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Ultra-Light Weight ILS/VOR Receiver for Flight Inspection

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Introduction

The goal of this project is to develop an ILS receiver system based on software-defined radio (SDR) technology, and to achieve the smallest size, weight, and power consumption as is required for the payloads of small unmanned aerial systems (UASs). The concept of operation, as shown in the Fig.1, involves a UAS flying different patterns within specific runway zones. The UAS uses the onboard ILS receiver to record the ILS I/Q data, process them, and provide flight inspection data and plots to the FAA users.

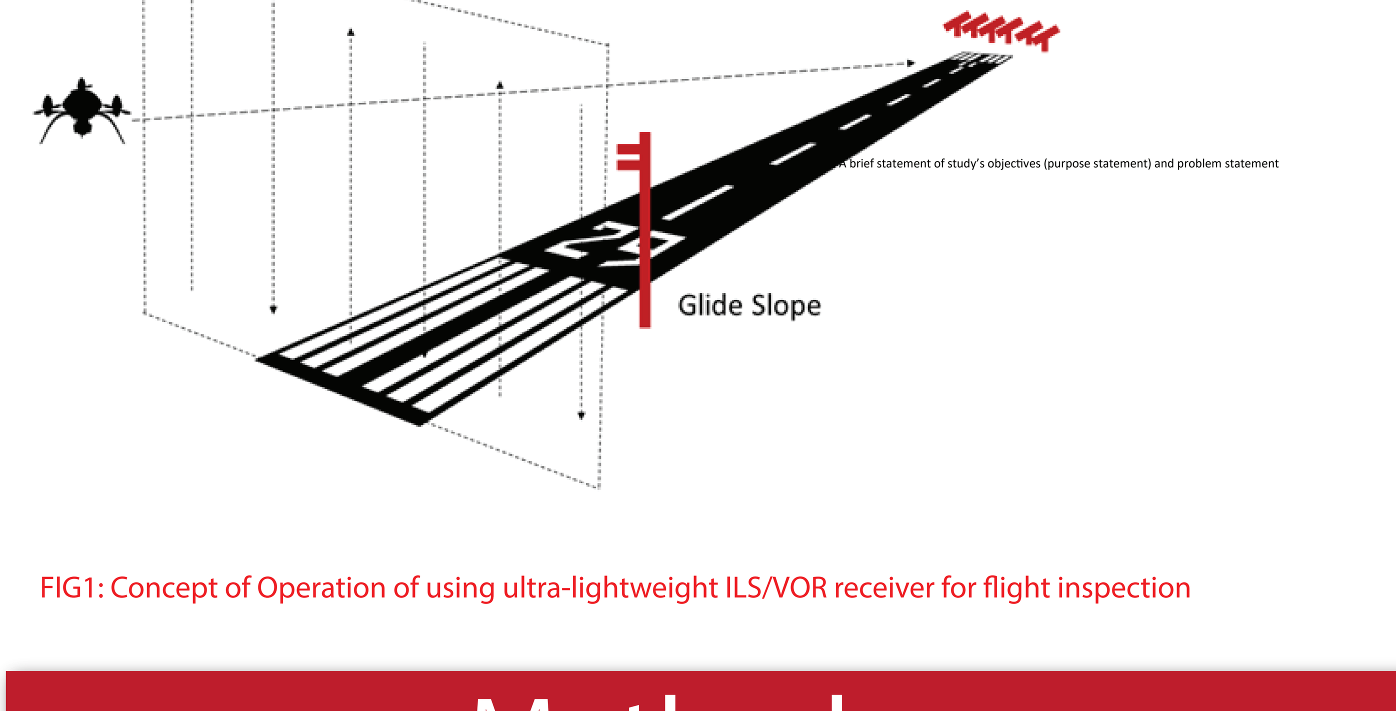

FIG1: Concept of Operation of using ultra-lightweight ILS/VOR receiver for flight inspection

Background

The biggest challenge of the project is the lightweight ILS receiver, which is required to have smaller size, weight and power consumption than any existing ILS flight inspection receivers on the market. More importantly, the receiver is built based on Software-Defined Radio (SDR), which is an emerging technology that allows the same RF hardware to be reconfigured for different frequency channels, and different functionalities. It is very important that by using SDR, the performance and quality of the receiver still meets the ICAO and FAA standards, such as ICAO 8071 requirements.

Methods

We started our receiver engineering design in November 2019. FIG2 shows the hardware system architecture. It contains the wideband antenna, front-end RF channel, and parallel dual radio channels, which are important for simultaneous VOR/LOC and GS receiver channel operations. The radio channels, ADC data sampling, and MCU/Data interface are provided with a single SDR circuit. A backend embedded PC then captures the I/Q data stream from the SDR, performs signal processing, and stores the results.

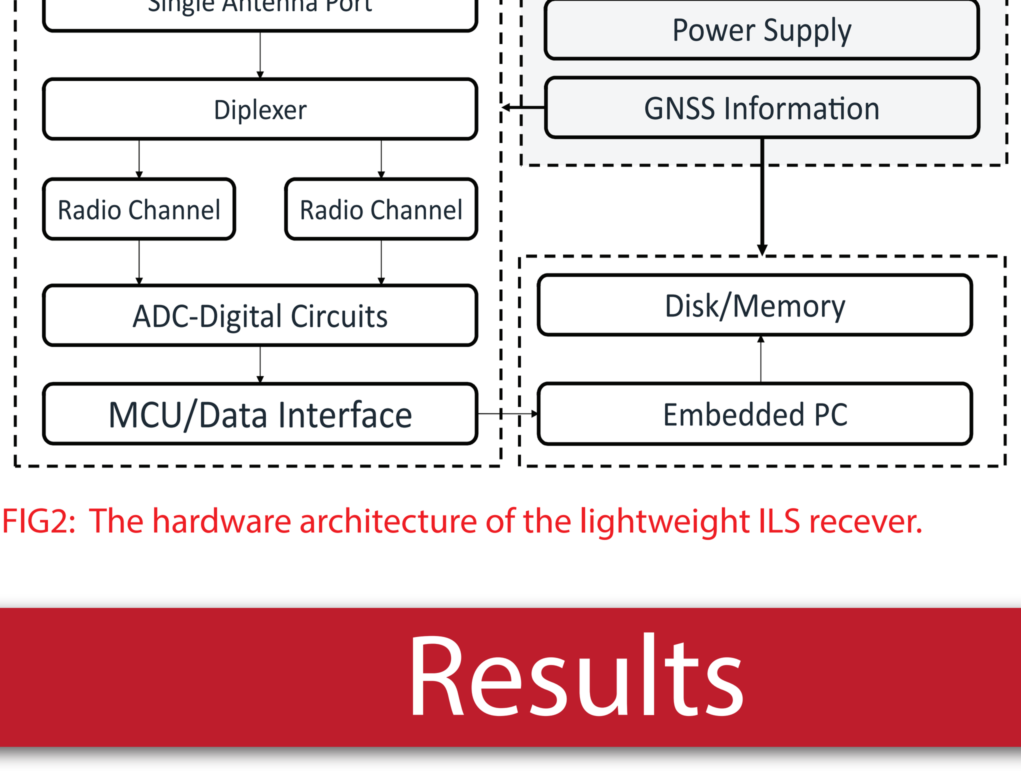

FIG2: The hardware architecture of the lightweight ILS recever.

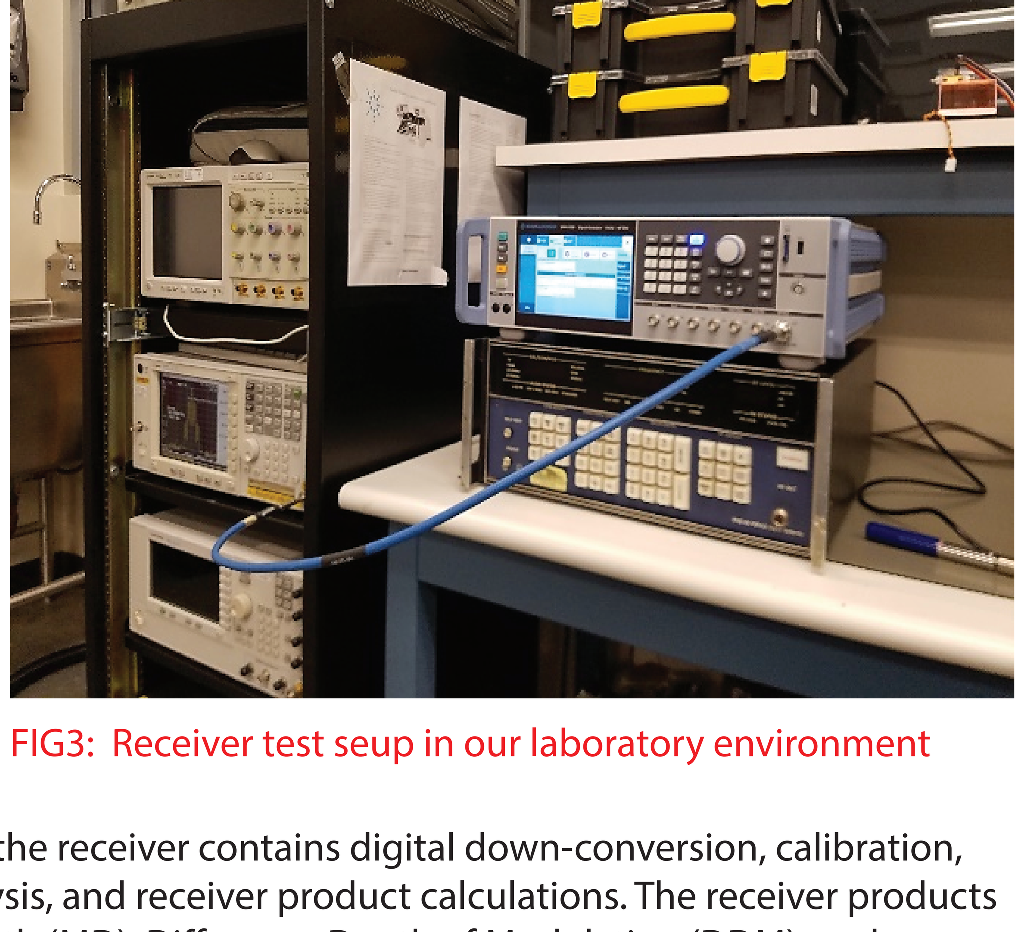

FIG3: Receiver test seup in our laboratory environment

The software system of the receiver contains digital down-conversion, calibration, filtering, spectrum analysis, and receiver product calculations. The receiver products include modulation depth (MD), Difference Depth of Modulation (DDM), and other information. The software and algorithms are mainly implemented in MATLAB, however, we are testing a Python version, aimed at achiving real-time processing onboard. A main portion of the project is testing the receiver performance in the lab. In FIG3, we show the laboratory test system setup.

Results

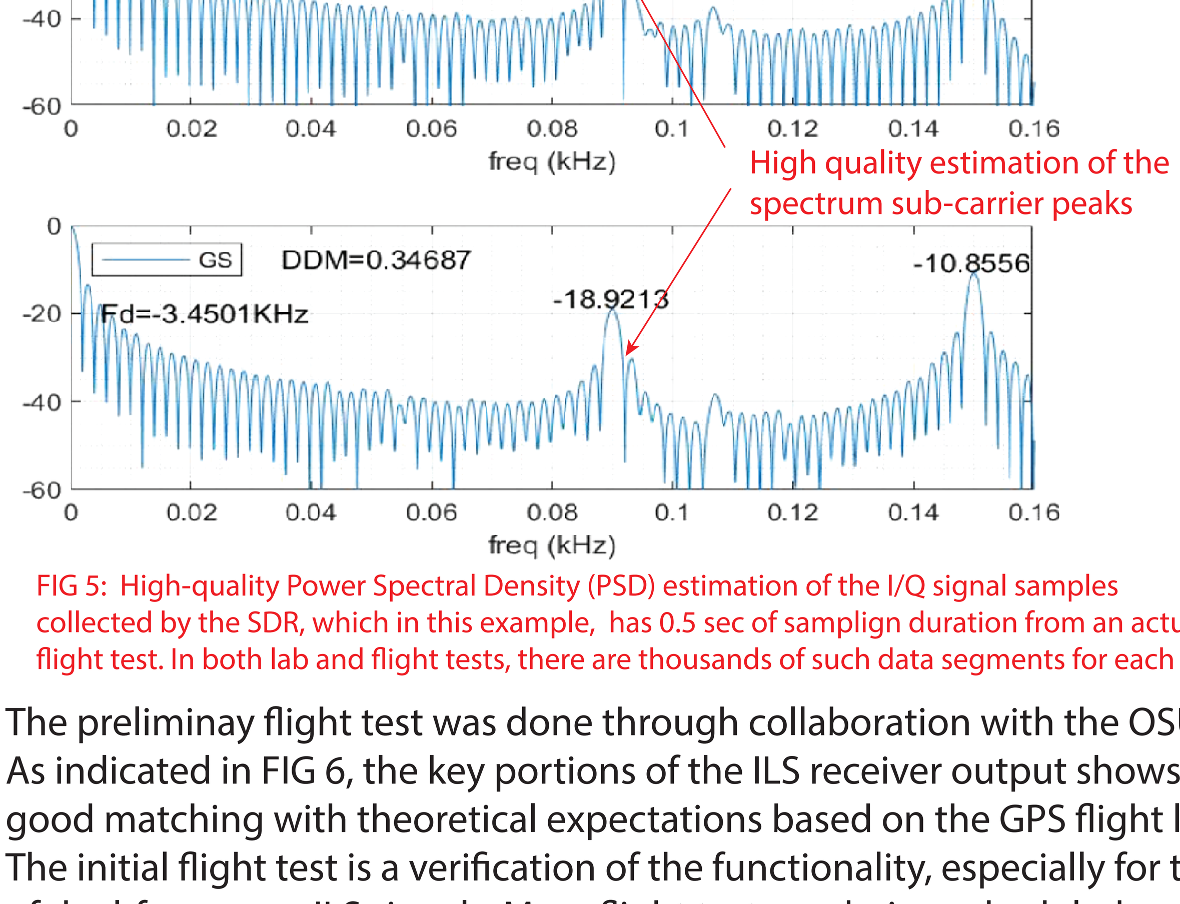

FIG 5: High-quality Power Spectral Density (PSD) estimation of the I/Q signal samples collected by the SDR, which in this example, has 0.5 sec of samplign duration from an actual flight test. In both lab and flight tests, there are thousands of such data segments for each test.

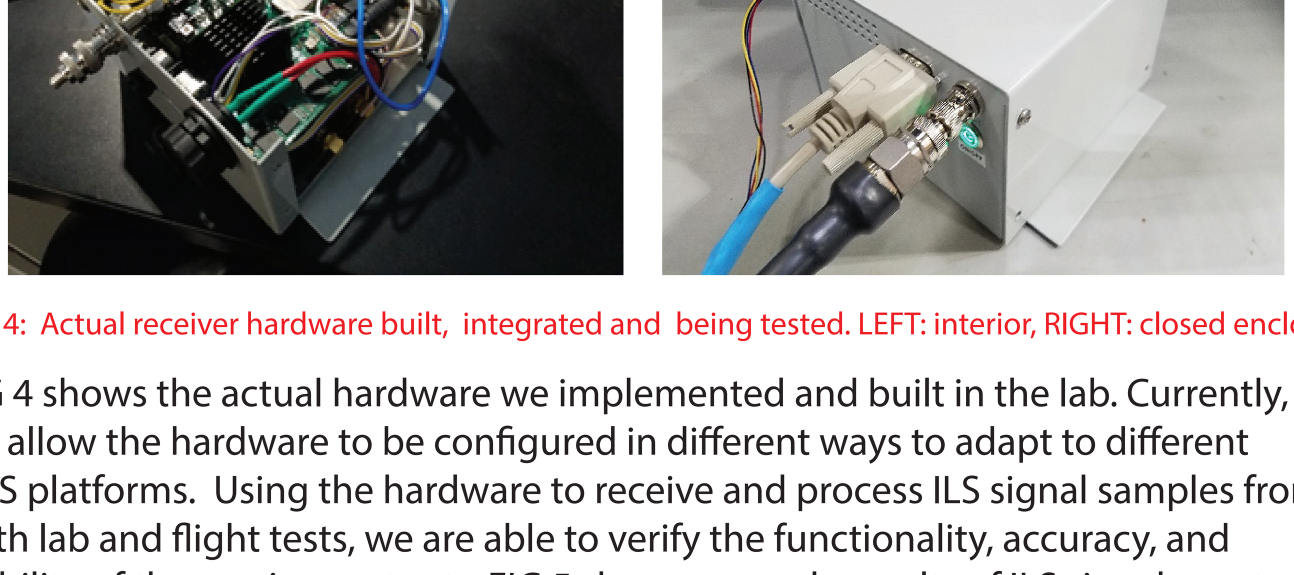

FIG 4: Actual receiver hardware built, integrated and being tested. LEFT: interior, RIGHT: closed enclousure

FIG 4 shows the actual hardware we implemented and built in the lab. Currently, we allow the hardware to be configured in different ways to adapt to different UAS platforms. Using the hardware to receive and process ILS signal samples from both lab and flight tests, we are able to verify the functionality, accuracy, and stability of the receiver outputs. FIG 5 shows example results of ILS signal spectrum.

The preliminay flight test was done through collaboration with the OSU team. As indicated in FIG 6, the key portions of the ILS receiver output shows very good matching with theoretical expectations based on the GPS flight log data. The initial flight test is a verification of the functionality, especially for the handling of dual-frequency ILS signals. More flight tests are being scheduled again with the OSU team, including the support of user interface developments.

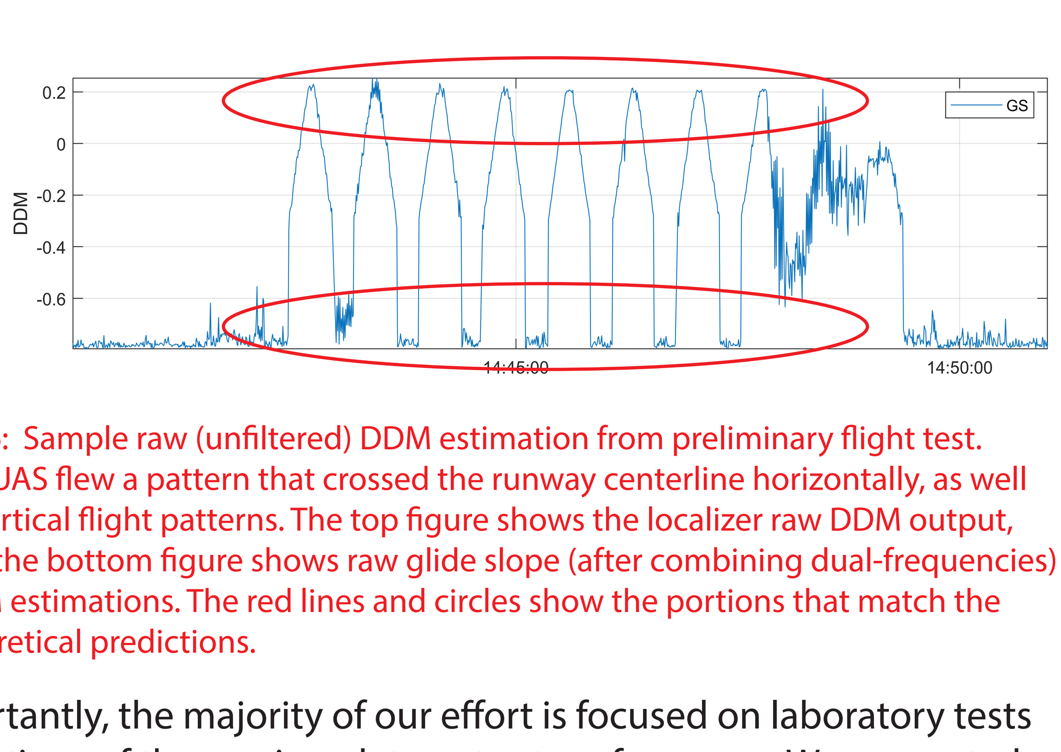

FIG 6: Sample raw (unfiltered) DDM estimation from preliminary flight test. The UAS flew a pattern that crossed the runway centerline horizontally, as well as vertical flight patterns. The top figure shows the localizer raw DDM output, and the bottom figure shows raw glide slope (after combining dual-frequencies) DDM estimations. The red lines and circles show the portions that match the theoretical predictions.

TABLE 1: Summary of the achieved receiver specifications compared to state of the art

Specification Parameters	State of the Art	Our Objective
Size/Dimension	About 12 inches by 5 inches	5.5 by 5.5 by 3.5 inches
Weight (ILS receiver)	3 to 10 lbs	1.5 to 2 lbs
Power consumption	NA	5 watts max
Receiver technology	Customized	Open source GNU/SDR, 14-bit ADC
Receiver channels	Simultaneous LOC/GS/VOR	Simultaneous LOC/GS, plus VOR
Flight inspection product update rate	10 Hz	10 Hz
Internal signal sampling rate	NA	Up to 3 MSPS, much lower in normal operation
Data Products	Simultaneous analysis of dual-frequency LOC and capture-effect GS	Simultaneous analysis of dual-frequency LOC and capture-effect GS, combined DDM
Standard compliance	ICAO DOC 8071	ICAO DOC 8071 FAA-96E01B1
Raw data output DDM estimation errors	0.005 to 0.01	0.001 to 0.005 (lab tests)
Filtered output DDM estimation errors	0.001 to 0.005	< 0.001 (lab tests)
Cost	>$10,000	About $1000

Most importantly, the majority of our effort is focused on laboratory tests and verifications of the receiver data output performance. We generated statistical records of long term (such as 7 hours continuous run) results compared to truth values set from instrumentation. Our current test data shows that within the lab instrumentation testbed and environment, we are able to achieve the accuracy (deviation) for modulation depth at a level of 0.004%, and total error (Mean Squared Error) and STD (standard deviation) for DDM estimation better than 0.002 for both localizer and glide slope. These results are very encouraging and have met, or exceeded the requireents of the ICAO and related standards. More lab tests are still ongoing at this stage. Testing with different environments including stronger temperature variation and RF interference (RFI) are being performed as well.

Conclusion

(1) The current progress of the project successfuly demonstrated the basic functionality of ultra-lightweight ILS/VOR flight inspection receiver, which is suitable as a UAS payload.
(2) The summary of achieved preliminary performance and a comparison with state of the art is provided in TABLE 1.
(3) Much more further work is needed: finishing the lab tests and detailed report, continuing flight test operations and demonstrations, completing implementation of VOR function, and maturing the Python-based software implementation to support onboard, real-time processing

REFERENCE

[1] ICAO DOC 8071 VOL.1. Testing of Ground-Based Radio Navigation Systems 4th Edition, 2000.
[2] ICAO ANNEX 10 VOL.1 Radio Navigation Aides
[3] Hervé Demule and Klaus Theißen, Using UAV multicopters as an extension of ILS ground measurements: This innovative idea has already become reality in Switzerland!, in Proceedings of the 2018 International Flight Inspection Symposium, Monterey, California, April 16-20, 2018

IMPACT

S&T Impacts: The project has demonstrated the initial success of using software-defined radio as the core of an ultra-lightweight ILS/VOR flight inspection receiver.
Operational Impacts: A new way of flight inspection operation based on the SDR-based receiver and small UAS will have significant impact on the operations, leading to reduced labor and cost, faster and more efficient facility inspection report, and new way of training the flight inspection operators.

Okahoma State University Collaborators: James West, Dane Johnson, Sabit Ekin, Gary Ambrose

FAA Collaborators: Brad Snelling, Cheng Zhong, Greg Cox, Todd Bigham, Jay Sandwell, Ricardo Carrizosa, Gary Bell, Flight Inspection Services, Aircraft Configuration Team (AJW-335)

Student and Team Bio: https://youtu.be/a9-IshN5AZU