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Improved Algorithm for Detecting and Jamming Video Channels of Unmanned Aerial Vehicles with FPV System

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Abstract

This article proposes the application of a closed-loop algorithm for electronic warfare means intended to counter analog FPV-UAV video channels. The system-level contribution is the integration of SDR-based radio monitoring, signal-parameter estimation, OSD-assisted classification, selective multi-frequency interference scheduling, and post-action channel monitoring within one information cycle. The individual detection and interference techniques are not claimed as new; the proposed contribution lies in their coordinated control logic and feedback transitions. A conditional-probability model and a response-time model are used to describe error propagation and delay. Because no comparative field-test or simulation dataset is reported, the expected gains in efficiency and response time remain hypotheses for future validation. The approach is presented as a conceptual basis for adaptive SDR systems.

KEY WORDS: *FPV-UAV, electronic warfare, adaptive complex, video channel, frequency determination, SDR.*

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1. Introduction

For the past century, the basis of firepower for most armies has been large, extremely complex and, of course, very expensive platforms – such as tanks, aircraft, artillery systems, missiles or warships. However, the emergence and mass introduction of FPV-UAVs has radically changed this priority. The combination of relatively low cost, high maneuverability, operational efficiency and the ability to use various types of payloads has contributed to their mass distribution at the tactical level [1].

Unlike traditional high-precision weapons, FPV-UAVs can be mass-produced and quickly manufactured using commercial components, quickly adapt to new combat conditions, and promptly upgrade in accordance with changes in countermeasures. This feature significantly shortens the cycle of technological adaptation between offensive and defensive weapons. If previously, updating weapons required years, now changing frequency ranges, information transmission protocols, antenna designs, or control algorithms can be carried out within a few weeks.

Simultaneously with the increase in the scale of FPV-UAV use, the requirements for electronic warfare have significantly increased. Modern electronic warfare systems for combating FPV-UAVs, created mainly to jamming digital control channels, have proven to be insufficiently effective in the conditions of mass use of small-sized unmanned systems that operate in different frequency ranges and use a wide range of analog video information transmitters [2].

The analysis of modern combat operations shows that the use of broadband noise interference in combination with the classic algorithm of operation of electronic warfare operators no longer provides guaranteed jamming of FPV-UAV video transmission channels [3, 4]. The use of a wide range of video transmitters with different video transmission frequencies requires a transition to new algorithms for the operation of electronic warfare means, which involves detecting the fact of operation of the video transmission channel, automatically determining the operating frequency of this channel, setting up radio interference, monitoring the operation of the video transmission channel, creating a new interference on a different frequency [5, 6].

Thus, the current scientific task is to improve the algorithm of operation of electronic warfare means by automatically determining the operating frequencies of channels in FPV-UAV video transmission and adaptively forming interference according to their frequencies.

2. Analysis of Current Research and Problem Statement

Analysis of scientific publications and practical approaches in the field of countering FPV-UAVs allows us to identify two main areas of research: the use of kinetic means of destruction and the development of electronic warfare means. [40, 42, 43, 45]

The first direction covers the development of means of physical destruction of air targets, in particular, short-range air defense systems, automatic guns, machine gun complexes, interceptors of unmanned aerial vehicles, mesh barriers and other kinetic means. Such systems can provide a high probability of destruction of individual air targets. At the same time, their mass use against FPV-UAVs is limited by the cost of ammunition, the number of available channels of destruction, reaction time and the complexity of simultaneously countering a significant number of small-sized targets [7-9]. Therefore, kinetic means should be considered as a component of a comprehensive countermeasure system, but not as a universal solution for protection against the mass use of FPV-UAVs.

The second direction is related to the development of electronic warfare means, the action of which is aimed at disrupting the functioning of control channels, video information transmission, telemetry and navigation support of unmanned aerial vehicles. Most of the known means implement the setting of broadband, narrowband or blocking noise interference in certain frequency ranges [10-14]. However, in short-range EW means, the operating frequency range of jamming is often fixed, and the speed of such a means directly depends on the actions of the operator.

At the same time, in conditions of the use by the enemy of a large number of UAVs with the FPV system, the number of frequency plans of video transmission channels is also increasing, a priori information about which may be incomplete or quickly lose relevance. As a result, jamming in a given or in the entire operating range of video transmitters does not always provide the necessary efficiency. Expanding the jamming band or increasing its power leads to increased energy consumption and increases the risk of negative impact on one's own radio-electronic means [15,16, 42-45]

Thus, there is a contradiction between the need for operational and selective electronic interference on the transmission channels of enemy FPV-UAVs in conditions of their dynamic change and the limited capabilities of existing means of automatically determining signal parameters and forming the corresponding interference in real time.

The scientific problem is to define and assess a closed-loop control algorithm that combines signal detection, frequency estimation, UAV affiliation assessment, additional reconnaissance, quasi-simultaneous jamming of several video channels, and feedback monitoring within one information cycle.

Compared with the SDR-based anti-UAV, RF detection, and RF classification approaches discussed in references [15, 20, 21], and [37], the proposed work does not introduce a new detector, classifier, or interference waveform. Its incremental contribution is the integration and scheduling of established functions in one feedback-controlled workflow. The comparison baseline is the operator-triggered model in Fig. 1: external alert, signal detection, manual frequency assessment, friendly/unfriendly decision, activation of one predefined interference action, and termination without an automated feedback loop. The proposed model adds integrated observations, automated state transitions, multi-channel scheduling, and feedback-based reassessment. Quantitative superiority over this baseline has not yet been demonstrated [40].

3. The problem of using classical electronic warfare means against FPV-UAVs

Many existing electronic warfare systems generate broadband or narrowband noise interference in specific frequency ranges and may have limited ability to adapt jamming parameters or generate multiple jammers at different frequencies simultaneously. ExpressLRS is primarily a digital command and control channel and should not be seen as proof that an analog video transmitter can also independently change frequency in flight. Where in-flight video channel frequency switching is available, it is performed through a separate video transmitter control mechanism. Therefore, the proposed algorithm considers video frequency switching as a possible platform-dependent event, rather than as a universal ExpressLRS feature.

An analysis of existing approaches to the construction of electronic warfare (EW) means shows that most of them are focused primarily on energy jamming of enemy signals. This is indicated by the constant increase in the jamming power of electronic warfare means over the past 2-3 years from 10-20 W to 100-150 W. At the same time, insufficient attention is paid to the automatic determination of signal parameters, the assessment of their informative features, and the adaptation of the EW complex to the current radio-electronic environment.

In this regard, the scientific task of developing an improved approach to the use of electronic warfare means arises, which is based on the integration of radio reconnaissance means, identification of signals of FPV-UAV video transmission channels, and algorithms for dynamically changing radio interference frequencies.

Given that video transmitters operate in a fairly wide frequency range: approximately from 460 to 8800 MHz, depending on the type of equipment, this significantly complicates the use of traditional means of electronic jamming, since for effective impact it is necessary to simultaneously perform electronic jamming of several independent communication channels, the characteristics of which may change during the performance of a flight mission [17-19].

Table 1 presents a representative, non-exhaustive sample of FPV video transmitters and their main characteristics, such as frequency range, channel width, number of possible video transmission channels, and radiation power, the values of which are used in the proposed algorithm [22-34]. The information is for informational purposes only and indicates that each video transmitter has its own frequency range.

Table 1

Main characteristics of the most common (used) FPV video transmitters - UAVs

Transmitter name	Operating frequency range, MHz	Number of channels	Single channel width, MHz	Output power, mW
Hobby 900 MHz 1500mW PAL	900-1040	5	20, up to 27	1500
Caddx 1.3 GHz VTX V2 1600mW	1060-1380	5	20, 40	25/1000
RMRC 900 MHz-1.3Ghz	910-1360	12	30, 40	800
Kimpok KP-T2245DE	2000-2280	8	40	252/800/4500
RushFPV 3.3G 2W	3170-3470	16	18	2000
AKK TX3000AC	4990-5945	80	20	25/250/500/1000/2000/3000
TBS Unify Pro32 DP (MMCX)	4990-6030	40-70	14-26	10/25/100/200/400/ 500/999/3000
TBS Unify Pro32 HV (MMCX)	5333-6025	40-70	20	25/1000
iFlight SucceX mini Force 5.8g 600mW VTX	5645-5945	40	20, up to 27	25/200/400/600
RushFPV 6.1G-7.2G XSPAN 3W VTX	6100-7200	64	17	25/200/1000/3000
PeakFPV THOR T67	6110-7210	64	17	25/200/1000/3000
PeakFPV THOR T78	7200-8000	40	20	25/200/500/1000/3000
PeakFPV THOR T89	8000-8800	40	20	25/200/800/1000/4000

An important problem remains the algorithm for jamming the video transmission channel. Most often, it looks like the one shown in Figure 1.

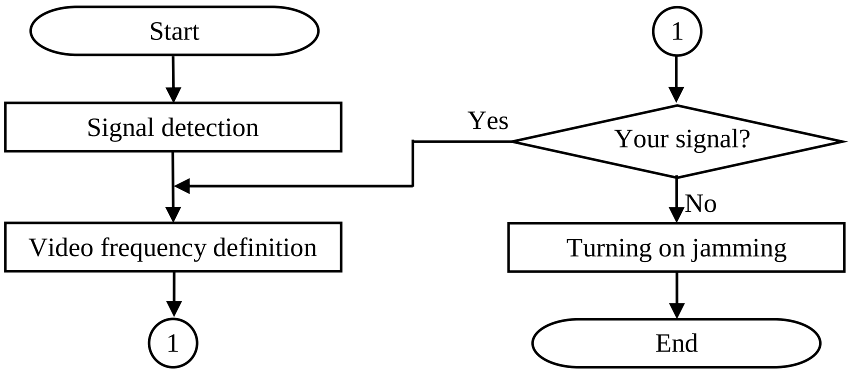

Fig. 1. Existing algorithm for jamming the FPV-UAV video transmission channel

For this study, the baseline is defined as an operator-dependent sequential workflow. Its input is an external alert or detected emission; its intermediate outputs are a selected frequency and a friendly/unfriendly decision; its action is one predefined interference setting; and its stopping condition is operator termination. The baseline does not include automated channel reassessment, retry limits, multi-channel scheduling, or a machine-readable success indicator. This definition is used only as the study comparison model and should not be generalized to all existing systems.

Moreover, the classical algorithm has the following disadvantages:

- the operator receives information about the presence of FPV-UAVs from various detection means that are not interconnected into a single detection and jamming system, as well as electronic warfare means of various types;
- the effectiveness of jamming is monitored after jamming. The operator has no information about the location of the UAV and whether jamming was effective;

- the speed of such a system directly depends on the operator.

The improvement of the existing algorithm consists of:

- integration of established SDR-based signal detection and parameter-estimation functions [20, 21] into the proposed feedback-control workflow;
- using a transmitter capable of quasi-simultaneously jamming several frequencies;
- FPV UAV identification by OSD (On-Screen Display) information (unit name, battery voltage, timer, direction to take-off point, etc.);
- pauses to monitor the operation of the video transmission channel in order to assess the effectiveness of radio jamming.

4. Description of the operation of the improved algorithm for jamming the FPV-UAV video transmission channel

To address these shortcomings, an improved algorithm for jamming the FPV UAV video transmission channel was developed, as shown in Fig. 2.

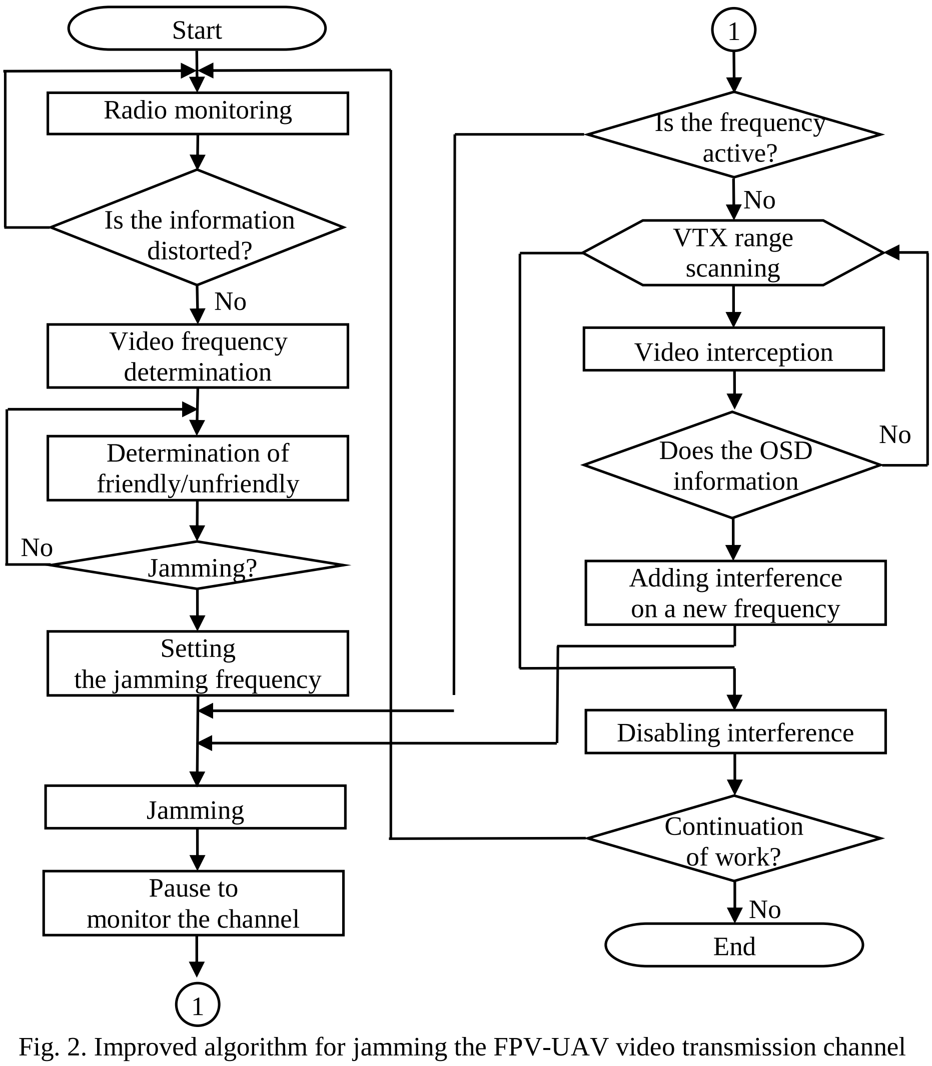

Fig. 2. Improved algorithm for jamming the FPV-UAV video transmission channel

Radio monitoring. The input to this state is a documented observation band and a stream of spectral measurements. The observable variables are center-frequency candidates, occupied bandwidth, received power, persistence, and time stamp. A threshold-selection rule based on a measured noise reference produces two outputs: no candidate signal, or a candidate signal with estimated parameters. Transition to the next state occurs only when the candidate satisfies the stated persistence and quality rules. Performance should be reported through detection probability, false-alarm probability, missed-detection probability, and processing time under a documented test protocol.

Video frequency determination. During this stage, the frequency parameters of the transmitted video signal (center frequency, spectrum width, and power level) are intercepted and determined.

Determination of friendly/unfriendly status. Based on On-Screen Display information: name of enemy unit, flight direction, battery status, distance from launch point (Fig. 3), the operator analyzes the UAV’s affiliation on the “friend/foe” principle and makes a decision on creating interference on the detected video frequency. However, OSD information can receive an affiliation assessment only when the video is available, readable, and compared with an approved reference record. If OSD information is missing, distorted, or inconsistent, the system should not process that data. In this paper, OSD-based classification is considered a hypothesis that needs to be tested. Future evaluation should report on the rates of falsely friendly, falsely hostile, and unknown classes, and identify safeguards that prevent actions against protected signals.

Fig. 3. Example of the name of an enemy unit and other OSD information

Feedback monitoring. After an authorized action interval, the workflow enters a monitoring state and records whether the candidate emission is still observable at the monitored frequency. The observable outcomes are active, absent, shifted candidate, or uncertain. Continued emission does not prove that the receiving link remains functional, and signal absence does not by itself prove successful disruption; both are proxy indicators. An active outcome returns to reassessment, an absent outcome ends the current channel task, a shifted candidate starts reacquisition and OSD comparison, and an uncertain outcome triggers a bounded retry or operator review. Simultaneous candidates are maintained as separate channel records with independent state, retry count, and stop condition.

The difference between the proposed algorithm and the classical one is:

- identification of the unmanned aerial vehicle by information parameters of telemetric information transmitted to the On-Screen Display;
- an expected reduction in reconnaissance and decision time through automation; this benefit must be tested against the defined operator-dependent baseline before a numerical claim is made;
- the possibility of quasi-simultaneously forming several aiming interferences at different frequencies, as opposed to one broadband one;
- proposals to raise the electronic warfare device above the ground to directly affect the operator’s console.

With this algorithm of operation of the electronic warfare means, the effectiveness is determined not only its technical characteristics, but the automation of all processes and the consistency of the algorithm's functioning and depends little on the operator, who, when stopping jamming and re-scanning the specified frequency range, has no information about the jamming or non- jamming of the detected video transmission channel.

5. Mathematical Model of the Operation of the Improved Algorithm

The information cycle of an electronic warfare device using an improved algorithm can be represented as a sequence of functional operators [35]:

$$F = \{M, D, E, C, J, Q\}, \tag{1}$$

where: M – radio monitoring; D – signal detection; E – estimation of its parameters; C – classification; *J* – radio interference setting; Q – efficiency assessment.

Unlike traditional approaches, where the main focus is only on the interference stage, the proposed model considers the entire process as a single information cycle, in which an error at any stage leads to a decrease in the overall efficiency of the system.

Therefore, it is proposed to evaluate the integral efficiency of the complex as the product of the probabilities of successful execution of each stage of the information cycle:

$$P_{\Sigma} = \{P_M, P_D, P_E, P_C, P_J, \mathrm{P}_Q\}, \tag{2}$$

where P_M is the probability of timely monitoring; P_D is the probability of correct detection given successful monitoring; P_E is the probability of correct parameter estimation given detection; P_C is the probability of correct classification given estimation; P_J is the probability of the intended channel action given classification; and P_Q is the probability of a correct effectiveness assessment given that action [36]. This conditional chain represents error propagation without assuming independence between stages.

This model reflects the fact that even a highly efficient jammer will not provide the required result if there is an error at the previous stages, in particular when determining the signal parameters or classifying it.

A feature of countering FPV-UAVs is the limited time available for observation and response. Equation (3) defines a conservative serial upper bound in which all processing stages are executed one after another.

$$T_{R,\mathrm{serial}} = T_M + T_D + T_E + T_C + T_J + T_{RAR}, \tag{3}$$

where $T_{R,\mathrm{serial}}$ is the serial response-time upper bound; T_M is monitoring time; T_D is detection time; T_E is parameter-estimation time; T_C is classification time; T_J is the authorized action time; and T_{RAR} is additional-reconnaissance time. If stages overlap or several channels are handled quasi-simultaneously, the actual response time must be calculated from the critical path and must include scheduling, switching, feedback-pause, and reacquisition delays.

For successful channel jamming, condition (4) must be met

$$T_R < T_i, \tag{4}$$

where T_i is the estimated time window, measured in seconds, during which the detected channel parameters and tactical relevance are expected to remain valid before a frequency change, loss of observation, or arrival at the protected-area boundary. T_i must be estimated from the observed scenario and updated after reassessment. The inequality $T_R < T_i$ is a necessary timing condition only; it is not sufficient evidence of successful disruption.

For an energy detector under additive white Gaussian noise, with binary hypotheses H0: noise only and H1: signal plus noise, the following Gaussian approximation may be used [37]. SNR is expressed as a linear power ratio, N is the time-bandwidth product under the convention used in the derivation, and the decision threshold is selected to achieve P_{fa}. The exact form must be verified for the implemented detector and observation model.

$$P_D = Q\left[\left(Q^{-1}\left(P_{fa}\right) - \sqrt{N \cdot SNR}\right) / \sqrt{(2 \cdot SNR + 1)}\right], \tag{5}$$

where P_D – is the probability of signal detection; P_{fa} – is the probability of false alarm; Q() – is the Gaussian Q-function; N – is the product of the observation time and the receiver bandwidth; SNR – is the signal-to-noise ratio at the receiver input.

The power of radio interference at the receiving point – at the ground control point of a UAV with an FPV system is calculated by the expression:

$$P_j = P_{js} G_j G_r (\lambda / 4\pi R_j)^2 / L_{sys}, \tag{6}$$

where P_j is received interference power; P_{js} is transmitter power; G_j and G_r are antenna gains; R_j is separation distance; λ is wavelength; and $L_{sys} \geq 1$ represents combined system losses, including feeder loss, polarization mismatch, pointing error, obstruction, and other implementation losses. Equation (6) is a free-space line-of-sight approximation. Terrain, multipath, shadowing, fading, antenna orientation, and uncertain distance must be treated through scenario ranges or sensitivity analysis rather than a single assumed value.

It is clear that it is practically impossible to know the distance from the electronic warfare station to the control panel, therefore, in this case, it is advisable to choose this distance as the maximum possible in the tactical situation.

To calculate the probability of jamming of an analog video channel, it is convenient to use the sigmoid function, which is empirical [38]:

$$P_{jam} = \frac{1}{1 + \exp\left[-\alpha\left(\frac{P_J}{P_S} - J_0\right)\right]}, \tag{7}$$

where P_{jam} is the probability associated with the analog-video response model; P_J / P_S is the dimensionless interference-to-signal power ratio at the receiver; J_0 is the ratio at which the model reaches 0.5; and α controls curve steepness. Both α and J_0 are calibration parameters and must be estimated from an identified dataset using a stated fitting procedure, with uncertainty intervals and validation on separate data. Until such calibration is reported, Equation (7) is an illustrative response function and should not be used as evidence of measured performance.

For consistency, Equation (8) is interpreted as a conditional two-factor metric for the detection and channel-action stage, while the full workflow effectiveness remains the conditional chain in Equation (2) [39]:

$$E_{cond} = P_D P_{jam} \,;\; E_{overall} = P\Sigma \tag{8}$$

Thus, the proposed algorithm is designed to reduce decision delay and improve selective channel handling through automation and feedback. These outcomes have not yet been demonstrated by comparative experiments or simulations. Claims of higher efficiency or lower response time should be made only after evaluation against the defined baseline across stated signal, propagation, workload, and multi-channel scenarios.

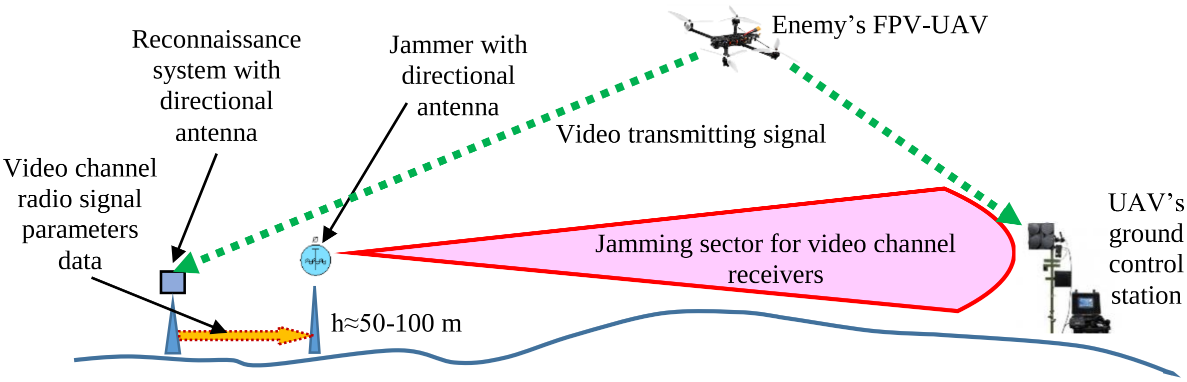

Fig. 4. Explanation of the operation of the electronic warfare tool with the proposed improved jamming algorithm

A schematic representation and operating principle of an electronic warfare device with an improved algorithm for detecting and jamming video channels of unmanned aerial vehicles with an FPV system are shown in Fig. 4.

6. Conclusions

The article analyzes the current state of development of electronic warfare means in the context of the mass use of FPV-UAVs and identifies the main factors that reduce the effectiveness of traditional approaches to suppressing control and video transmission channels.

A conceptual closed-loop workflow is proposed that integrates radio monitoring, video-frequency estimation, affiliation assessment, additional reconnaissance, multi-channel jamming, and feedback monitoring. This is an architecture proposal rather than a validated performance result.

A conditional-probability chain and response-time model are provided to show how stage errors and delays may affect workflow performance. Their parameters have not yet been estimated from comparative data.

The analysis indicates that automation and shorter information-cycle time may improve performance, but the magnitude of any improvement remains to be established experimentally.

The study does not yet validate OSD-based affiliation assessment; estimate false-friendly, false-hostile, or unknown-class rates; quantify propagation uncertainty; test dependence between information-cycle stages; or compare response time and effectiveness against the stated baseline. The current scope is primarily analog video links and should not be generalized to digital, encrypted, or frequency-agile links without separate modelling and evidence.

Subject to the stated validation steps, the proposed workflow and models may be used as a basis for future adaptive SDR-system design and controlled evaluation.

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