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Computer Vision for Space Exploration

"Stereo vision on Mars."

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***Abstract*—It would not be wrong to tell that the times we live in is the dawn of a new space era. When all the major private and public space sectors are in the race to be the first to reach Mars, the interplanetary missions are gaining immense momentousness. Not only mars, but Europa and Venus are also considered to harbor life. Autonomy is a fundamental part of achieving these goals of interplanetary mission. Deep learning and computer vision can be used to achieve the spacecraft autonomy. This article addresses the role of computer vision in space applications and the progress of computer vision on mars exploration. It also summarizes the stereo vision algorithm which was used in the NASA MER mission which is an exemplary showcase of computer vision in space exploration.**

Keywords—Spacecraft Docking, Orbital Maneuvering, Stereo vision

I. INTRODUCTION

Computer Vision is a field of Artificial Intelligence which gives machines the power to understand the visual world. It has become a topic of extreme importance since a majority of applications today use the power of Computer Vision. It has had a revolutionary impact on technology which has led to the development of sophisticated tools and services ranging from driver-less cars to building autonomous robots for satellite missions. It's application in Space Science is something worth mentioning. The study of space science involves planet imagery, satellite tracking, satellite communication, exoplanet research, minimization of space junk, and increasing the autonomy of space vehicles. Computer Vision plays a crucial role in each of these applications and also opens up other areas of research in Space Technology like spacecraft docking and orbital maneuvering. This paper is briefly divided into two sections. The first part presents a review of some of the exciting applications of Computer Vision in the exploration of the universe and how the existing problems pertaining to human-space missions can be minimized. It also briefly introduces the idea of spacecraft docking using the idea of Computer Vision. The second section of the paper provides a review of Computer Vision techniques used in Mars exploration emphasizing on how autonomous rovers using Computer Vision systems can be built and their advantages in future space missions.

II. ROLE OF COMPUTER VISION IN SPACE SCIENCE

Computer Vision can be extensively used to automate space exploration. It can be used in planet tracking, satellite imagery, heavenly body detection, obstacle detection for aircraft navigation and most importantly it reduces the magnitude of risks faced by astronauts during human-space missions.

A brief list of applications of Computer Vison is presented in this section.

1. **Satellite Imagery** provides an unprecedented way of capturing the surface of Earth which is widely used in Remote Sensing. The images captured by the satellite are then processed using a variety of Computer Vision techniques where every part of the image is detected and essential features are extracted accordingly. This then facilitates scientists to build predictive models for specific remote sensing applications like natural disaster identification and prevention.
2. **Tracking Space Debris–** Space debris is a major threat as they might collide onto an operational aircraft or spacecraft leading to unsuccessful space missions. The major ways in which computer vision techniques can be applied in order to monitor space junk and find ways to reduce them are presented below:
    - Detecting and tracking space debris using Computer Vision models
    - Using real time video analysis to keep a check on operational activities of spacecrafts
    - Pre-trained Machine Learning models can be used to make predictions on future dangers on missions that space debris could potentially cause.
3. **Asteroid Detection**: Image processing which is a subfield of Computer Vision involves a variety of techniques like image identification, image enhancement, linear stretching and Gaussian stretching. They help in identifying and classification of new types of asteroids from large image data sets collected by the ground station from the satellite. They can extensively be used to detect new species of asteroids with great precision.
4. **Spacecraft Docking:** There are a lot of space missions which require spacecraft docking. A variety of docking systems exist which are classified based on the velocity of approach. Computer Vision systems have the power to enable autonomy in the process of spacecraft docking by estimating the relative orientation and position of spacecrafts in 3-dimensional space. The estimates received from the computer vision system are then used by the guidance and control loops of the docking system to control the spacecraft orientation in six degrees of freedom which is essential during docking. Translational velocity between the spacecraft

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and the space station is also determined by the feedback received from the computer vision system. Thus, the Computer Vision approach for spacecraft docking is expected to be dramatic in the years to come.

III. COMPUTER VISION FOR MARS EXPLORATION

It has been a long time since the planet Mars has been under observation and surveillance by remote spacecrafts sent from the surface of the Earth. One of the primary objective of this was to gain insights about the Martian System which focused on understanding the geological features and determining the potential of the planet to sustain habitat.

During early times, the space missions for the exploration of Mars have seen a drastic failure rate because of the high complexity involved in the interplanetary journeys. There were few missions which failed even before they could reach their destination. Computer Vision when implemented when robotic techniques have enabled the automation of spacecrafts substantially increasing the success rate of missions. The various tasks that could use vision assistance are:

Autonomous precision landing on Mars surface.

During the decent phase of the spacecraft, a computer vision algorithm can be used to estimate the relative position and attitude and the landmark recognition-based algorithm can be used to estimate the relative position and motion. Computer Vision algorithms find a major role in performing the following tasks during the descent phase of a spacecraft:

- Performing surveillance and building of terrain maps of the Martian surface.
- Monitoring the loading and unloading of required equipment.
- Rock handling activities, mining and excavation
- Performing routine testing and inspection.
- Deploying and retrieving payloads.
- Obstacle Detection and Avoidance.

It is often very difficult to control long distance rovers and communication between the surface of Earth and Mars due to various constraints posed by the deep space network and other disturbances in space. This requires onboard autonomous navigation to improve efficiency, reduce operations cost and increase mission safety. Autonomous systems need huge computational power which is one of the major constraints. Hence only local obstacle avoidance and detection was made possible with the help of Stereo Vision. Stereo vision is used as a sensor for finding the range between two objects for obstacle avoidance because it uses efficient algorithms, compact and low power cameras which are highly suited to be operated in space conditions.

Stereo Vision:

Stereo Vision refers to the process of obtaining 3-D information from a digital image. The process is analogous to the biological process called Stereopsis and hence gets its name. The process of extracting features from a digital image used in Stereo Vision is similar to the working of a Charge Coupled Device In simple words, it refers to the process of getting to know the depth of a digital image taken at the same time by two or more cameras. Stereoscopic images are stored as MPO (multi picture object) files. Scientists have found efficient methods to maintain the resolution and the quality of the images and at the same time substantially reduce the memory space occupied.

Right from the Mars Pathfinder Mission (MPF) to the MER, the goal of the rover has seen a huge improvement. In the MFP, the rover was just capable of staying within 10m from the lander whereas in the MER it was capable of travelling up to 100m/day and at least 600m in 90 days. In an effort to make obstacle detection and avoidance more efficient LADAR and Stereo Vision were used as alternatives. LADAR has an advantage of greater range, but this not required due to the slow driving speed and relatively low obstacle frequency. Stereo vision has the advantage of being all solid-state, hence having greater mechanical reliability and longer life. From the Mars Pathfinder mission, Stereo Vision was believed to work on the surface of Mars fairly well. It was already established that simple stereo algorithms based on area correlation could produce sufficiently dense, sufficiently accurate range imagery with sufficient speed within the available computing power. Hence out of all the trade-offs that were conducted, Stereo Vision was chosen as the best possible visual algorithm in terms of cost, risks involved and performance.

A glimpse of the algorithm used for the NASA MER Mission is summarized below:

• The images captured which were 1024 × 1024 in dimension were compressed down to 256 × 256 and rectified with bilinear interpolation.
• The images after compression were filtered by subtracting out local block averages.
• 7 × 7 sum of absolute differences scores were computed for the disparity search range and minima were computed independently for each pixel.
• The left-right check was applied to eliminate ambiguous matches.
• Subpixel disparity was computed by fitting parabolas to the three SAD scores that were obtained around the minima.

IV. FUTURE OF COMPUTER VISION

With further research, the future of Computer Vision will see a drastic advancement. Computer Vision algorithms would become much easier to train and the algorithms would further improve in their performance. Many other technologies like Artificial Intelligence and Machine Learning when incorporated with Computer Vision can make it possible to build powerful autonomous systems. Complete automation of spacecrafts and space robots may be achieved with deep neural networks. Computer vision and AI are going to dominate the entire space sector in the near future. It would not be wrong to tell that there is a lot more in the field of Computer Vision which is yet to be explored and will see a quantum leap in the coming years.

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