Real-Time OcuSync Demodulator: A Software-Defined Radio Based Implementation

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***Abstract*—The increasing use of commercial drones and the evolution of communication protocols, such as DJI's OcuSync, have raised concerns regarding unauthorized drone activities. While previous studies have examined downlink signals such as DroneID, the uplink Command and Control signals have received relatively little attention. This paper presents a real-time OcuSync demodulator built on a software-defined radio (SDR) platform with a parallel processing architecture. The system supports live signal reception, visualization, and uplink demodulation through an interactive graphical user interface. The architecture ensures responsive operation by distributing demodulation workloads across multiple processes. Future work includes decoding recovered bitstreams to analyze uplink payloads and support advanced counter-drone applications.**

***Index Terms*—OcuSync, Drone Communication, OFDM, Uplink, Demodulation**

I. Introduction

In recent years, drones have become widely used across various industries, including agriculture, media production, and logistics [1]. However, this widespread adoption has also raised security concerns, such as unauthorized drone intrusions into restricted areas and violations of personal privacy [2]. Additionally, drones have proven their strategic value in military operations, notably in conflicts like the Russia-Ukraine war [3].

DJI (Da-Jiang Innovations), which holds an estimated 70% share of the global consumer drone market [4], has continually advanced its own communication protocols—from Enhanced Wi-Fi and Lightbridge to the more sophisticated OcuSync protocol. The OcuSync protocol has evolved through versions 1.0, 2.0, and 3.0, offering improved communication range, higher data rates, and greater reliability. However, as drone communication systems become more advanced, the risk of misuse by unauthorized users also increases, posing serious safety and security threats.

To effectively address these emerging threats, it is essential to understand both the downlink and uplink signals of the OcuSync protocol. While previous studies have primarily focused on analyzing downlink signals [5], [6], such as DroneID (drone metadata), relatively little attention has been given to uplink Command and Control signals. Furthermore, most existing research relies on offline analysis of recorded data and lacks user-friendly interfaces, limiting its usefulness for real-time threat detection and situational awareness.

In this paper, we present a real-time OcuSync uplink demodulator based on a software-defined radio (SDR) platform. Unlike previous studies, our system supports real-time processing and features an interactive graphical user interface (GUI). It provides a live IQ sample plot, a power spectral density (PSD) plot, and a waterfall visualization. Additionally, the system extracts uplink segments from raw IQ data and demodulates them to produce bitstreams in real time.

II. System Implementation

A. Estimation of OcuSync Uplink Specifications

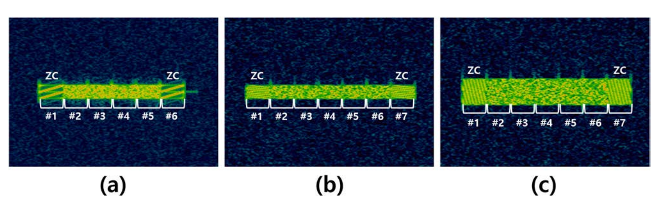

Fig. 1. Spectrogram of OcuSync Uplink: version (a) 1.0, (b) 2.0, (c) 3.0

As shown in Fig. 1, we conducted a spectrogram-based analysis of the uplink signals in DJI's OcuSync protocol to estimate key communication parameters. The results indicate that OcuSync versions 1.0, 2.0, and 3.0 commonly use QPSK modulation and follow an OFDM-based structure, although different QAM modulation schemes may be used adaptively depending on the channel conditions in each version. Each version shows a scalable design, where the FFT size, number of occupied subcarriers, and number of OFDM symbols increase progressively, resembling the layered structure of LTE systems.

	OcuSync 1.0 UpLink	OcuSync 2.0 UpLink	OcuSync 3.0 UpLink
Modulation	QPSK/QAM(16~64)		
FFT Size	128	128	256
Occupied Subcarrier	73	73	145
Total Symbols	6	7	7
Demodulated bits length	576	720	1440
Sampling Rate	1.92 MHz		3.84 MHz

Fig. 2. OcuSync UpLink Estimated Specifications

OcuSync 1.0 and 2.0 use a 128-point FFT with about 73 occupied subcarriers, while version 3.0 employs a 256-point FFT and 145 subcarriers, effectively doubling the bandwidth. The number of OFDM symbols per frame increases from 6 to 7, with demodulated bit lengths growing from 576 to 1,440 bits. Similarly, the sampling rate scales from 1.92 MHz in versions 1.0/2.0 to 3.84 MHz in version 3.0. These scalable parameters reflect a design approach similar to LTE and were used to configure the uplink demodulation algorithm.

B. Uplink Demodulation Algorithm

To demodulate the uplink Command and Control signals of DJI drones using the OcuSync protocol, a unified signal processing pipeline is designed, based on [7], to handle their proprietary and non-cooperative nature. As illustrated in Fig. 3, the pipeline begins with signal segmentation, where the raw IQ data is divided into candidate regions through short-time Fourier transform (STFT) analysis. These segments are filtered based on duration and bandwidth to select plausible uplink signals.

Next, coarse frequency offset (CFO) correction is performed to align the frequency, followed by low-pass filtering and resampling to match the target sampling rate. The refined signal is then used to estimate the coarse timing offset (TO), after which the Zadoff-Chu (ZC) sequence is used for root index acquisition and fine timing estimation.

Subsequently, fine frequency offset (FFO) correction is applied, and the signal is equalized to compensate for channel effects. Finally, demodulation is carried out to extract the bitstream from the uplink signal.

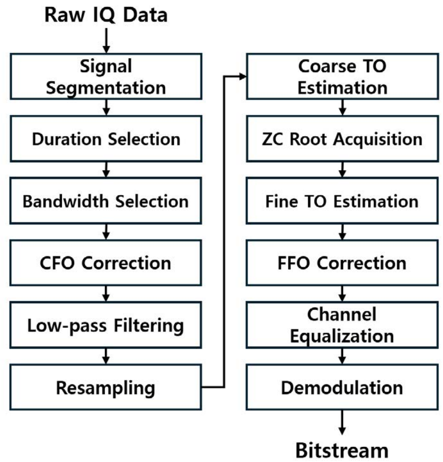

Fig. 3. Drone Signal Demodulation Flowchart

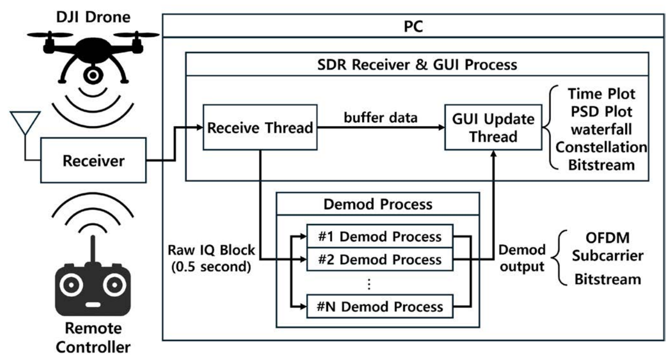

Fig. 4. System architecture of the real-time OcuSync Demodulator

C. Real-Time Processing Pipeline and GUI Architecture

To achieve real-time acquisition, visualization, and demodulation of DJI OcuSync uplink signals, the system was implemented using a multiprocess architecture, as illustrated in Fig. 4. The overall pipeline consists of three main components: the Receiver, the SDR Receiver & GUI Process, and the parallel Demodulation Process.

The Receive Thread in the SDR process continuously acquires raw IQ samples from the receiver. This thread forwards the data to two separate components:

- For real-time visualization, buffered IQ segments are streamed directly to the GUI Update Thread. These short segments are used to update the time-domain waveform, PSD, and waterfall plot in real-time.
- For demodulation, the Receive Thread accumulates fixed-duration blocks (e.g., 0.5 second) of IQ data. Once enough data is collected, each block is dispatched to one of the available Demod Processes via a multiprocessing queue. These blocks are processed independently by the demod workers, each performing the OcuSync uplink demodulation pipeline, including frequency offset correction, resampling, timing synchronization, equalization, and symbol demodulation. The demodulated OFDM

symbols and bitstream outputs are then sent back to the GUI thread for display.

This architecture allows the system to manage continuous real-time GUI updates alongside parallel high-latency demodulation tasks, ensuring both responsiveness and computational scalability.

Component	Details
Operating System	Ubuntu 20.04.6 LTS
Language	Python 3.8
GUI Framework	PyQt5
Visualization	PyQtGraph
Parallelism	Multiprocessing module
SDR Receiver	USRP B200-mini
SDR Interface	UHD API

Fig. 5. Development Environment and System Components

As shown in Fig. 5, the system was developed using Python 3.8, with the PyQt5 framework for GUI components and PyQtGraph for visualization. PyQt5 provides Python bindings to the C++-based Qt framework, enabling fast execution and responsive interface rendering despite being implemented in a high-level language. GUI development was partially guided by [8]. Multiprocessing modules were employed to implement parallel demodulation processes, and the UHD API was used to interface with the USRP SDR hardware.

III. System Demonstration and GUI Overview

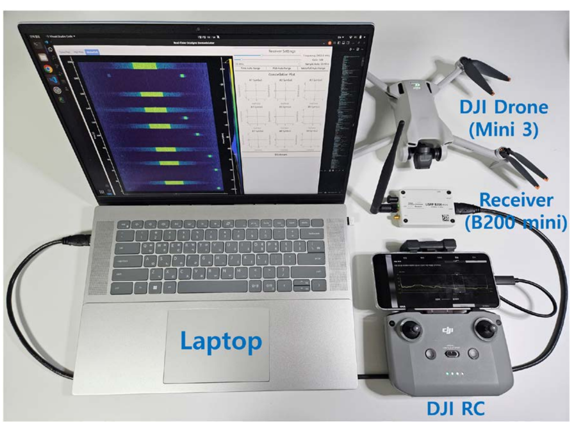

Fig. 6. Experimental setup for real-time reception and demodulation of DJI OcuSync signals.

Overall experimental setup is shown in Fig. 6. It includes a DJI Mini 3 drone and its remote controller sending OcuSync signals, a USRP B200-mini SDR receiver, and a laptop running the real-time demodulation software.

The main screen of the developed GUI is shown in Fig. 7. The GUI provides a clear view of the received signal and the demodulation results. This helps the user monitor the signal and check if the demodulation is working correctly in real time.

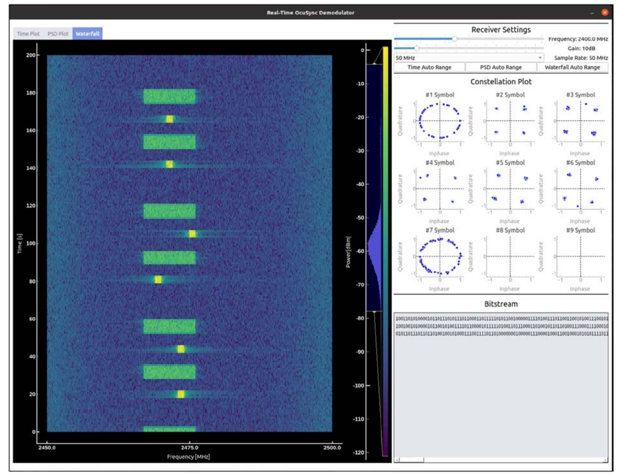

Fig. 7. GUI Overview of Real-time OcuSync Demodulator

The GUI is divided into two main parts: the left panel shows signal visualizations, and the right panel shows controls and results. As shown in Fig. 8, the left panel has three tabs:

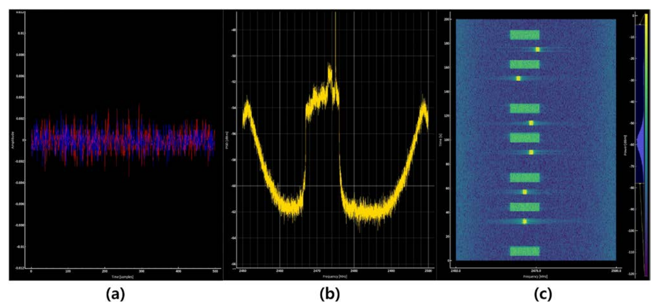

Fig. 8. (a) Time Plot, (b) PSD Plot, (c) Waterfall

The visualization panel supports three modes, selectable via tabs:

- Time Plot (Fig. 8a): Shows the I/Q waveform of the signal over time.
- PSD Plot (Fig. 8b): Shows the signal's power across frequencies.
- Waterfall (Fig. 8c): Shows how the signal changes over time and frequency.

On the right panel, the Receiver Settings (Fig. 9b) let the user change the frequency, gain, and sample rate of the receiver. Below that, the Constellation Plot (Fig. 9a) shows the demodulated OFDM symbols, helping the user verify that the demodulation is working properly. At the bottom, the Bitstream Output (Fig. 9c) shows the bitstream extracted from the uplink signal.

The GUI gives instant feedback and makes it easy to interact with the system. It works together with background demodulation processes, keeping the interface fast and responsive even when doing heavy processing.

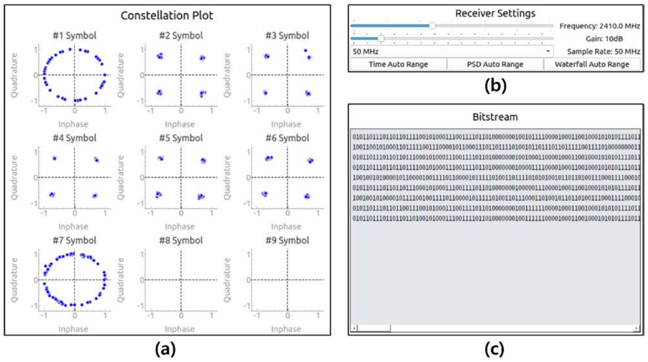

Fig. 9. (a) Constellation Plot, (b) Receiver Settings Menu, (c) Bitstream Output

IV. CONCLUSION

This paper presented a real-time demodulation system for DJI OcuSync uplink signals using a software-defined radio (SDR) platform. The system adopts a parallel processing architecture with a user-friendly GUI, enabling live signal acquisition, visualization, and demodulation. The GUI provides intuitive feedback through time and frequency plots, constellation diagrams, and extracted bitstreams, enhancing situational awareness during live operations. Parallel demodulation across multiple processes ensures responsive performance and efficient handling of signal processing tasks.

Future work will aim to support real-time decoding and interpretation of uplink payload data for advanced analysis of drone control signals and unauthorized activity detection.

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