

Avionics System Development for a Rotary Wing Unmanned Combat Aerial Vehicle

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Abstract—This study covers the avionics system design for an unmanned combat aerial vehicle (UCAV) that can successfully detect and lock down rival unmanned aerial vehicle targets as many times as possible in air-to-air combat. With the artificial intelligence (AI) supported development board and high resolution/wide-angle camera on it, easy detection of competitor systems is provided. The captured images and flight data are processed with the AI-algorithm working on the developer kit with 48 tensor cores on it. Moreover, flight telemetry data is transmitted to the ground station at a range of 40 km, end-to-end encrypted and with low latency. Through 2.4 GHz radio frequency control, manual control can also be performed in an encrypted way and at a sufficient distance. Designed as a hexacopter, the UCAV can also avoid locking up of counter-unmanned systems with its high maneuverability. As a result of the proper design of the avionics and electrical system architecture, it can perform different tasks such as snapshot and data transfer, as well as being able to fly fully autonomously.

Keywords—unmanned combat aerial vehicle, avionics, hexacopter, printed circuit board, electronics design

I. INTRODUCTION

Parallel to the technological developments, while the usage area of fixed-wing and rotary-wing unmanned aerial vehicles (UAV) are increasing, the capabilities of these vehicles are also taken to the next level [1]. They are now an indispensable part of human life due to their advantages such as faster manufacturing, low cost, taking part in dangerous missions [2], being used in situations where human access is not possible [3], and practical hardware updates compared to conventional aircrafts. In line with the requirements especially in military fields, unmanned systems with superior hardware and software features are being developed by pushing the limits of current autonomous systems knowledge and capacity [4]. Moreover, the ease of access to UAVs enabled researchers and professionals from various fields to contribute with a broader perspective, thus more innovative applications emerged [5]. These systems, which are frequently used in applications such as remote sensing [6], surveillance and mapping [7], are also widely preferred vehicles in intelligent transportation systems [8]. Due to the increasing demand for their use in various potential applications, their software and hardware are updated on a mission-specific basis, giving them a more autonomous feature [9]. These unmanned systems are on their way to become one of the popular outputs of artificial intelligence, along with new sensors recently embedded to their hardware.

Rotary-wing systems provide a significant advantage to fixed-wing UAVs due to their high maneuverability. The ability to use this maneuvering capability even in extremely narrow flight areas makes many potential applications possible [10]. Although quadrotors are the most popular of the rotary-wing systems, another important variant, the hexa-

copters, continue to grow in popularity. These unmanned systems, which are controlled by six rotors that are equidistant from each other around the main body, have become more utilized with the advances in their software and hardware [11]. They can be considered as an alternative platform to the conventional ones for surveillance purposes since they can stay stable in the air [12]. Although this ability also allows them to be used for many commercial applications, such as aerial photography, it is one of the tactical features sought in an unmanned combat aerial vehicle (UCAV) [13].

A critical advantage that makes hexacopters extraordinary is that they can fly at high altitudes and even in thin air [14]. Another distinct advantage of their powerful rotors is that they can be kept under control even when exposed to intense and harsh weather conditions [15]. Having six propellers not only increases the maneuverability, but also ensures that it maintains to fly even if one of the rotors fails [16]. They can carry heavy payloads and can be equipped with a wide variety of accessories. Hexacopters, similar to other rotary-wing systems, consume large amounts of battery due to the onboard avionics system and other avionics-based equipment [17]. This causes limited mission times and is a major shortcoming, particularly in UCAVs where operational time is critical. More batteries can be integrated into the UCAV to solve this problem, however it is not an optimal solution as it increases weight dramatically. This additional load will also reduce maneuverability, which is a significant disadvantage for UCAVs. An alternative solution to this can be the appropriate design of the avionics system. Critical features of a UCAV such as operation time and high maneuvering ability can be made more effective through a proper avionics system. Moreover, the benefit of proper avionics system emerges in swarm applications where cooperative work is highly demanded [18]. Although trajectory generation and optimal path planning for UCAVs in combat is a software-level problem, it also indirectly depends on the avionic system of these vehicles [19]. That is, the high-level interpretation of the algorithm steps implemented through the software and proper and instant processing of sensor outputs and reflecting them on the behavior of the UCAV are among the tasks of the avionics system [20]. Besides, further advancement of radar technology and anti-aircraft systems requires advanced software and optimization techniques for UCAVs, as well as the design of advanced avionics systems.

In this study, the avionics system architecture of a UCAV that can successfully detect and lock UAV/UCAV targets as many times as possible in air-to-air combat is designed. Formed as a hexacopter, the system is equipped with avionics and electrical systems in accordance with its structural features and mission objectives. Through the AI-supported development board and embedded sensors, it is aimed to gain a distinct advantage in possible combat scenarios.

II. SYSTEM OVERVIEW

TheUCAV, illustrated in Fig. 1, designed as a hexacopter to operate at an altitude of 6500 feet, theUCAV will be able to perform both fully autonomous and manually controlled flight for about 17 minutes, considering the 22000 mAh power of the battery and the current drawn by the motors. Through its AI-assisted development board, and a mission specific camera with a minimum resolution of 8 MP, a wide viewing angle (h: 62.2°, v: 48.8°) and a high data rate, it can detect otherUCAVs in its vicinity. Moreover, it also has the ability to lock onto the systems it detects, create a target position vector, and dogfight with evasive maneuvers. The captured images and flight data are processed with the AI-based algorithm working on the developer board, which has the ability to perform 21 trillion operations per second with 48 tensor cores on it. In addition, flight telemetry data is transmitted to the ground station at a range of 25 miles, end-to-end encrypted and with low latency. Moreover, flight telemetry data is transmitted to the ground station at a range of 60 km, end-to-end encrypted and with low latency. It can take about 30 frames per second through object detection with AI-based algorithm. The video transmission system transmits images from a range of approximately 3 miles with delays of less than 30 milliseconds. While the data is shared with the ground control station (GCS) and authorized servers (via MinlaHDW App) over 3G/4G internet connection, the data of otherUCAVs are received over the server, and sub-systems are provided that can follow the course with simultaneous localization and mapping (SLAM) in order to steer towards the targetUCAV as well as to control its own route. Thanks to the unique identity of the transmitter and receiver in the 2.4 GHz RF control, after the transmitter and receiver are paired, they only communicate with each other, preventing other systems from accidentally connecting or preventing the system from operating, and thus manual control can be performed at a sufficient distance (500-1500m air-to-air range). Besides, its dual antenna structure provides the FS-iA10B with unmatched reception (transmitted at over 1km) and interference rejection. In the case that there is no targetUCAV in the field of view, the location information of the target determined by the GCS, which is the most suitable for locking, is sent to the primary mission computer. In this way, the rivalUCAV enters the camera view and the AI-based algorithm takes over the control.

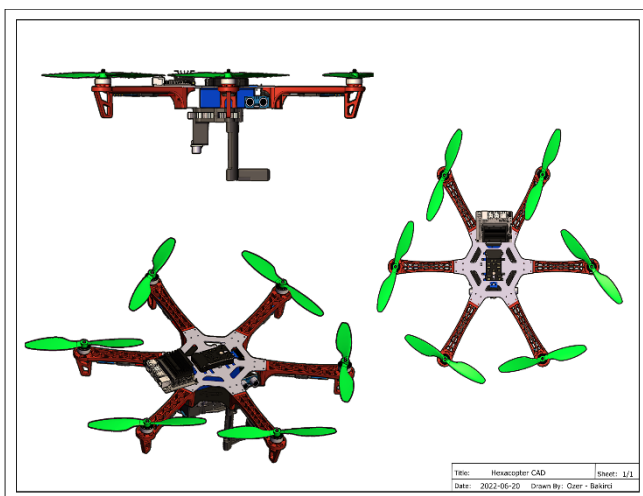


Fig. 1. CAD illustration of the 6-wing unmanned combat aerial vehicle (UCAV).

A. System Requirements

The purpose of theUCAV whose general scope is stated, is to successfully detect enemy targets that will be in the air at the same time as many times as possible, and to lock on the image and destroy the target. At this time, the camera to be used while trying to lock on the view must be fixed in terms of angle and (standard camera angle) position, facing forward during flight. Firing is provided by the locking drone's image of enemy targets into its own camera image. For locking to occur, it must be held within a square area in the center of the camera image until the moving enemy target is destroyed.

During autonomous locking, theUCAV should be able to be performed automatically by the system in autonomous mode without any user intervention. If the hit detection of the opponentUCAV entering the target strike area is done automatically by manually moving theUCAV during manual locking, and this should be considered as a manual hit. For manual hit, the user should be able to do hit detection and by manually specifying the target UAV area.UCAV should be able to document the footage during the lockdown with video recording. Moreover, the camera images used for locking should be able to be transmitted to their ground stations in real time. While performing all these, it should be able to escape from the opponent with its maneuvering ability.

B. System Components

High CPU, GPU, TPU, and RAM are needed, as it is necessary to run highly computational AI-based softwares that perform tasks such as lockdown to rivalUCAVs and avoid deadlocks of rivalUCAVs. The avionics system, whose schematic is given in Fig. 2, used Nvidia Jetson NX Javier mission computer working with Ubuntu Linux operating system to meet these needs. Pixhawk Cube Orange flight controller is used to enable theUCAV to fly manually/autonomously, to provide fully equipped flight with external and embedded sensors, and to have sufficient computing power to process data instantly.

In a compartment isolated from vibrations and other external effects, three IMUs and two barometric pressure sensors and a GNSS sensor communicating with SPI protocol provide high-accuracy and real-time information. The module also supports communication protocols such as UART, CAN, I2C, USB, DSM and S-BUS. Additionally, there is an integrated backup system with dedicated processor and independent power supply and protocols such as fail-safe and manual override in flight.

Moreover, since the tracking of theUCAV is essential, the Radiolink Se100 M8n is used as a secondary GPS sensor, which transmits location information with high accuracy and has a low margin of error. Positioning commands obtained as a result of the algorithm necessary for the image processing algorithm to detect the target are transferred with Minla HDW. Thanks to its compatibility with Minla HDW Ardupilot-based flight controllers, it functions as telemetry and allows ArduPilot-based flight controller (Pixhawk) to configure (flight plan, waypoint, etc.) and controlUCAV(both automatic and manual). Due to this feature, while the data received from the ground station is transferred to the JetsonNX hardware via autopilot, the transfer of data such as desired speed, position and orientation to the ground station is carried out uninterruptedly with 4G technology. This data is provided by Radiolink Se100 M8n GPS, TF Mini Lidar Plus and MPU9250 IMU, MS561 barometer, L3GD20 gyroscope,

In the detection of opponent UCAVs, Sony IMX219 camera module embedded with Raspberry Pi with 8-megapixel sensor, which includes features such as color saturation, light focus, exposure control, white balance, brightness detection, high-speed data transfer rate, and supports 1080p30, 720p60 and VGA90 video modes, is used. It connects to the CSI port on the Raspberry Pi or Jetson Nano with a 15 cm ribbon cable. To transfer the camera image to the ground station in real time, an ImmersionRC Tramp HV video transmitter with high-frequency radio signals with 40 channels support, providing analog communication of more than one video transmission device in the same environment, and generating signal power at 5.8 GHz frequencies between 1mW - 600mW at 2 km range with low transmission delay, is used. As a video receiver, Furious FPV True-D 4.0 which works in harmony with the selected video transmitter, offers high FPS and low delay, and can produce solutions to interference with signal processing algorithms is used. Parameters such as operating band, receiver sensitivity, signal threshold value can be changed with a single button. In order to convert the digital image to be transferred from the UCAV avionics computer to the GCS into composite video format, a low-mass Mini HDMI2AV video converter is used, which converts the HDMI image to analog video format and provides video transfer in NTSC, PAL and SECAM formats. BST Easy Capture Card USB 2.0, which performs transfer with low delay, is used for converting the image transferred to the GCS with FPV video transfer devices from analog to digital and converting it to the ground control computer in appropriate formats.

To prevent collision with other UCAVs during the mission, Benewake TFMini Plus distance sensor which has a detection range of 12 meters, can measure distance with a small error margin of ± 5 cm between 0.1-6 meters and $\pm 1\%$ between 6-12 meters, and the data acquisition speed reaches up to 1000 times per second, is used. A 16-channel analog digital multiplexer with a switching speed of 9 ns and a data transfer rate of 10 MHz is connected to the RX/TX pins of the developer kit so that four distance sensors, which are planned to be used, can perform data receiving-transfer operations. This will also ensure that the sensors that send the analog signal, which cannot be connected due to the fact that there is only one RX/TX pin in the Jetson Xavier NX kit, control the digital data and transfer it to the developer kit.

In order for the UCAV, which weighs 4 kg with the weight distribution in Table 1, to hang in the air, considering the parameters such as wind and acceleration, each engine provides 669 g of thrust, a climb rate of 13.3 m/s and a maximum speed of 30 km/h. Considering this power data brings an estimated range of 8454 meters. To properly react to such parameters, the total thrust of the motors must be at least double the weight of the UCAV. Considering these parameters, a Racerstar AirA 2508 1200KV which can provide thrust with an efficiency of approximately four times the weight of the UCAV (6 g/W), is used. For the 4 kg UCAV, Racerstar AirA 2508 1200 KV with sufficient trust is used, taking into account extreme weather conditions. The HGLRC Forward FD-50A 2-6S Blheli 32 Bit ESC module, compatible with Li-Po battery, is used to accurately control the speed of brushless DC motors and guide the flight. XGL 200A power distribution board, APM 30V 90A power module, and Emay XL4016 voltage regulator are used to feed the hardware such as motors and control card from the battery. GemFan (80x45) propeller with high trust and high power coefficient is used,

Table 1. Weight distribution of the UCAV.

Component	Weight (g)
BLDC (Racerstar AirA 2508 1200KV)	$50 \times 6 = 300$
ESC (HGLRC 50A 2-6S Blhel, 32bit)	$5.2 \times 6 = 31.2$
Propellers (GemFan 80x45)	$7.7 \times 6 = 46.2$
Power Distribution Board (XGL 200A)	$7 \times 2 = 14$
Developer K. (Nvidia Jetson NX Javier)	200
Control Board (Pixhawk Cube Orange)	74
Battery (ZDF 22000 mAh 5S 25C Li-P)	2195
Telemetry (CUAV P9 XBP9X Radio)	31
Control Receiver (Flysky FS-IA 10B)	15
Camera (Raspberry Pi Camera v2)	3
Video Transmit. (ImmersionRC T. HV)	35
Power Module (APM 30v 90A)	25
Power Regulator (Emay XL4016)	77.5
Fuse (300A Circuit Breaker)	102.5
Lidar Sensor (TF Mini Lidar Plus)	$11 \times 4 = 44$
PDV (PDV)	5
HDMI TO AV (Mini HDMI2AV)	50
GPS (Radiolink Se100 M8n)	34.9
Wifi and 5MP Camera (Minla HDW)	29
Airframe (Carbon Fiber)	700
TOTAL WEIGHT	4012.3

which is suitable for a 5000 rpm motor. The 300A current required for feeding the flight control board, which is also used for voltage and current measurements, is supplied by APM 30V 90A power module.

In case that the electronic equipment draws excessive current, a 300A fuse is used by adding a tolerance value to the current drawn by the circuit, in order to protect the electronic circuits, to prevent any fire situation and to cut the energy easily. ZDF 22000 mAh 5S 25C Li-Po battery is used as the main power source to run the entire avionics system.

C. Aerial Vehicle Performance

Considering the weight of the 6-wing unmanned aerial vehicle system, approximately 669 grams of thrust per engine falls for the hover mode. Considering engine power and maximum battery capacity, the amount of rotation of the UCAV's rotors, n , is 252 rps. The total amount of thrust produced by the six rotors of the UCAV is obtained as 14.9 N by using the propeller thrust (C_t), air density (ρ), propeller radius (d), and the speed per second (n) just obtained. The thrust required for the aircraft can be calculated as 6.512 N with Wg/N expression, where W is the weight of the aircraft, g is the gravitational acceleration and N is the number of engines. As can be seen from this result, the total amount of thrust produced by the six rotors of the UCAV is more than the required amount of thrust, which means that a safe flight will be ensured.

III. MISSION OPERATIONS AND INFORMATION MANAGEMENT

The flight control card is the unit, where the data of the subsystems on the UCAV, embedded (or added externally) sensors and receiver data are brought together to perform smart behaviors and kept accessible when necessary. The unit that processes the images obtained from the camera integrated into the UCAV with AI-based algorithms and analyzes the information collected on the control card is the developer computer. All the data obtained are directed to the main computer to be used in autonomous flight, path planning and

Table 2. Performance metrics of You Only Look Once (YOLO) Algorithms.

Model	Size (pixels)	mAP ^{test}		mAP ^{val}		Speed V100 (ms)	Params (M)	FLOPs 640 (B)
		0.5:0.95	0.5:0.95	0.5	0.5			
YOLOv5s	640	36.8	37.4	56.8	56.8	2.0	7.2	16.5
YOLOv5m	640	44.5	45.4	64.1	64.1	2.7	21.2	49.0
YOLOv5l	640	48.1	49.0	67.3	67.3	3.8	46.5	109.1
YOLOv5x	640	50.1	50.7	68.9	68.9	6.1	86.7	205.7

dogfight tasks that performed by the UCAV. In addition, the output image showing the lock pad, flight mode and similar information needs to be converted to analog video in the digital-to-analog convert (DAC) unit in order to be sent from the main computer to the GCS. The realization of this process is provided by placing information about the target UCAV, such as location and relative size, into three determined pixels in the image. Thus, the task of transferring live video to the server is accomplished by utilizing the low latency capability of analog video transmission devices.

A. Target Detection through Image Processing

While detecting and tracking targets with image processing, the processing of the data received from the camera, its rapid transfer, and the real-time operation of the system are of great importance. Therefore, while transmitting data, the packet structure and the speed of the transmission channel are chosen to minimize the delay. To implement the prepared plan, convolutional neural networks (CNN), which is a sub-branch of artificial intelligence and expresses multi-layer artificial neural networks, are used. For target detection and autonomous locking, a CNN-based You Only Look Once (YOLO) method, which reduces the number of parameters in the artificial neural network in pattern recognition, and therefore does not require the entire image to reach the goal during the application, is used. YOLO performs object recognition and detection in one go and quickly. In other words, when the algorithm works, it simultaneously detects the positions of the objects in the pictures or videos. While the algorithm works repeatedly for videos, it works once for images (single frame). The algorithm first segments the image into regions, then boxes the objects (bounding box) it finds in each region. The key feature in choosing it is because it is implemented natively in PyTorch (rather than Darknet), it is pretty simple to change the architecture and import it into many distribution environments.

Detailed specifications of the models within YOLOv5, which have four different architectural structures, YOLOv5s, YOLOv5m, YOLOv5l, YOLOv5x are shown in Table 2. The table shows the detailed characteristics of the overall performance evaluation at the time of implementation. The Nvidia Jetson NX Javier card, which is chosen for some operations to be performed by the UCAV, such as image transfer and communication, has enough memory to handle these operations. It is also supported by a spare 500GB SSD memory module. Another important parameter is the latency time. Latency times correspond to 500, 370, 268 and 163 data passes or data processing per second for 2, 2.7, 3.8, and 6.1 m/s, respectively.

Although YOLOv5s seems to be the most efficient model, the lag time can be ignored since high FPS (frame per second) rate is needed. However, mean average precision (mAP) is used to evaluate object detection models such as R-CNN and YOLO. The mAP value compares the base reality bounding box with the detected box and gives a score. Higher the score,

higher the accuracy in pattern detection. One of the most important features of the YOLO algorithm is that its mAP value is higher than other object detection algorithms.

Based on all these criteria, YOLOv5x, which has higher latency and FPS value, finds optimal results, can continue to follow and detect the opponent vehicle without delay due to 200 times per second operation rate, is used. The algorithm, which works with the data set containing 50,000 UAV photos, detects the rival vehicles with high accuracy during the fight. The desired 60 FPS value is easily obtained with the model trained using the Nvidia Jetson NX Javier. The distances of the rival UAVs can be found from the area they cover within the frame determined in the camera. Besides, there are lidar distance sensors at the front and rear of the UCAV for safety purposes against collisions.

B. Target Tracking through Image Processing

Selecting the target to be followed based on the location information of the rival UCAVs received from the server plays a critical role in the execution of the tracking process. To accomplish proper tracking, it is necessary to use an iterative neural network that can establish a relationship between the past and present location of the object. The selection criterion of the UCAV to be followed is that it is the slowest moving competitor in the immediate vicinity. The (LSTM) ‘long short-term memory’ (LSTM) model is used to perform this process. When sufficient data is collected for the LSTM algorithm to process, the possible route of the slowest UCAV to be followed is estimated from the three-dimensional map. Thus, the disadvantages that may be caused by the delays in communication with the server are minimized and it becomes easier to catch the opponent. In addition, a laser distance sensor is used to avoid collisions with other UCAVs while performing this operation. In order to increase the insufficient viewing angle of the laser distance sensor, ± 10 degrees “yaw” movement is made until the UCAV to be followed enters the field of view.

An algorithm is developed using the LSTM model in order to produce solutions against scenarios such as image distortions, disruptions in target detection, encountering more than one target at the same time, which may prevent the SİHA from locking up during the competition. As shown in Fig. 3, the position data of the objects obtained from the YOLOv5 neural network on the images are taken. According to the location data shared by the server, when the target pointed by the rival UCAV determination algorithm, the GPS orientations of the UCAV that is desired to be tracked while having more than one UCAV in the field of view and the movements of the UCAV s detected by the camera are determined. A tertiary position is estimated by LSTM through the positions detected on the video frame. By comparing the positions of the UCAVs from the tertiary video frame with the positions estimated by LSTM in the second frame, the UCAV with the highest match percentage is followed.

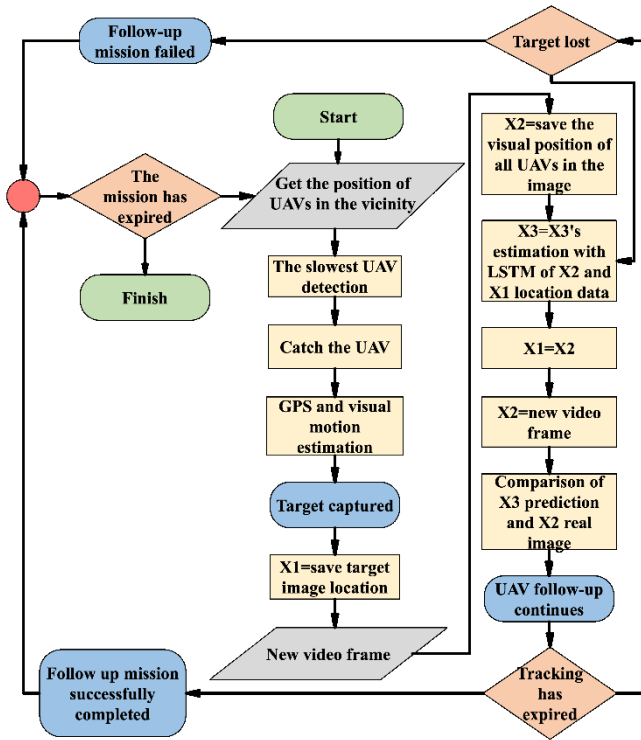


Fig. 3. Tracking algorithm flowchart.

IV. COMMUNICATION

A. In-vehicle Communication

The communication protocol realized in UCAV is given in Fig. 4. All communications between components are gathered and processed on the Pixhawk Cube Orange. Communication between UCAV and GCS is carried out over this protocol. In communication within Jetson, data transfer is carried out by sending from YOLOv5 to UCAV embedded C application via IP. The time to be used between this application and GCS is sent over telemetry via UART. HDMI audio and video data are transferred digitally without compression in 1080p, 60 Hz format with TMDs or FRL protocol. An interface developed for this purpose uses the HDMI Interface when outputting the data processed on the UCAV host and sent live to the GCS through HDMI2AV-DAC device.

R/C receivers use digital serial data communication technology to transmit control signals between the receiver and the flight control board, which is used as a digital communication protocol. On top of that, the high speed (max 10-20 ms delay) SBUS protocol is used, which supports digital transmission of up to 16 channels, enabling digital transmission of multiple channels from the receiver to the flight controller. The compass, which is used externally in the UCAV and will be located on the GPS, communicates with the control card via I2C protocol, which transfers the data at a low rate along a single cable (SDA). The UART protocol is used to exchange information between the control card in the UCAV and the GPS and telemetry modules. Serial communication protocols are also used in order to send the data kept in the form of MAVLink messages on the control card to the computer continuously and for the computer to send messages to the control card. For video transmission in NTSC and PAL formats to the GCS, analog video transmission devices that carry standard definition video (typically 480i or 576i resolution) as a single channel are used.

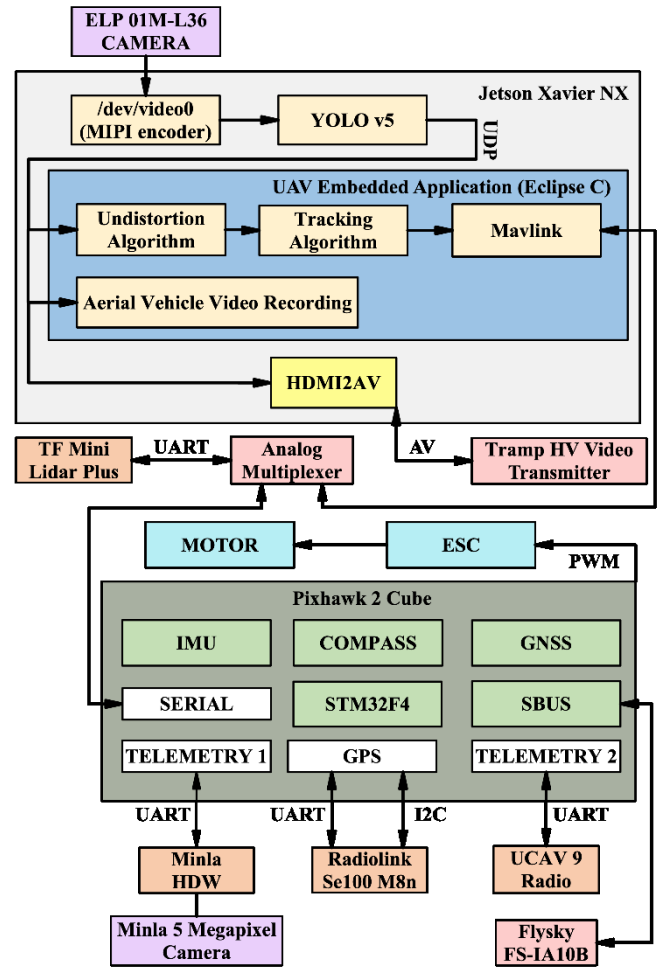


Fig. 4. In-vehicle communication system architecture.

B. Ground Control Station (GCS) Communication

The communication system architecture of the image and telemetry data transferred from the aircraft to the ground station via transmitter and telemetry is shown in Fig. 5. Telemetry 1, with an output power of 0.5 W, provides bidirectional Mavlink communication between the autonomous flight board and the GCS by broadcasting in the 915 MHz band. FlySky IA10B receives the data sent by the receiver controller and sends it to the autonomous flight board with SBUS packet structure. It makes one-way communication in the 2.4 GHz Band. Telemetry 2 provides bidirectional communication between the main computer and the GCS.

C. 3G/4G Internet Communication

Although the communication system used in the aircraft offers high-speed data transfer and 256-bit Advanced Encryption Standards (AES) point-to-point, point-to-multipoint, relay communication for UCAVs by preventing interference, a communication is also built on 3G/4G since it has advantages such as high mobility and high speed access. Due to its advantages such as high quality video transfer, high range, low latency, light weight and supporting MavLink messages, MinlaHDW module is used for communication with LTE. There is an onboard camera on the telemetry and image transmission module (MinlaHDW) used in UCAV. The image taken from this camera is transferred to the ground station over the internet, and it is determined whether the lock on the opponent has taken place successfully and whether it is followed by the enemy. MinlaHDW can transmit both tele-

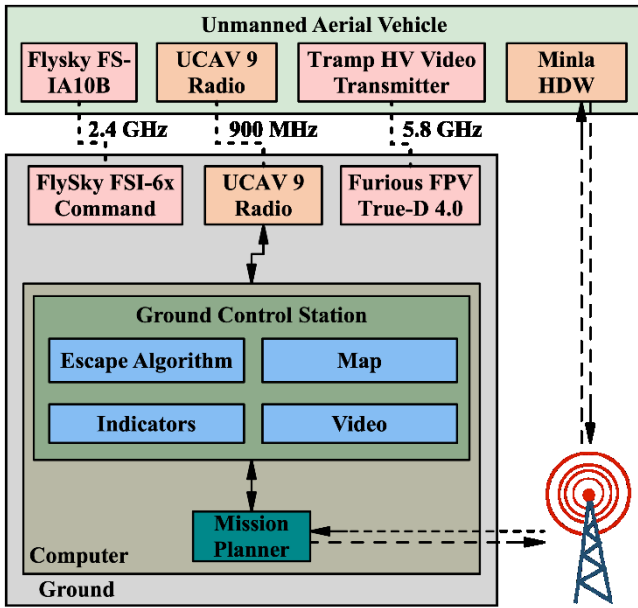


Fig. 5. GCS communication architecture.

metry and camera data simultaneously. It realizes point-to-point communication for operators with 800/900/1800/200/2600 MHz LTE bands. Telemetry and processed image data transmitted to the ground station can be shared with authorized servers via MinlaHDW App.

D. Radio Frequency (RF) Communication

The key parameters used when analyzing the radio link, also indicated in Fig. 6, are received power (P_R), transmit power (P_T), transmit antenna gain (G_T), receive antenna gain (G_R), and receiver sensitivity (SR). Details of the environment between the transmitting antenna and the receiving antenna are also critical, including the distance between them, any obstructions, antenna height (above the ground), and radio noise. The signal is emitted from the transmitter so that only part of the power reaches the receiver. This is represented by path loss (L_p), which models the power loss due to distance and antenna area. Since the antenna area (how wide the antenna can receive power) is frequency dependent, the path loss is frequency dependent. A common misconception is that high-frequency signals provide a weaker connection in vacuum than low-frequency signals. However, this is not the case. The frequency dependence of the path loss is the result of scaling the electrical size (and physical size) of the antenna with wavelength. A low-frequency antenna is larger in size than a high-frequency antenna, so it has a larger communication area that can receive more power from the transmitter. As long as the P_R is greater than the sensitivity of the RC module, the packet will normally be received correctly. The link margin gives information about how much margin is on the communication link before the LM starts getting packet errors: $LM > 0$ indicates the link is good, $LM < 0$ indicates the link is broken or packets are corrupted. Considering the random variation of path losses due to ambient RF noise or signal attenuation, adjusting the connection margin to a margin of a few dB is essential to establishing a reliable connection.

E. Path Loss and Range

Path loss is the reduction in power density of a radio signal as it propagates through space. It is an important component in the analysis and design of the link budget of radio systems.

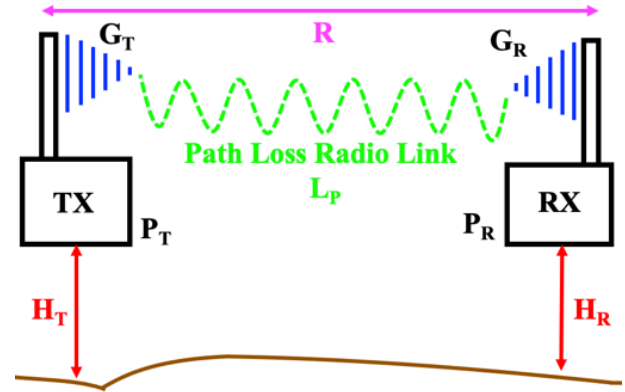


Fig. 6. Radio link diagram.

The estimation of path loss depends on the distance and environment between transmitter and receiver. Today, propagation models are used to estimate path loss, which computation of path loss for real conditions is only an estimate. Precise estimation is only possible for simpler cases such as free space propagation or flat earth model. For practical situations, it should be computed through the approach best suited to the situation.

V. AVIONICS TEST METHODOLOGY

A. Propulsion Test

Theoretically, it is known that certain thrust is provided with certain current values in the UCAV's thrust system. However, theoretical calculations are tried in practice with the thruster used for testing brushless DC (BLDC) motors. In this way, results in accordance with the label values of the motors can be observed. At the same time, an infrared temperature measuring device is used to observe the temperature change that occurs while the engines produce an average thrust during the flight period.

B. LSTM Locking Test

In cases where there is more than one enemy target in the frame of the UCAV at the same time, it should be locked to a single target. Through this, the LSTM model is trained and solutions are produced for scenarios that may occur when more than one target is present at the same time. The trained LSTM model can be tested on a YOLOv5x model, where it is detected using different objects for convenience. Some of the steps performed in the tests are i) identifying the closest target while multiple enemies are in sight at the same time, ii) compensating for frame losses in the target detection model and continuing to lock onto the initially determined enemy, and iii) completing the lock without mingling with other enemies.

C. Flight Test and Control

The body of the UCAV consists of carbon fiber material. After completing the mechanical parts, equipment and controller settings of the aircraft, the purpose and target outputs of the flight test are determined. Necessary security measures and protocols within the scope of flight control are applied on a date when the weather conditions are suitable by obtaining the necessary permits for the flight area and flight. Some of these are; obtaining legal permits for the flight, checking battery capacity, secure fastening of all components, checking the current breaker, ensuring that the propellers are not attached during calibration and testing, control and calibration of the remote control, calibration and control of

accelerometer, barometer, compass and gyroscope, controlling flight modes, checking that there is no error (Glitch) of the GPS and ensuring that a sufficient number of satellites are connected, ensuring the "Failsafe" mode is active and the operation is correct (Land or RTL), control of engine rotation directions and propeller compatibility, tightening the propellers well so that they do not jump out of the engines, checking that the propellers do not touch any object.

During flight tests, the test outputs are obtained by recording parameters such as flight time, response delay, the temperature created by the rotors during a mission when the aircraft is fully loaded. Similar to the pre-flight protocols, the required protocols are applied after the flight. Some of these can be listed as stopping the rotors with the remote control, cutting the energy with the current breaker, checking the battery percentage, checking the ESC and motor temperature, checking whether there is any deformation in the UCAV mechanical and electronic components, checking the propeller heads and checking the flight records to see if there is any abnormality. In the final prototype to be produced, it is planned to carry out the tests in this direction by using the equipment in the system instruments.

VI. CONCLUSIONS

Avionics system for a rotary wing unmanned combat aerial vehicle (UCAV) that accurately detect and lock down rival aerial targets in air-to-air combat is presented. The mission requirements of the UCAV under consideration are defined in detail, and the avionics system is designed according to these requirements. Based on the cost-performance index, an avionics system with high mission capacity but reasonable cost is developed. The maneuverability of the UCAV, which is a hexacopter and equipped with an artificial intelligence-based development board and various sensors, is maximized. Through its integrated camera and high computational processor, it can accurately detect competitor systems. The captured images and flight data during air-to-air combat are processed on the development board by AI-based algorithm and used for behavior optimization of UCAV. By establishing an effective communication with the ground control station, it is ensured to be more effective in air combat. Its advanced avionics system design enables it to fly missions both manually and fully autonomously.

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