Ain-Shams University
Faculty of Engineering
Computer and Systems Engineering Department

# Design and Implementation of a Star Sensor Experimental Prototype

A Thesis

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Department in Partial fulfillment of the Degree of
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(Computer & Systems Engineering)

by
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# Summary

The Thesis aims at studying the basic theoretical and practical problems concerning a star tracker design and implementation. For instance, attitude determination, star pattern matching, star image filtering and star detection are among the theoretical aspects of star tracker design. Whereas, camera parameters calibration, choice of computational platform, interface and the solution hardware – software architecture are among the practical problems.

Chapter I presents an introduction to spacecraft orbits, attitude and attitude sensors. A motivation for the study is consequently presented. Chapter II starts with some definitions followed by a review of the theoretical aspects related to the star tracker. Embedded in this chapter are some details and examples clarifying the solution of the attitude determination problem. A review of star pattern matching literature is provided by the end of the chapter. Chapter III is a thorough study of existing pattern matching algorithms. Basic matching algorithms are described and analyzed and finally we present our solution for the pattern matching problem; trying to combine the advantages of the described methods. Chapter IV is a description of all the practical aspects related to star tracker implementation. We describe the system level design; give detailed description of the hardware configuration and the frameGrabber implementation. Next, we list the main function of onboard software and its components. Possible modes of operation for the star tracker are readily examined. Chapter V analyzes the comparison results between pattern matching algorithms and proves the superiority of our algorithm in terms of time and performance under noise. Some results of the integrated system test and hardware operational test are presented. Finally, we list the achievements of this study as well as required future work in Chapter VI.

# Abstract

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Spacecraft Attitude Determination from vectors observations, star detection, centroiding and stars pattern matching are studied in this thesis. Algorithms for star pattern matching are analyzed and a novel algorithm is suggested. It is shown that it supersedes the classical pattern matching techniques like Grid and Triangle matching, in terms of performance and execution times. It is found that the conclusion preferring Grid Algorithms over Graph based ones is not totally correct. In fact, four stars matching in graph based technique outperforms their grid counterpart. It is found that carefully selecting search technique and avoiding pivoting can substantially decrease the algorithm execution time without affecting its performance.

A modification to the eigenproblem solution is implemented for the special case of Hermetian Operators. The use of the spectral theorem for Hermetian operator expansion as well as the classical power method enabled us of calculating all the eigenvalues and eigenvectors of a hermitian matrix.

Moreover, a complete design and implementation of the interface hardware and software is realized. A framegrabber with programmable logic and its software driver were fully and successfully designed and tested with the camera. Pattern matching algorithms are also tested onboard the star tracker and is found to perform adequately in an acceptable execution time. Software components for attitude determination are implemented based on a native matrix library that we also developed.

**Keywords:**
Star Tracker – Star Pattern Matching – Attitude Determination – Space Systems – Satellite

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My final and most sincere greetings go to the Egyptian Space Program. It allowed me an unrepeatable opportunity to get acquainted and in a close contact with a developed space industry. Moreover, it helped me in this research by providing all necessary means for testing and debugging the hardware.

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# List of Symbols

| | | |
|---|---|---|
| $i, j$ | : | Star Indices |
| $J$ | : | Wahba's Objective Function Value |
| $C_{est}$ | : | Estimated Value of the Direction Cosine Matrix |
| C | : | Real-Value of the Direction Cosine Matrix |
| N *or n* | : | Number of observed stars |
| M | : | Space Dimension |
| $w_i$ | : | Star Unit Vector Observation in Inertial Coordinates |
| $v_i$ | : | Star Unit Vector Observation in Body Coordinates |
| $W$ | : | The set of unit vectors in Body Coordinates |
| $V$ | : | The set of unit vectors in Inertial Coordinates |
| $\theta_{ij}$ | : | Interstellar angle between star $i$ and star $j$ |
| $\Lambda$ | : | Diagonal Matrix of Eigenvalues |
| $\acute{\alpha}$ | : | A fraction of stars in the triangle algorithm |
| $k$ | : | Number of stars in a shot in the triangle algorithm |
| $I$ | : | The Identity Matrix |
| x | : | Cross Product |
| $\circ$ | : | Dot Product |

# Acronyms

| | |
|---|---|
| CCD | Charged-Coupled Device |
| FOV | Field of View |
| JPL | Jet-Propulsion Laboratory |
| MLE | Maximum Likelihood Estimator |
| M-D | of Dimension M |
| N-D | of Dimension N |
| PSF | Point-Spread Function |