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Kiwi: Elevating Avionics Reliability for the Aerospace Team Graz

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Testing leads to failure, and failure leads to understanding

– Burt Rutan

Affidavit

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Jakob Faltisek

Abstract

Kiwi is an avionics test bed designed to efficiently evaluate the avionics of the Aerospace Team Graz (ASTG), with the goal of enhancing its reliability. The focus is on providing a flexible design that can easily adapt to the team's frequently changing projects. While similar Hardware-in-the-Loop testing systems exist, they are typically tailored for larger rockets or satellites, leaving this specific use case unaddressed. To bridge this gap, a structured approach was taken to evaluate requirements, progressing from broad Level 1 objectives to detailed Level 3 requirements, based on the 2024 ASTG project, ALCEDO. These requirements informed the system design, leading to the Kiwi test bed, which connects the avionics to the Kiwi Interface Printed Circuit Board (PCB), controlled by Kiwi mission control. The Kiwi Interface PCB is engineered to be modular, with Kiwi Interface Modules allowing functionality changes without requiring a complete redesign.

The initial implementation of this design is simplified, focusing on sensor data streaming, enabling Kiwi to simulate a flight for the avionics and perform analog measurements to test its critical recovery actuation. This preliminary implementation was evaluated through tests on the ALCEDO avionics, simulating flights to ensure the proper execution of all critical flight events. The system proved effective in simulating desired flight conditions and validating the correct deployment of the parachute system. These results demonstrate that Kiwi offers valuable benefits in enhancing the reliability of the ASTG avionics, suggesting that the full implementation of the design holds significant potential. The thesis successfully achieved its goals by defining detailed requirements, presenting the test bed design, and assessing the effectiveness of the initial implementation.

Kurzfassung

Kiwi ist ein Avionik-Teststand, der entwickelt wurde, um die Avionik des Aerospace Team Graz (ASTG) effizient zu evaluieren und deren Zuverlässigkeit zu verbessern. Der Schwerpunkt liegt auf einem flexiblen Design, das sich leicht an die sich häufig ändernden Projekte des Teams anpassen lässt. Während ähnliche Hardware-in-the-Loop Testsysteme existieren, sind diese typischerweise für größere Raketen oder Satelliten ausgelegt und berücksichtigen diesen speziellen Anwendungsfall nicht. Um diese Lücke zu schließen, wurde ein strukturierter Ansatz verfolgt, bei dem die Anforderungen von breiten Level 1 Zielen bis hin zu detaillierten Level 3 Anforderungen, basierend auf dem zu testendem System, der Avionik des 2024-Projekt des ASTG, ALCEDO, bewertet wurden. Diese Anforderungen bildeten die Grundlage für das Systemdesign, das im Kiwi-Teststand gipfelte, welcher das zu testende System mit dem Kiwi Interface Printed Circuit Board (PCB) verbindet und von der Kiwi-Kontrollsoftware gesteuert wird. Das Kiwi Interface PCB ist modular konzipiert, wobei Kiwi Interface Module Funktionalitätsänderungen ermöglichen, ohne dass eine vollständige Neuentwicklung erforderlich ist.

Die erste Implementierung dieses Designs ist vereinfacht und konzentriert sich auf die Sensordatenübertragung, sodass Kiwi einen Flug für die Avionik simulieren und analoge Messungen zur Prüfung der kritischen Recovery-Aktuierung dieser durchführen kann. Diese vorläufige Implementierung wurde durch Tests an der ALCEDO-Avionik evaluiert, bei denen Flüge simuliert wurden, um die ordnungsgemäße Ausführung aller kritischen Flugereignisse sicherzustellen. Das System erwies sich als effektiv bei der präzisen Simulation der gewünschten Flugbedingungen und der Überprüfung der korrekten Auslösung des Fallschirmsystems. Diese Ergebnisse zeigen, dass Kiwi wertvolle Vorteile bei der Verbesserung der Zuverlässigkeit der ASTG-Avionik bietet, was darauf hindeutet, dass die vollständige Implementierung des Designs erhebliches Potenzial birgt. Die Arbeit erreichte erfolgreich alle Ziele, indem sie detaillierte Anforderungen definierte, das Design des Teststands präsentierte und die Wirksamkeit der ersten Implementierung evaluierte.

Contents

CHAPTER 1

Introduction

This section explains the critical importance of reliability in rocket development and serves as the motivation to enhance avionics testing for the Aerospace Team Graz. It also outlines the research questions and presents the structure and organization of the thesis.

When purchasing an electronic system, it is generally expected that it will function as intended, which is one key aspect of reliability (cf. [11], p. 3). For devices like personal computers or smartphones, occasional malfunctions and the need for restarts are relatively common. This can be attributed to the manufacturer assigning lower reliability requirements, as these are not considered critical applications (cf. [11], p. 170). In contrast, the situation is vastly different for safety-critical applications, such as medical devices, automotive systems, or aerospace technologies.

In rocket avionics, you cannot simply reboot the system during the critical phases of flight. A failure in a commercial rocket could put human lives, living environments, and other species at risk [12], while also causing financial losses (cf. [11], p. 12). They can even have a widespread negative effect on the spirit of a nation (cf. [11], p. 15). Therefore, reliability becomes a paramount concern, representing a fundamental aspect of the mission.

The same applies to the Aerospace Team Graz (ASTG) [13], a student team that competes in the European Rocketry Challenge (EuRoC) [14] with rockets capable of reaching altitudes of 3 km to 9 km. While failures may not result in significant financial losses, they can still endanger people and likely lead to the loss of the vehicle. This negatively impacts the team's ranking in the competition and potentially diminish the trust of their supporters. Moreover, such failures can affect team morale and dampen their spirit.

To minimize the risk of avionics failures and subsequent rocket loss, this thesis introduces the avionics test bed Kiwi, which is designed to comprehensively assess the critical components of the rocket's avionics system, ensuring optimal performance and reliability.

1.1 Motivation

Since ASTG's founding in 2019, the primary focus of the one-year projects AVES [15], AVES II [16], and HALCYON [17] was the implementation of new systems and features, while comprehensive, reliable, and reproducible system testing received less attention.

One of the main challenges in testing is to create a simulated environment that the avionics interprets as a fully integrated rocket, while also monitoring rocket signals to verify its correct behavior. In previous projects, this verification was performed on a limited scale by manually stimulating barometer sensors using a vacuum chamber and monitoring system outputs for correct behavior. Although this approach achieved some success, as evidenced by recent project outcomes (cf. [16, 17]), it had several limitations.

For instance, the testing process was difficult to reproduce, as it relied on human oversight and manual control of the vacuum chamber, which does not simulate all onboard sensors. This limitation made it challenging to test different flight profiles and introduce fault scenarios effectively.

Furthermore, due to the lack of reproducibility, it was difficult to test all backup electronics, which may need to be rapidly switched if issues with the flight electronics arise shortly before launch. It is crucial that all electronics undergo thorough testing.

To address the challenges of creating a system that simulates all sensors in a reproducible way and facilitates the testing of critical avionics, this thesis outlines the key requirements for such a system and and presents the design and initial implementation of a test bed named Kiwi. Kiwi enables full system testing in a reproducible manner and serves as a platform for software development and validation.

1.2 Research Questions

The primary objective of this thesis is to establish a foundation for enhancing the reliability of the ASTG avionics using Kiwi. The requirements that such a system must meet — essentially, what needs to be tested — will be defined as part of this thesis. Based on these requirements, a flexible system will be designed that can be used for the current project and adapted for future endeavors. Following this design, an initial version of the system will be implemented. This initial implementation will be evaluated using the 2024 ALCEDO project [18] to assess whether such a system can be beneficial for the ASTG and to explore how future improvements can be made and what impact they will have on the overall reliability of the avionics system.

The main research questions addressed in this thesis are:

- What requirements should a fully-featured avionics test bed fulfill?
- What should the design of this test system for the ALCEDO project look like?
- How effective is this initial implementation for the ALCEDO project?

1.3 Thesis Structure and Organisation

To address these research questions, this thesis first provides a detailed explanation of the ASTG avionics system, with a focus on the current project ALCEDO, and an overview of embedded system testing in Chapter 2. In Chapter 3, an overview of similar test systems is presented, highlighting key differences and establishing the foundation for the proposed solution.

In Chapter 4, the requirements for the test system are derived based on the background information and related work. Chapter 5 covers the system design, including the electronic system layout and software architecture.

The implementation of the initial electronics and software are presented in Chapter 6. This is then evaluated for its effectiveness in testing the ALCEDO project in Chapter 7.

Finally, Chapter 8 analyzes the results of the testing, providing conclusions on the system's performance and recommendations for future improvements.