Validation of the fine guidance system for the PLATO-Mission

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Abstract

abstract test

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Chapter 1

Introduction

The PLATO–Mission from the European Space Agency (ESA) is the successor of the Kepler and Corrol missons and aims to find more planets outside our solar system. Therefore the satellite will carry several cameras, which are pointed on as many stars as possible. Over a period of time, the luminosity of each star will be measured and saved. This data can be used to create light curves of single stars. Periodic peaks in those curves indicate that there are planets around the corrisponding stars. This is called the transit method and will be explained later in greater detail.
The success of the mission is highly dependant on a stable position of the satellite in space. Disturbances have to be countered with thrusters. For the exact control of those thrusters, a fine guidance system (FGS) is developed by the DLR Berlin. This is an optical system which will depend on the optical input of the onboard cameras of the satellite. It will ensure that the satellite will be in place over a long period of time with neglectable deviation.
It's not easy to test such applications, since it is not feasable to build and launch a prototype of the mission. On the other hand, it is of utmost importance to ensure before the start of the mission, that all systems and especially the fine guidance system work as they should. Therefore simulators are needed, which generate data approximated with all known sources of disturbance. Simulators allow to study the scientific community to study the performance of the instrument, its noise source response and the data quality. For the FGS there are two simulators used at the time the parallel developed DLR simulator, tailored for this exact task and the more general and more independantly developed PLATOSim simulator by the the KU Leuven.
Goal of this report is the summary of all steps taken to test the fgs and make sure all requirements for the mission ahead are met. Within this document the planned methods for detecting exoplanets and the according hardware of the PLATO–Mission are described. Next, the effects and probable sources

of disturbances, as well as their possible influence is discussed. The third chapter deals with the used simulators. Their architecture and their methods of tackling the problem are described. The fourth chapter is about the generation of output data using the simulators and their use for the fgs. Strengths and weaknesses are discussed. The last Chapter is a summary of the work done and a prospect on the future testing of the fine guidance system.

Chapter 2

The PLATO–Mission

PLATO (PLanetary Transits and Oscillations of stars) is an ESA mission launching in late 2024 with the goal of finding terrestrial exoplanets within the habitable zone of solar-like stars. The mission will be delivered with a Soyuz 2-1b launch vehicle with Fregat-MT upper stage. The satellite will be placed in a large amplitude liberation orbit around the earth-sun lagrange point 2 (L2 Point). In its orbit it will conduct multiple ultra-high precision, long duration, uninterrupted photometric monitoring of at least two different star fields over two years each. After that, a "step-and-stare" phase will be started, in which the spacecraft is pointed to areas of special interest for several months. This phase will last for another two years. Two additional years of use of the satellite are possible. To guarantee a continuous power supply, the spacecraft has to be rotated around its line of sight every three months to make sure its solar arrays are pointed to the sun. This has to happen without altering the line of sight between spacecraft and the observed sky array.
In this chapter the specifications and requirements of the Plato–Mission in general and its fine guidance system in detail are presented.

2.1 Goals

PLATO pursues the objective of detecting and characterizing exoplanetary systems, including both the planets and their host stars, reaching down to small, terrestial planets in the habitable zone. Furthermore the host stars will be characterized via asteroseismic analysis, which will provide the masses, radii and ages of the host stars, from which the characteristics of hypothetical planets can be derived. Promising planetary systems will be the target of further analysis in later missions. The difference to previous missions like Kepler and CoRot is that PLATO aims to cover a much larger portion of the sky. Up to 1000000 stars will be observed over the runtime of the mission.

2.2 The payload

The payload of the satellite consists of 32 identical "normal" cameras and 2 fast cameras. All cameras have an aperture of 12 cm and are operating in the 500-1000nm spectral range. The normal cameras are arranged in 4 sub-groups of 8 cameras with the same field of view. Each cameracluster is slightly tilted from the mean line of sight, which is the LOS of the fast cameras, of the payload. This allows a large surveying field.
Each camera has its own CCD focal plane array consisting of 4 CCDs. Each CCD of the normal cameras has 4490x4490 light sensitive pixels. These cameras will monitor fainter stars with a magnitude higher than 8. The fast cameras employ a 4 CCDs with 4490x2245 light sensitive pixels each, which will observe bright stars with a magnitude less than 8. The fast cameras are used for the position and altitude determination of the spacecraft needed for the FGS.

2.3 The means

Key to the detection of exoplanets with PLATO is the transit method, which is, up to now, the most succesfull way to detect planets in other solar systems. Approximately 80% of all known exoplanets were found with this method.

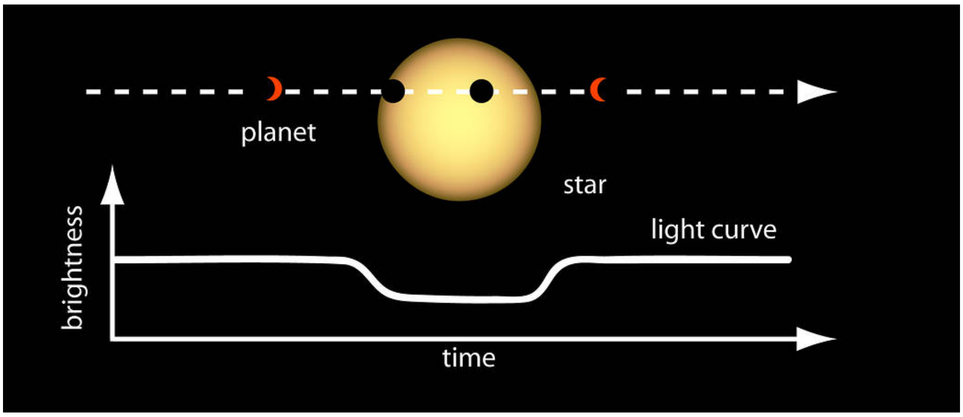

Figure 2.1: Transit method

At the current state of the art, there is no way to watch a planet, which orbits a star thausends of lightyears away. To prove its existence, the corresponding star itself is watched over a long period of time and its luminosity is recorded. This data is captured in light curves. A reappearing dent in this light curve can indicate an object which orbits the star and periodically obstructs the line of sight of the telescope/camera. This is clarified in figure

2.1. To exclude the possibility of a coincidence, this change in the luminosity of the star has to be detected three times with the same time interval. Other than proving the existence of an exoplanet, more information can be derived from the course of the light curve. It is possible to calculate for example the planets radius, its inclination and its distance to the star. Through spectral analysis, statements about the atmospheric composition, the temperature and the albedo of the planet can be made.
This indirect method is dependent on the planets orbit crossing the line between telescope and star. The chance of this happening is only around 1%. PLATO will counter this problem by watching thousands of stars at once over years. Statistically it will have discovered ... stars by the end of the mission.

2.4 The fine guidance System

The requirements for the fine guidance system are described here.

Chapter 3

Validation tools

3.1 PLATOSim

PLATOSim is a Simulator developed by the University Leuven which generates data as the PLATO mission will do, by simulating the whole acquisition process. The process aims to synthesize the satellite images as realisticly as possible by including all known noise sources and generating a numerically modelled imagette for each considered star.
PLATOSim is planned to be a tool for the scientific comunity which is easily adaptable for other high-precision photometric space missions as well, therefore it is build very versatile and easy tweakable in its parameters. At the time beeing its main usage is by the different workgroups which develop software applications for the PLATO mission. PLATOSim is operational but stil in the process of testing and is adapted according to the needs of the different users from the aformentioned workgroups.
In this section the architecture and the mode of operation of the tool and all considered influence parameters are described.

3.1.1 In- and Output

In this section the in- and output of PLATOSim is discussed.

Output

The goal of PLATOSim is the generation of the imagettes which are used to create the light curves of a star. Those imagettes are squared grayscale pictures centered around a star with an edge length of only 9 pixels. For every exposure there is a seperate imagette. All imagettes for a single star are stored in a hdf5 file. To retrace the steps which let to the creation of the different help matrices as well as the subpixel map of the imagette and the corresponding psf are included to. Furthermore all information about the star like its position in space and on the CCD, its ID number and its magnitude are stored in the hdf5 file.

Input

To create the desired data some information have to be given by the user of the simulator. The basis of the input is the star catalog which lists all stars, a simulation should be run for. This is a simple text–file which contains the right-ascension, the declination and the magnitude of every star in one line seperated by white spaces. Furthermore, there is an input–file where the user can configure the parameters of the simulation. There are possibilities to in- or exclude certain effects or noise sources and to alter numerical data like the orientation of the used telescope or of the CCD with respect to the pointing direction of the spacecraft. Some sources of disturbance need more direct input than random generated numbers, therefore files of the jitter movement and the thermo–elastic drift are present as well. The jitter–file includes the yaw, pitch and roll angles over which the axises of the spacecraft is rotated for a given time. Those data are stored as numbers, seperated by white spaces, in a text–file in which every line represents a measuring step.

3.1.2 Architecture

PLATOSim3 aims to simulate the work of the PLATO satellite as close to reality as possible. Therefore the architecture of the program consists of 5 major parts to depict the spacecraft in its orbit and all the processes necessary for the data generation and one governing part, which controlls the information flow between them. Those parts are namely the platform, the telescope, the camera, the detector, the sky and the simulation. The main objective of each of those program parts is as follows:

- platform – stores information about the satellites movement e.g. jitter
- camera – application of the point spread function
- detector – administration of the different (sub-)pixel maps
- telescope – provides information about the thermo-elastic drift
- sky – includes data about the stars
- simulation – organisation and flow control

In this section the workflow of PLATOSIM will be presented along these program parts. First the managing simulation process is shown after which the details of the different simulation parts will be revealed.

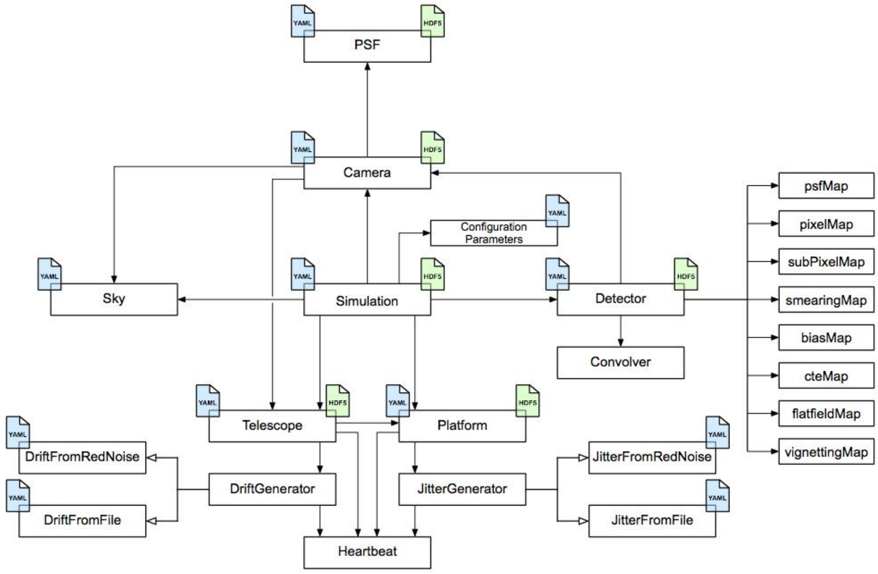

Figure 3.1: PLATOSim process

3.1.3 Simulation Process

The working process of PLATOSim is shown in figure 3.2. In this section The single steps are shown and analysed for their relevance for the fine guidance system.

PLATOSim aims to generate only one imagette for one star with one exposure of the camera at the time. The whole CCD is generally not calculated because of the high memory consumption, which would be needed for such a task. Instead only the small section, where the light of the specific star falls on the CCD is simulated.
To correctly simulate motions and noise effects even the relatively small size (18 mycrometer) of the pixels is too large. Therefore it is necessary to subdivide each physical pixel in a number of subpixels to display intra-pixel sensitivities. The aforementioned imagette is enlarged in its dimensions depending on the number of subpixels the user wishes. All effects like the PSF or noise sources are applied on this subpixelmap, before it's rebinned again to the small imagette in the end. The more subpixels are used, the more accurate the result will be in theory. However a larger subpixel map comes always at the price of longer processing times and more needed memory.

Geometry

The first step is to determine where a star falls on which CCD of a camera. Therefore a few input data are required. The most important ones are the information about the currently relevant star and the orientation of the pointing axis of the satellite.

3.1.4 Using PLATOSim for the FGS testing

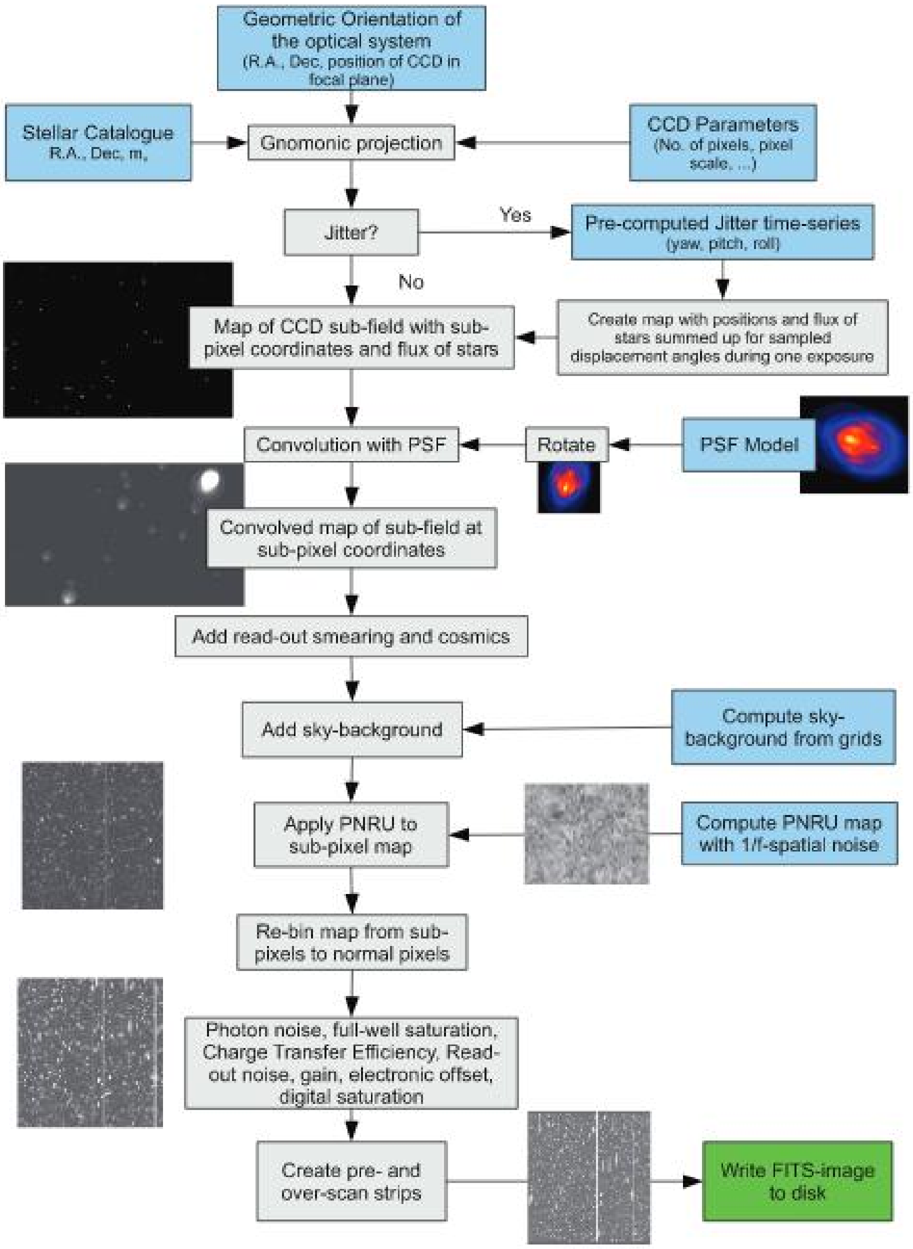

Figure 3.2: PLATOSim process

Chapter 4

Summary

This is the summary of the work done to validate the FGS for PLATO.