SYSTEMS DEVELOPMENT OF A TWO-AXIS STABILISED PLATFORM TO FACILITATE ASTRONOMICAL OBSERVATIONS FROM A MOVING BASE

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Introduction: Many examples of modern electronic and optical systems require inertial stabilisation for them to achieve their maximum performance[1, 2]. Inertially Stabilised Platforms (ISPs) are systems capable of isolating a sensor from its host by attenuating rotational disturbances coupled from the host to the sensor which result in a reduction in the sensor's performance. ISPs aim to control the line-of-sight between a sensor and a target. They perform two distinct operations: first, keeping track of the target as the sensor host and target move in inertial space and, second, attenuation of rotational disturbances incurred to the sensor by host vehicle motion[3]. This project aimed to develop a two-axis ISP for use in astronomical applications. Due to the high magnifications associated with astronomical observations, target objects are quickly lost from the field of view (FOV) of a stand-alone telescope due to the Earth's rotation. It was hypothesised that by mounting a telescope on a stabilised platform with an automatic target tracker it would be possible to overcome this problem as well as extend the allowable operating conditions of the telescope to include mountings on moving vehicles. Due to budget constraints, it was decided early in the project to evaluate the hypothesis with a low-cost approximated system which made use of a mechanical assembly designed to mount a low-cost camera inside a model of a Meade ETX90 3.5" telescope. The model represented the telescope accurately regarding its geometry and mass and inertia properties. This allowed the ISP development and testing to be performed at a lower cost than with the telescope itself.

Project Development Process: To achieve the above aim, a structured systems engineering approach was followed with a set of ideal system specifications first being developed to guide design decisions. A selection of these are given in the next section. During the project, all components of the electro-mechanical structure of the ISP were designed and implemented. This structure served the purpose of constraining the motion of the telescope/camera being stabilised. Sub-systems designed here included all mechanical parts of the physical structure, specification and integration of the associated electrical systems required to facilitate control of this structure including the various sensors, actuators, and digital controllers required to achieve control of the mechanical assembly such that stabilisation and target tracking could be achieved. The control hardware systems were specified and included a Raspberry Pi Model 3 B computer used to perform image processing tasks required to detect the Moon in the camera FOV, an STM32F0 microcontroller running firmware written to manage the various control and communications tasks required by the system, and a laptop running a user interface program facilitating intuitive operator control of the system and datalogging of system runtime data. In addition, a complete simulation model for the system was written in the simulation language, Simul_C_EM, and used to design the various controllers for the ISP control system which were implemented on the STM32F0. For each gimbal, compensated PI controllers were designed to allow manual orientation control of the telescope, compensated P controllers were designed to achieve target tracking, and compensated PI controllers were designed to reject rotational disturbances and achieve the inertial stabilisation of the telescope modeller.

Main System Specifications: The specifications to follow formed part of a broader set of technical design specifications and defined the overall design goals for the ISP system developed:

i. The system should facilitate the inertial control of a 3.5" telescope.
ii. The system should allow for motion control about two control axes.
iii. The total mass should be less than 9 kg.
iv. The target tracker should have a tracking error of less than 0.25 mrad.
v. System jitter should be limited to 2 mrad under dynamic host conditions and 0.5 mrad under static host conditions.

Results: The electro-mechanical assembly designed for the project is shown by Figure 1 below. This assembly shows the pitch platform telescope modeller designed to model the ETX90 telescope.

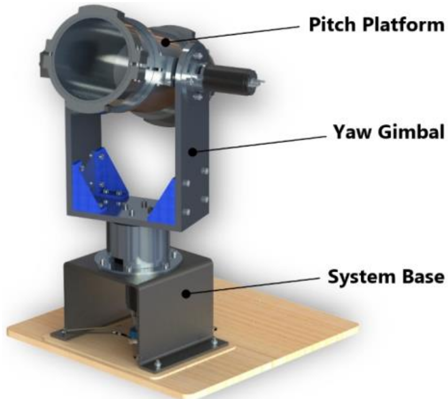

Figure 1: Final design of the ISP system developed

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The assembly had a total mass of 6.40 kg and facilitated the accomplishment of specifications i-iii above. Overall, the performance of the ISP developed correlated well with the system simulation under various test conditions. A key metric describing the performance of an ISP is base motion isolation (BMI) and has been defined as the ratio of the amplitude of a rotational rate of the platform about a specific axis to the corresponding input rotation disturbance signal about the same axis, in dB. The ISP achieved BMI properties of the order -31 dB and -34 dB for the yaw and pitch channels respectively, which matches well with other platforms developed in contemporary literature[4, 5]. Figure 2 below is indicative of the type of attenuation achieved by the ISP for disturbances about axes parallel the control axes

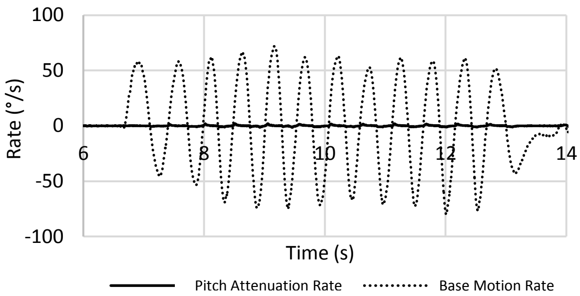

Figure 2: Pitch channel base motion attenuation

In the test above a base motion was applied to the ISP along an axis parallel to the pitch platform control axis. This motion had a median value of 60.89 °/s at a frequency of approximately 1.8 Hz. The ISP attenuated this disturbance signal to a magnitude of approximately 1.16 °/s. The overall performance of the ISP developed is summarised by Table 1 below.

Table 1: Summary of the ISP's tested performance

Metric	**Pitch Channel**	**Yaw Channel**
BMI with disturbance axis aligned with attenuation axis	-34.4 dB (1.1 rad/s at ~2 Hz disturbance)	-31.5 dB (1.2 rad/s at ~2.5 Hz disturbance)
BMI with disturbance axis cross-coupled with attenuation axis	-30.0 dB (0.5 rad/s at ~1.5 Hz disturbance)	-26.3 dB (0.5 rad/s at ~1.5 Hz disturbance)
Maximum tracking rate	0.75 rad/s	0.99 rad/s
Maximum track overshoot	11.6 mrad	12.3 mrad
Maximum track step settling time	1.5 s	1.5 s
Maximum dynamic jitter	2.35 mrad	2.52 mrad
Maximum stationary jitter	1.0 mrad	0.5 mrad

Conclusion and Recommendations: Testing of the system showed a good correlation between the hardware and simulated results which indicates an accurate simulation model that can be used to test future design developments. Overall, most specifications developed for the initial system were met or approached by the performance of the implemented model, with the notable exception of the tracking error of the system which overshot the specification by 50 %. This was due to the need to reduce the image resolution to 640x480 pixels in order for the Raspberry Pi to be able to process the images and provide target position data at a rate suitable for the tracking controller commands. Line-of-sight jitter was limited to a maximum of 2.5 mrad in response to tested disturbances of up to 1 rad/s at approximately 1 – 2 Hz. below is indicative of the type of attenuation performance.

Overall it was concluded that the project successfully achieved its aims and that future development should be continued with the ISP to include the ETX90 telescope. Suggested improvements that should be made include the change of computation hardware on which image processing is performed to improve the tracking performance of the system, the upgrading of the yaw motor such that a greater torque may be applied to the yaw gimbal and so attenuate stronger disturbance signals, and an investigation into the use of modern control methods which may help to improve the performance of the stabilisation control system.

References:

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