knowledge of the movement model library. Due to the randomness of non-cooperative target structure and movement of the body, it is difficult to obtain in advance a complete visual data and prior knowledge of body motion data, etc. Therefore, the non-cooperative target space attitude estimation and tracking use the model-based approach.

Using of visual processing to establish a non-cooperative target visual model, must capture an image of non-cooperative target surface first. For a 3D-goal, through a series of 2D images acquired from different angles, the three-dimensional feature extraction targets identified three-dimensional visual model[24]. The difficulty lies in how to carry out a similar transformation can be achieved the best similarity between Object and the original object of a three-dimensional model[25]. Extracting a plurality of images from various angles, i.e. block collection, in theory, the more the block, for each part of the more detailed observation, establish the higher similarity of the model and the original object. Therefore, a large number of samples, a large number of image compression, transmission, processing
and other tasks completed to bring a great deal of difficulty. This paper studies mainly "the non-cooperative target with characteristics of complex spatial motion and no visual feature". Topics include: (1) research on image reconstruction of non-cooperative target based on compressed sensing; (2) research on visual model Identification to non-cooperative targets; (3) research on attitude estimate and target tracking to non-cooperative target gesture based on multi-regional joint particle filter.

3 KEY TECHNOLOGIES

From the existing research point of view, the research on attitude estimation and tracking of non-cooperation in space is already quite mature, but non-cooperative target for attitude estimation and tracking research is not enough. The paper studies the key technologies of visual-based non-cooperative target model identification and target tracking, the following research on the status of model identification and tracking of key issues were reviewed and analyzed.

2.1 Visual Image Acquisition of Non-cooperative Target

First, we must consider key issues of non-cooperative target visual image acquisition in space, it exists the problem of the structural characteristics is unknown, it exists the problem of the presence of spin precession and other complex forms of non-uniform changes in attitude, and it exists the problem of rapid recovery efficiency, effectiveness and cost required meet the requirements of the mandate. The traditional image acquisition and processing process including sampling, compression, transmission and decompression of four parts, which must meet the Nyquist/Shannon sampling theorem, theorem describes the sampling frequency must be greater than twice the highest frequency signal to complete restoring the original signal[26-27]. Therefore, the traditional image restoration method will cause a lot of samples, then compression, transmission, decompression, etc., forcing our visual processing equipment put forward higher requirements, and the process can not meet the real-time (may be very long, and even years terms). Compressed sensing theory in order to overcome the inherent shortcomings of traditional image restoration, make full use of the sparsity of the signal measured using a very small amount of recovery of the original signal with high precision[28-30]. Compressed sensing solves space high sampling rate, a large amount of data, storage transport difficulties, high costs and other issues of time offers the possibility in non-cooperative target recognition[31], exploration and research of new technologies based on compressed sensing space non-cooperative target data acquisition, image restoration and recognition[32], has an important theoretical and practical significance.

2.2 Three-dimensional Visual Model Identification of Non-cooperative Spacecraft

Second, consider the space of non-cooperative target three-dimensional visual model of the key issues identification, the core is sparse dictionary, measurement matrix and reconstruction algorithm design. In compressed sensing theory, the sampling rate is no longer dependent on the signal bandwidth, and depends on two basic principles, namely sparse and non-coherent, or sparsity and isometric binding. Currently coefficient dictionary include: orthogonal basis dictionary, the tight framework of the dictionary, over-complete dictionary. Characterize the space of non-cooperative target often contain smooth regions, step edge, texture and other structural components of the oscillation, over-complete dictionary of atoms should be able to match the different types of structures, so the use of over-complete dictionary-based learning[33-35], effective image edge contour lines and other exotic features and texture features, its sparse representation effect, low computational complexity. In principle, the measurement matrix design includes two aspects: one
measuring element of the matrix, one dimension measurement matrix[36]. Most of compressed sensing theory in the literature, the measurement matrix are linear and designed without adaptive changes observed signals. For the space of non-cooperative target, its complexity and high dimensionality leads to the need of adaptive compression measurements, measurement of nonlinear adaptive compression, compressed sensing is bound to improve compression performance. Compressed sensing reconstruction is a process of seeking solutions to the most sparse common algorithm are: the classic matching pursuit algorithm (Matching Pursuit, MP)[37], the improved iteration ensure optimal orthogonal matching pursuit algorithm (orthogonal Matching Pursuit, OMP)[38], to provide improved computational speed segment orthogonal matching pursuit algorithm (Stagewise Orthogonal Matching Pursuit, StOMP)[39], the noise robustness of compressive sampling matching pursuit algorithm (Compressive Sampling Matching Pursuit, CoSaMP)[40], as well as track gradient algorithm (Gradient) [41,42-43], and hard threshold[44] and soft threshold[45] algorithms. In addition, some perceptual model-based compression algorithm[46] can be combined with the above algorithms to provide the restored image accuracy and efficiency. These algorithms are faced with ultra-high computational cost recovery, huge storage space required for sampling samples and other issues, although Sungkwang Mun et al proposed block compressed sensing method (Block Compressive Sensing)[47] in order to improve the efficiency of compressed sensing sampling But directly applied to the non-cooperative target such a large space of complex high-dimensional signal, to complete the identification it takes a long time, this deficiency could affect the completion of the task. Non-cooperative target complexity and high dimension needs to make adaptive compression sampling and reconstruction algorithms. Rapid changes in posture or non-uniform, there is a certain range of time-domain correlation between changes over time captured images, establish a set of images and associated domain of another non-cooperative target existence of spin precession and other complex forms spatial relationship between the non-cooperative target three-dimensional model is the above method can not be directly implemented. Compressed sensing and joint particle filter block (Block Particle Filter) combined to block a joint particle filter (described in detail in the next section) as a sparse spatial and temporal transformation, the use of moving images in the background particle filter sparsity Image restoration is completed to meet the real-time, and improve the accuracy of the image.

2.3 Attitude Estimation and Tracking of Non-cooperative Spacecraft

Finally, consider the non-cooperative targets attitude estimation and tracking problem, the key is the image matching method, real-time from a sequence of images in real time to calculate the current track and target the relative attitude, which is a visual attitude estimation and tracking problems. Currently, visual tracking methods are generally divided into three categories, one is based on a target pattern matching search algorithm[48], this method is equivalent to the visual tracking problem of pattern matching local optimization problem; one is based on the target state estimation, filtering algorithms, this method by moving target state estimation, learning knowledge of the scene of the tracking process to evaluate a variety of assumed position to achieve tracking, including traditional Kalman filter[49], extended Kalman filter[50, 51], sequential Monte Carlo[52, 53], a variety of particle filter[52-55,56-61]; the other is based on the classification of the tracking algorithm[62-64] the target tracking convert the classification of the foreground and background processing. For three methods described above, the image tracking applications, the posterior probability distribution is often non-linear, non-Gaussian, multi-modal, and there-fore subject
to certain restrictions Kalman filter in solving practical problems. Particle filter is a suitable strong non-linear non-Gaussian filter constraints. Posterior probability of the particle filter applies a certain number of a random sample of particles distributed random variables that the system is suitable for any nonlinear stochastic systems. Visual target tracking that is the visual image of each frame from a sequence of interest in the position and orientation relative motion data of the target or area. Visual tracking handle some special problems encountered, such as tracking complex scenes, partially obscured target, and the target's own appearance varied issues, in addition there is a certain vagueness restored by compressed sensing images. Characteristics of the object for the image: tracking scene complexity, the target can easily be blocked (block spacecraft windsurfing, astrophysics and other irregular structure between), recovery fuzziness of the image, the existing particle filter tracking can not be directly applications. The paper to address the problem, the goal is expressed as a number of key areas to be adopted joint particle filter multi-regional information fusion. This idea expressed by the target into a plurality of sub-regions, the above-described problem into multiple regions of the target motion tracking problem, and the problem of blurred image by solving the correlation between the multi-area images.

3 CONCLUSION

Overall, traditional methods to achieve the attitude estimation and tracking for non-cooperative targets with no visual feature need to collect a lot of data, through a very long time, and in the process, once part of the image data is lost or damaged must be re-collection; compressed sensing theory for natural images of high-dimensional (non-cooperative target particularly typical) compression reconstruction is not ideal. Therefore, for non-cooperative targets with no visual feature, we urgently on the basis of existing technologies, design more effective methods to achieve vision-based attitude estimation and tracking of non-cooperative target. Meanwhile, it is necessary to fill the blanks in complex, high-dimensional reconstruction of the theory of natural phenomena compression. For non-cooperative targets attitude estimation and tracking, this paper uses modeling method based on compressed sensing to identify non-cooperative three-dimensional visual model, and on this basis, uses multi-regional joint particle filter information fusion to achieve non-cooperative target image restoration and attitude estimate, tracking. For various aerospace rendezvous guidance and control tasks, solving the general non-cooperative target for space rendezvous and approach issues, it has guidance in important theoretical significance and application value.

REFERENCES

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