Intelligent Real Time Systems & Space Applications

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Scheduling of Intelligent Real Time Systems
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1 Introduction

The relevance of space applications has increased over the past years, leading the scientific community to show more interest in this topic. Also, due to new space missions further investigation is required to accomplish new goals in this area.

This work focuses on two specific topics of space applications and how real-time systems are used to give state-of-the-art solutions to problems involving these topics.

Firstly, rovers, which are mostly known for their use in planetary exploration missions. Which are gaining more and more relevance as we deepen into space exploration.

Secondly, space debris, which are objects which cause space pollution, which has exponentially increased since the start of human space exploration. Due to the increase in space missions and satellite usage these are considered are threat for space applications since may cause a collision which could lead to the failure of a space project.

2 Planetary Rovers

Rovers are devices designed for planetary surface exploration[11]. These move across solid surfaces of planets or other celestial bodies. There are two different types. Ones designed as land vehicles, used to transport space crew members. But this work focuses on the second kind, which are partially or fully autonomous robots.

These rovers are typically used to collect information and taking samples of the terrain. This is afterwards analyzed to consider the presence of water, habitability conditions and even look for signs of past or present life. Meaning they are an essential tool for space exploration.

Currently, there is 1 rover on the moon from the CNSA, China National Space Administration. Meanwhile, Mars has 2 rovers from NASA, National Aeronautics and Space Administration, and 1 from CNSA[10].

Due to the difficulties to control rovers remotely, mainly because of the delay between sending an action and performing it, rovers mainly operate autonomously. It is mandatory that their decision scheduling is done in real-time to ensure the security and well functioning throughout a whole mission period.

Figure 1: NASA's Current Mars Mission: Perseverance the Mars 2020.

2.1 Scheduling for Rovers

Scheduling is one of many tasks that rovers must perform during their deployment. This is a key factor to improve task realization by the rover. Usually, schedulers are embedded in this devices to perform real-time tasks. As of today is not feasible to schedule tasks from Earth or even manually operate with the rover. This is because the delay between Earth and Mars is approximately 14 minutes so feedback would take another 14 minutes. So this embedded systems are a necessity not only for autonomous activity but because if a critical event occurs human interaction is extremely slow to deal with the situation.

As exposed above, an embedded scheduler is a must for planetary rovers. However, for NASA's next rover Perseverance, it is very surprising to see that this systems are very unsophisticated as it uses a simple algorithm for scheduling. It is based on a greedy, priority-first, non-backtracking scheduler. Looping through the requested activities in priority first order. It seems NASA's approach is to accomplish objectives in a secure manner instead of trying to improve their runtime or resource used. Coming up different studies will be described which try to reduce the assigned scheduling time during rover's execution so it can better use its run time for task completion.

First, several terms a defined to better understand the following studies. Fixed cadence scheduling is performing rescheduling every certain period time. Meanwhile, event driven scheduling invokes scheduling only when certain events occur. This seems a better approach as no unnecessary scheduling can be done, but in reality low priority tasks can starve and infrequent events may cause scheduling problems.

The following two papers work towards optimizing the commit window usage, because if a plan finishes early there is some runtime lost before rescheduling occurs. So there is freed run time which could be used for idle time, performing default policies or the previous schedule, but it is difficult to plan ahead the utility of this actions.

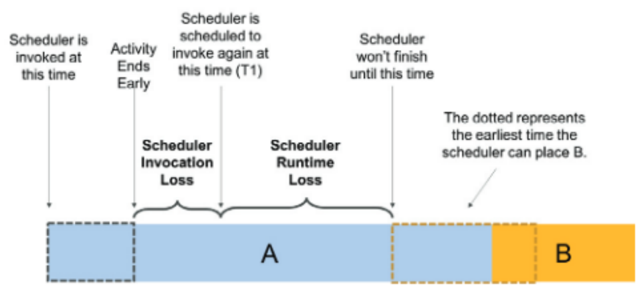

Figure 2: Commit window example.

In [2] a hybrid between both event driven and fixed cadence scheduling methods is proposed were rescheduling is invoked in an event driven way but there is a minimum and maximum cadence to prevent the commented problems. Also incorporates, flexible scheduling, so when an activity finishes early its successor scheduled activity may start early its execution. However, this is only useful for local optimization as this can allow inconsistent executions with the schedulers knowledge.

The goal is of this work is to schedule activities such that the schedule as the shortest possible make span as the optimization metric. As a shorter make span implies that resources such as energy,data volume, and unit resources (time) are freed. However, this formulation has some errors. The real goal is to maximize utility function over executed activities. So in this sense is successful but fails to take into account as much other factors, such as priority, energy consumption or data volume.

On the other hand, [1] develops a predictive model for scheduler runtime to improve scheduler and execution performance.

Additionally, this work goes a step further taking into account other factors as execution context such as the state of the rover and tasks to be scheduled may require thermal requirements.

Flexible execution was also tested but did not achieve result improvements. Neither a variable commit window but is a better alternative to flexible execution as it takes into account energy constraints. As estimated a longer committing window may offer higher flexibility than a tighter window.

Two predictive models were tested, based on current scheduler inputs and based on scheduler runtime from the previous invocation. Both enable an increase in productivity during rescheduling by accurately predicting the scheduler's runtime.

In contrast to the previous studies, [3] focuses on doing an energy efficient approach to extend the battery life of the rover. Rovers have a limited battery capacity so decreasing their system energy demands increasing their runtime and ultimately, improving their effectiveness.

Given that energy consumption becomes more and more strict it has been noticed that context switches add an alarming time overhead and battery usage to rovers. Therefore, this work proposes a way to reduce context switches effectively to mitigate this problem.

The different tasks scheduled by rovers can be classified in to system tasks and application tasks to avoid interference between system- and other tasks. Application tasks refer to the specific functionality such as added sensing devices.

The experimental results show that the proposed scheduler can reduce context switches by about 1% and decrease energy consumption by about 0.6% for given tasks. This may be negligible but all improvements need to explored and welcomed in this areas as they are in still in their infancy.

2.2 Sinkange and Terrain Analysis

Nowadays, this is a fundamental task that rovers must deal with as they generally work autonomously. Therefore it is critical that they are able to avoid putting at risk a mission by getting stuck or being damage.

Although this problem might seem trivial at first, time-response of the system and resource management is key for a good, on field, performance. As using deep neural networks is not a wise decision for this task and other techniques are used. As data acquisition and analyses must be done in real-time to tackle sinkage problems and prevent mission delays from becoming stuck.

Despite the fact commented earlier computer vision is the preferred tool to overcome the challenge of sinkage detection. The common approach is to analyze the contour of the rover's wheel to define its sinkage state.

In [6], offers a solution with 99% accuracy in test with a analyses delay time of 0.07s. Their approach consists on monitoring via a fixed camera the wheel. The wheel is colored blue, a rare color in nature, so the segmentation is easily done. Then the wheel contour is calculated analyzing separately each RGB color instead of transforming the image to shades of grey. This way comparing the intensity and ratio of each color it is possible to segment the wheel contour of the image. Giving a binary output of the wheel and the background. Afterwards, the lowest point of the obtained wheel is considered as the highest sinkage point of the wheel. Finally, to calculate the sinkage distance of the wheel only the lowest point of the wheel is need. As the camera is at a fixed position, this point can be easily be calculated considering the rotation state of the wheel. Therefore, tt is possible to do a simple subtraction to calculate this value.

This investigation is done for legged wheels but it can be extrapolated to normal wheels. Also, specifically for rovers, it is only necessary to monitor the 2 leading wheels. However, another option is to use a 360 degree camera and do the necessary transformations to monitor all individually.

Recently, [4] presents a more sophisticated method of sinkage evaluation. As the previous work it the image state of the wheel into a binary image. However, further on takes a different approach. The next step for the proposed method is to compute the edges of the binary image. Showing the contour of the wheel and the highest point of sinkage of the wheel. After this, the wheel rim is estimated. Given this information the rover calculates the sinkage entrance and out angles with a dedicated sensor.

A high-fidelity machine learning model is used to analyze the impact of wheel lug, sinkage, wheel radius, wheel width, load effect and other 11 additional empirical parameters. Through iterative optimization, the algorithm is able to detect the rover's wheel slippage and immobilization. This method give estimations with only 4.73% error for low and moderate slip scenarios. In high slip scenarios the error varies from 5.73% to 15.22%.

Moreover, other solutions have been studied to overcome ordinary monitoring methods for terrain analysis. In [5] avoids the idea of using dedicated sensors for this task. Vibration sensors are susceptible to weight and the suspension system used. Cameras fail to operate correctly with poor illumination and different types of image occlusion (dust, fog or smoke). Accelerometers limit the mobility of the rover so measurements can be done accurately. Standalone sensors have good results analyzing terrain and the have unique weaknesses. However, considering using a multi-sensor is an approach which creates a huge overhead. Meaning it is not optimal for the rover's operating conditions.

Therefore, this paper proposes using the robot itself as a sensor. Using only its control inputs and pose information to estimate the condition of a terrain via support vector machines. Their solution consists in given these inputs, feature engineer them and perform a principal component extraction for the SVM input.

This work shows results over 80% accuracy in terrain detection which is not as high as device based analyses but results in a less resourceful solution. Nevertheless, this method only allows the rover to move at a velocity between 0.2 and 0.5 m/s. Also experimentation was limited to certain types of terrains available on Earth and alike ones found in the Moon or Mars.

3 Space Debris

Debris can refer to a number of different things, such as rubble, wreckage, ruins, litter or discarded garbage. However, in a space context it usually refers to the spacecraft remains which are orbiting Earth or have already fallen to Earth. Chunks of rock and ice are natural components which can also be considered as space debris[12]. Colloquially, they can be considered as space junk.

Nowadays, there are millions of fragments of debris orbiting Earth due to 550 known past events related to space missions. Debris range in size from millimeter fragments to entire satellites not functioning. This are an issue because these pieces travel at many kilometers per second. Meaning, that any with other objects threatens the to atleast impair the functioning of a working spacecraft, or even destroying it altogether, leading to the creation of even more debris[9].

Our planet's atmosphere gradually slows down and brings these elements back down to Earth. Nevertheless, this process is too slow to remove them this way as it could take from a couple of decades to a thousand years. Depending on the altitude of the fragments.

Given the nature of these objects it is essential to monitor them as accurately as possible and if possible remove them. This would not only benefit the space environment as trash is removed from space, but also make space operations more efficient as they would not have to spend time and energy.

As the trajectories of satellites and spacecraft have to take into them into account to avoid any disasters.

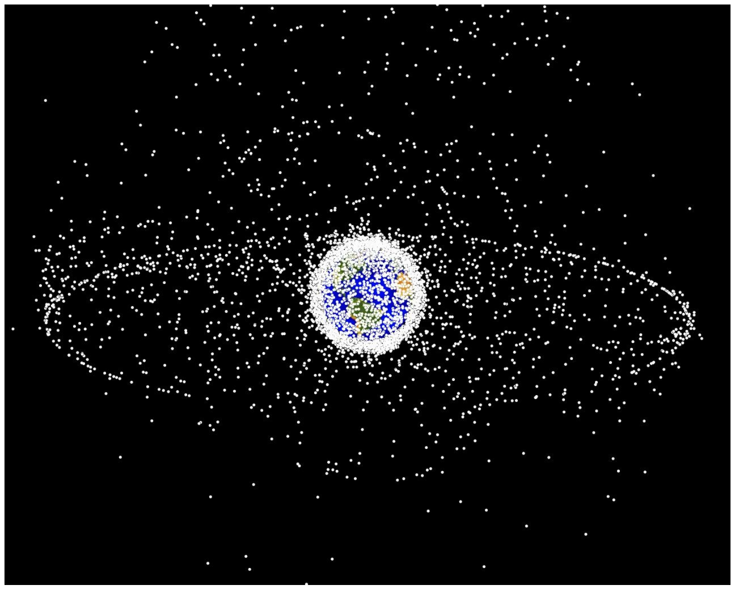

Figure 3: Computer-generated image of space debris. The two main debris fields are the ring of objects in geosynchronous Earth orbit and the cloud of objects in low Earth orbit.

3.1 Space Debris Detection

This is a task that is gaining more attention as debris are increasing exponentially. It is critical to detect and track debris trajectories effectively to avoid any undesired collisions or other catastrophes. This problem will become more relevant as further space missions are realized. Additionally, it will be a complementary field of study with debris removal. Which in a future it will become a standard operation. This is why it valuable for space safety a fast and reliable detection method.

In the present day, this matter is being solved with computer vision algorithms combined with different techniques. Although neural networks dominate image analysis tasks, this field's studies show they are not the only solution to consider and classical methods are still relevant for space debris detection.

The first work which is in the state-of-the-art solutions in this field is [8]. This paper shows how to effectively detect weak stellar targets, space debris and tracks in noisy images from charge-coupled devices, a imaging sensor usually used in astronomy.

The image undertakes a complex process to remove different smears and noise, as well as, inter-frame correlation algorithm to calculate the path of debris.

Firstly, for image preprocessing part, the background is suppressed with a non-linear low pass filter. Leaving most relevant information of the image. Secondly, a special smear noise of the charge-coupled device is removed. In third place, vertical straight smears appear due to stellar targets movings very slowly, so slowly they can be considered stationary during the exposure of the frame image. Finally, the smear of space debris is removed.

Once several frame are ready, the algorithm is prepared to calculate a track, which is the path taken of a debris. Calculating a regression of all points in the image would be too expensive time-wise. Therefore, the image is divided into N sub-graphs so the computation amount is reduced. Additionally, computations are further reduced using a triangular function indexed table.

The pipeline proposed by this paper is able to process a 2048*2048 grey image in 600ms with high accuracy. Given the size of the image analyzed the results obtained are really successful in a very small size window.

As expected between the most novel solutions appears the use of neural networks as the one proposed in [13]. Giving a small and efficient answer to confront this problem. Moreover, this paper focuses on debris in geosynchronous orbit, which are the outer ring of debris seen in figure 3. This means that the target pixels consist of less than 0.15% of the image.

This study considers different networks for implementing a solution but discards Long-Short Term Memory network as they are memory and time intensive. Instead a convolutional network is proposed to analyze 256x256 images.

The second important decision made is to define the output of the network. The image is divided into 14x14 regions. For each region a 1 is assigned if a debris is predicted and 0 if no debris present.

The last decision was the network topology. This is a very straight forward model where convolutions are stacked and the image is reduced 5 times using max-pooling.

This is a very interesting work as it achieves very high performance with a minuscule time delay, being 98.89% and 2.3ms respectively. Furthermore, the resources needed a surprisingly low shockingly low as the experimentation is done with CPU instead of GPU.

All the solutions commented above requiere night time imaging of the sky but [7] offers a novel solution to avoid this time restriction of debris monitoring. It introduces laser ranging method during daylight to increase the potential observation times. As normally it is only possible during twilight, which is about 6 hours, and this method enables visualization during daylight, increasing it to 22 hours.

Laser ranging was already possible in 1964, as satellite were equipped with retro-reflectors. These are devices or surfaces which reflect radiation back to its source with minimum scattering. But now it is possible with a high repetition rate identify individual retro-reflectors and with the collected data determine the spin and altitude parameters of debris and active satellites.

This system involves 2 components. On one hand, there is the active one, which fires the laser at space debris targets. On the other hand, there is the passive one, which detects reflected photons, independently if the laser is in operation.

The procedure presented focus on large objects which can be identified during daylight. In first place, a visible target is manually searched with a telescope. Then the satellite laser ranging (SLR) telescope is aligned with the target taking into account time-bias. Time-bias refers to the temporal displacement of an event whereby people perceive recent events as being more remote than they are and distant events as being more recent than they are. This is done before SLR search routine starts so the telescope centers targets correctly with SLR field of view.

Secondly, observations are done having an observation telescope with a very high aperture with a short exposure time to make better observations as these are limited by the contrast of debris and the sky background. As a long exposure lets pixels accumulate sky light while not being exposed to star light. Leading to a low contrast between the sky and the target as the brightness of the target would had a low influence. Therefore, a short exposure time enough to freeze the current atmosphere is desirable.

Lastly, the paper mentions that their computer vision software ensures in real-time results. Overall, more than 40 different upper stage rocket bodies were visualized with this technique during daylight. Detected by the real-time image analysis software. Up until now only a few stations worldwide contribute to space debris measurements, but with the advancements shown in this paper clearly points out that including twilight and full day light will drastically increase the output of all stations capable of doing space debris measurements.

4 Conclusions

Completing this project has been really useful and interesting because of different factors.

In first place, it was a unique opportunity to delve into space applications and study the state-of-the-art approaches to tackle rover scheduling, rover terrain analyses and debris detection.

In second place, it can be seen the importance of intelligent real-time systems in this field of study and how time delays and deadlines can affect different on field performance. Being also to analyze the critical tasks needed to be performed by the reviewed space systems.

With respect to rover scheduling, the current used embedded schedulers have a secure but primitive approximation. Recent studies show that a better runtime execution can be achieved. So hopefully, future missions will incorporate more intelligent scheduling systems.

Terrain analysis has been very important for extending rovers longevity and operational time. Up-to-date studies are able to overcome this problem successfully. Also, computer vision based approaches are being effectively challenged by other sensor approaches. To reduce rover workload, overcome occlusion problems and maintain real-time performance for critical situations.

With the exponential increase of human space interaction the population of space defunct has substantially grown over the past years. Therefore, the collection of space debris information is key to perform safe space operations. So the last studies not only offer improved results for this area but will become more and more relevant in the future years as human is able to reach further into space.

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