Neural Network Approach to Star Tracking

Iteration 0

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ABE 598

3/24/18

# Section 1: Introduction and problem motivation

Determining the attitude of a satellite is an important problem in controls due to the lack of information present. The attitude information available varies greatly depending on the type of sensors implemented on the satellite. For many use cases, some combination of magnetometers, gyroscopes, sun sensors, and horizon sensors can be used in along with sensor fusion to determine satellite attitude to a decent degree of accuracy. However, for missions that require high accuracy attitude determination, the star tracker is generally used since it is the most accurate sensor for attitude determination.

Star trackers are also the only class of sensors that are able to solve the “lost-in-space problem” (LISP) for a satellite far away from any planetary bodies or stars. The LISP is as follows: given a satellite that has no previous memory of its attitude, find the current attitude and rotational rate. Other types of sensors either rely on having data about the satellite’s previous attitude or on features of a nearby planet to find absolute attitude, making it impossible for them to solve this problem in general. Star trackers on the other hand are generally able to solve this problem since they utilize an image sensor which takes pictures of the celestial sphere, then compares the images to a catalog of stars.

An ideal satellite attitude determination and control system is nearly autonomous in its operation, requiring only a desired attitude and rate from a ground station. As part of this autonomous operation, a star tracker gives the attitude as a point in a state space. The satellite then uses this information as an input to a control algorithm, which selects control output from an action space. The transition function therefore takes the current attitude to the desired attitude. In order to penalize differences between current and desired attitude, a cost function minimizing the Euclidean norm between these two attitudes can be implemented.

Given the high accuracy of star trackers, it may be no surprise that they are also the most expensive class of attitude determination sensors. The least expensive star tracker on CubeSatShop.com is the *MAI-SS Space Sextant,* which is priced at $32,500 [1]. Other star tracker systems can cost well over $100,000, making them too expensive for smaller missions to use. An improved star tracker would have a lower cost while still maintaining high accuracy attitude determination. We therefore need a solution that would reduce the overall cost of implementing a star tracker system.

# Section 2: Limits of current practice

Star tracking algorithms are able to solve the LISP, but there is still headway to be made in improving these systems. The current limitations to current star tracking algorithms are related to improving the robustness of the algorithms to errors such as noise or unexpected objects that may obstruct stars in the images taken [2: 12-13]. This can cause problems in some star tracking algorithms, as the data in any single image of the celestial sphere is sparse in information, and any information lost greatly affects the attitude estimate. A typical image taken by a star tracker is shown in *Figure 1* which highlights the sparseness of information in each image.

Figure : A typical image from a star tracker. The colors have been inverted to more clearly highlight the stars in the image.

# Section 3: Background literature and state-of-the-art

Several approaches to star tracking algorithms have been proposed and implemented. One common approach to star tracking is to extract star features from images of the celestial sphere, then compare these features to a database of known features of stars. Improvements in star tracking algorithms over the past 30 years have largely focused on choosing different features in the images to increase star identification accuracy, improving the speed of the database search, and reducing memory requirements for the database of star features. [2: 4-9]. This is generally seen as the “classical” method for implementing a star tracking system, and the other main method for attitude determination involves neural networks.

Neural networks were first proposed in [4], and further work was done in [5] as one of the first “modern” implementations of neural networks as a method of star tracking. Several other papers including [6], [7], and [8] made further progress to the problem of star identification using neural networks. Especially given the results of [6], these developments showed that neural networks could be used to effectively solve the LISP given enough computational power. The main drawbacks to the methods used in these papers is that they seem relatively primitive by today’s standards. [6] was unable to get a backpropagation neural network to work in simulation and resorted to a genetic algorithm in order to get their star tracking system to be able to solve the LISP. The results in these papers show that neural networks are able to accurately and quickly solve the LISP.

# Section 4: Your solution method and contributions

Given recent developments in the machine learning community, it previous results can be recreated and improved with modern techniques. Machine learning can be effectively applied to star trackers to work toward the goal of reducing costs of star tracking systems. Therefore, we propose a machine learning-based star tracking system that allows for lower cost components to be implemented on the star tracker. For this project, a recurrent neural network will be used for the ability to “remember” data over time. This will lead to system rate estimate being able to converge to actual rate of the satellite.

The proposed solution has two major components to implement. First, a simulation of a satellite must be implemented. To accomplish this goal, a program will be used that allows an initial rate, attitude, and simulation time to be specified. This program must then be able to correlate the rate and attitude to a particular swath of the sky to be swept out and simulate the satellite’s motion through this swath.

To then use this simulation as part of a neural network, random initial conditions will be chosen for the satellite, and the image data taken from a particular swath of the sky at each timestep will be given to the neural network as an input. The network will then output estimate of the rate and attitude at each timestep which will then be compared to the actual rate and attitude. After this, standard machine learning techniques will be used to train the network.

This system will first be trained on clear images of the celestial sphere, then the quality of the images will be decreased to fit a more realistic model of a star tracking camera. Only after this is working will further developments like adding noise and other disturbances to the image data be implemented.

# References

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