IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received October 14, 2020, accepted October 31, 2020, date of publication November 16, 2020, date of current version December 8, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.3037760

An Integrated Scheme of a Smart Net Capturer for MUAVs

CHENG DONG, CHAOFENG LIU, JIE LIU, NIMIN ZHOU, HANG ZHANG, AND TONG FANG
Shanghai University of Engineering Science, Shanghai 201620, China
Corresponding author: Chaofeng Liu (liucf@fudan.edu.cn)

ABSTRACT Micro Unmanned Aerial Vehicles (MUAVs), including consumer-grade ones, have been frequently threatening urban low-altitude security in recent years. This article analyses the necessity to develop specialized technology of anti-MUAVs. Then the article proposes an engineering scheme of a Smart Weapon Capturing MUAVs (SWCM) in an automatic and soft-killing way. The scheme includes a ground subsystem and an aircraft subsystem. The ground subsystem mainly includes optical sighting equipment and handheld launch control device. The aircraft subsystem includes guidance, control, structure, aerodynamic, etc. The design principle of this scheme embodies the technical characteristics of autonomy, high efficiency, low cost and civil-military dual use. The validity of the smart weapon system design is proved by numerical simulations and experiments, and its application is also prospected.

INDEX TERMS Anti-MUAVs, civil-military dual use, low altitude security, smart weapon, soft skill.

I. INTRODUCTION

In recent years, the application of consumer-grade Micro Unmanned Aerial Vehicles (MUAVs) has shown an explosive growth, which leads to the increasing abuse of MUAVs. For example, there are frequent reports of MUAVs invading airports and gathering crowds. Because MUAVs have the characteristics of portability, simple operation and many acquisition channels, the possibility of criminals using MUAVs for illegal activities has increased. It is a real threat to the security of important areas or venues for major events. Specifically, MUAVs have the characteristics of ‘‘difficult to be predicted in advance, difficult to be handled in the event and difficult to be traced afterwards’’. Therefore, it has become a world public safety problem how to prevent accidents of MUAVs [1]–[3].

Although the traditional anti-MUAV interception schemes, such as the technology of intercepting rotor UAV by using rotor UAV, has the advantages of low cost, but also has the disadvantages of slow flight speed and low remote control accuracy, which makes the rapidity and operability of the mission are subject to a lot of restrictions. In addition, some interception schemes with high accuracy and fine interception effect (especially a series of micro precision guided weapons with low indirect damage) are mostly used for military purposes, and the cost is too high for civil security [4]–[6]. Therefore, the research on a portable, low-cost, precise guidance, flexible mission of the anti-MUAV intelligent interception system to meet the dual-purpose needs of military and civil use, improve the operation efficiency of anti-MUAV and reduce the cost of anti-MUAV operation, has theoretical research and practical significance for intercepting micro air vehicles endangering public safety.

In this article, an anti-MUAVs scheme with essentials of automatic tracking and soft kill is proposed. Main technological innovations of the scheme include:

1) A low-cost smart anti-MUAVs scheme being realized by using four-quadrant image guidance in a micro-aircraft (40mm in diameter).

2) The automatic stability control design is adopted to satisfy the stability of the aircraft at low speed.

3) The soft killing scheme of net-intercepting being adopted, which is optimized and integrated into a space less than 40 mm in diameter to realize smart capture of MUAVs.

II. ANALYSIS OF OTHER RESEARCH CASES

In the field of MUAVs detection, there are several technical directions: active radar, passive radar and photoelectric radar. Each of them has its own advantages and disadvantages, which can be used together.

The representative work of active radar is the Anti-UAV System (AUDS) from Britain. Its working principle is to launch Ku waveband for scanning detection (similar to bat positioning), which can detect MUAVs several kilometers or

The associate editor coordinating the review of this manuscript and approving it for publication was Wai-Keung Fung.

TABLE 1. Parameters of typical micro rotor UAV.

Model	DJI Phantom 3	DJI T600
Weight (including battery)	1280g	2870g
Maximum horizontal flight speed	16m/s	22m/s
Maximum vertical flight speed	5m/s (up) 3m/s (down)	5m/s (up) 4m/s (down)
Maximum flight altitude	6000m	4500m
Flight duration	About 25 minutes	About 18 minutes
Working temperature	0℃~40℃	-10℃~40℃
Maximum dimension	451mm	559mm

even 10 kilometers away. However, in rainy or foggy days, this waveband is easily depleted by water vapor. Passive radar is suitable for detecting consumer-grade MUAVs. It can detect the signal of UAV within 1 km range, without emitting any radio waves or affecting the surrounding electromagnetic environment. Photoelectric radar is a kind of equipment that uses photoelectric technology to achieve detection effects. In terms of function realization, the photoelectric radar mainly detects the target's azimuth and measures the target's position (distance and azimuth angle), speed and time.

In the field of MUAVs interception, some anti-MUAVs products or technical solutions using hard kill or soft kill mode have been presented, and there is no shortage of creative moves that are worthy of reference.

In terms of vehicle interception equipment, there is the "Skynet-1" micro air vehicle target interception system of the second Academy of Aerospace Science and industry of China. Laser interception equipment, such as the laser gun weapon developed by Boeing company of the United States. Electromagnetic interception equipment, for example, a development agency named "Battelle" in Ohio, USA, launched an anti-UAV equipment named "Drone Defender" radio wave gun in 2015. In 2015, a French research team used a DJI MP200 to capture a DJI Phantom 2 by pulling a net during the test flight. DroneShield in Australia launched the DroneGun Mk III in 2019. By transmitting electromagnetic pulse, the equipment destroys the wireless connection between UAV and remote-control platform to trigger the emergency landing measures of UAV. In 2020, Blighter Surveillance System in British launched A800 3D UAV detection radar for detecting UAVs.

III. THE CONDITIONS OF DESIGNING THE ANTI-MUAVS WEAPON SYSTEM

A. TECHNICAL CHARATERISTICS OF MUAVS

This article takes DJI Phantom 3 and DJI T600 as two typical targets to analyze the characteristics of MUAVs. The technical parameters are shown in Table 1.

In terms of technical characteristics, MUAVs have the characteristics of "Low, Slow and Small"(LSS), that is, it belongs to a category of aviation equipment with flying altitude below 1000 meters, flying speed less than 200 kilometers per hour and radar reflection area less than 2 square meters. The concept of LSS was first proposed from the field of radio frequency detection technology. Specifically, it refers to flying close to the ground at low altitude with strong ground clutter; slow flying or even hovering without Doppler effect; and small radar reflection area [7], [8]. The technical characteristics of LSS make it difficult to discover and track MUAVs by traditional radio frequency detection technology. As a result, MUAVs pose a great threat to the existing air defense security.

B. CHARACTERISTICS OF URBAN LOW-ALTITUDE ENVIRONMENT

Low-altitude airspace is an important event space for the general aviation industry. With the rapid development of UAV system manufacturing industry and service industry, security defense of urban low altitude has also ushered in new challenges. With the intensive application of electronic equipment and the continuous expansion of radio communication field in the city, the electromagnetic environment and photoelectric environment of the city are becoming more and more complex, which has a negative impact on the detection and tracking of MUAV. And with high-rise buildings, the urban low-altitude vision is not wide, which increases the difficulty of detecting the MUAVs. At the same time, the large population and dense traffic in the city make the operation of anti-MUAVs difficult to avoid additional damage [9].

IV. INTEGRATED SCHEME OF ANTI-MUAVS WEAPON SYSTEM

A. MAIN TECHNICAL IDEAS

Due to the difficulties of being discovered, intercepted and handled of MUAVs, the traditional disposal method cannot perform anti-MUAVs operations effectively. Specifically, traditional manual operation in anti-MUAVs has the problem of slow response speed. Compared with the traditional non-guided flight mode, the guided flight mode adopted in this scheme has high accuracy and good responsiveness. In the stage of aiming and launching, there is no need for precise aiming like non-guided mode, which reduces the difficulty of operation. The scheme of autonomous capture of UAVs can greatly shorten response time to intercept invading MUAVs and improve the operational efficiency of anti-MUAVs.

The smart anti-MUAVs weapon system is a precision guided weapon system. Guidance includes guidance subsystem and control subsystem. The function of guidance subsystem is to measure the relative position and relative speed between the guided weapon and the target, to calculate the deviation of the actual flight trajectory from the theoretical trajectory, to give a correction signal deviation, and then to deliver it to the control system. The function of the control subsystem is to adjust the movement or posture of the guided weapon according to the correction signal output by the guidance subsystem for changing the missile trajectory, so the guided weapon can accurately fly to the target [10], [11].

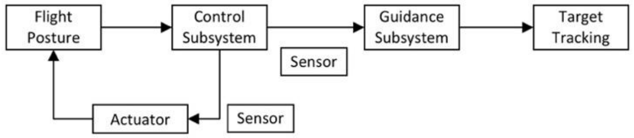

FIGURE 1. Schematic diagram of guidance and control subsystems.

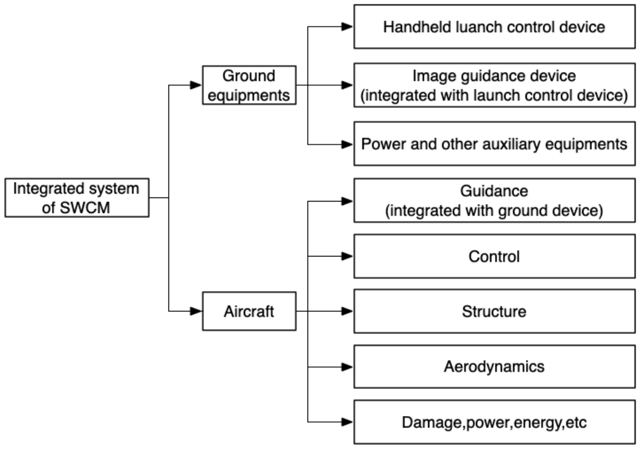

FIGURE 2. Integrated technical program framework of SWCM.

The schematic diagram of the aircraft technology using guidance control technology is shown in Figure 1.

B. INTEGRATED SCHEME OF SMART WEAPON CAPTURING MUAVS

The technical program framework of Smart Weapon Capturing MUAVs (SWCM) is shown in Figure 2. The components of SWCM include handheld launch control device, image guidance equipment, control subsystem, structure and aerodynamic, etc. Following is the framework of the overall scheme and the subsystem schemes.

1) INTEGRATED SCHEME OF THE HANDHELD CONTROL DEVICE

The handheld launch control device of SWCM is mainly composed of a hand-held launch control device and a power supply. The hand-held launch control device is retrofitted with a military crossbow machine. The launch control device, which is a combat control center of the smart weapon system, is used to identify and capture targets and to control the launch of aircraft. The adoption of handheld rather than shoulder-mounted launch control devices is intended to facilitate the operate in vehicles or helicopters to achieve the need for maneuvering tasks or pursuing targets. It is technically more demanding for integration and miniaturization of electronic components. The battery on the rack provides power for the launcher and the initiating explosive device.

2) IMAGE GUIDANCE SCHEME OF SWCM

Four-quadrant image instruction guidance is adopted in the guidance mode of this scheme. The guidance system is mainly composed of four parts: image acquisition and display module, image processing module, data transmission (automatic command machine) and guidance light source on the aircraft.

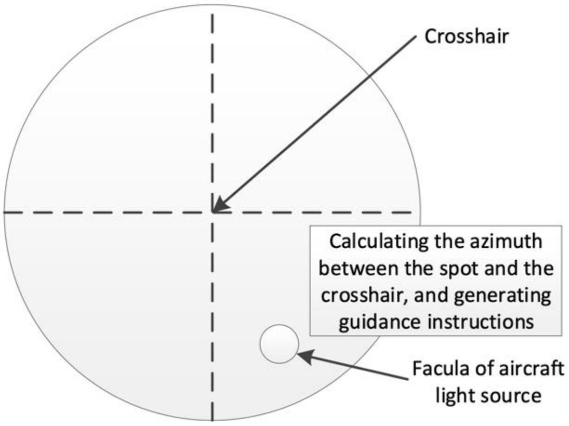

FIGURE 3. Schematic diagram of four-quadrant image instruction guidance.

The guidance device makes the friend UAV intercept target according to certain flight trajectory according to the movement information of the foe UAV and the friend UAV. As shown in Figure 3, the fundamental of four quadrant image guidance is as follows: The operator uses ground-based sighting equipment to align the target with the crosshair. When the light source of the aircraft enters the field of view of the CCD camera, the image processing module calculates the azimuth equation between the light source and the crosshair in real time. According to the azimuth equation, the commands (including ascending, descending and steering) are generated and sent out by radio to guide the aircraft to fly to the target [12], [13].

The basic working process of image instruction guidance mode is as follows:

a. The operator uses visible light CCD camera to manually capture the target in the crosshair.

b. The aircraft is launched at a calculated angle, so that it can enter the sight range of the ground observation equipment.

c. The ground observation equipment quickly captures the guidance light source on the aircraft from the image taken by the CCD camera.

d. The image processing module calculates the azimuth difference between the guidance light source and the crosshair in the image, obtains the real-time guidance instruction, and sends the guidance instruction to the aircraft through the wireless instruction launching module.

e. According to the received guidance instructions, the control system of the aircraft controls the flight direction and attitude and guides the aircraft to fly to the target. In this process, the guiding light source is always ensured to coincide with the crosshair.

CCD strapdown imaging guidance has sufficient accuracy in combating stationary and low speed targets [14]. Due to the high sensitivity and low price of visible light CCD devices,

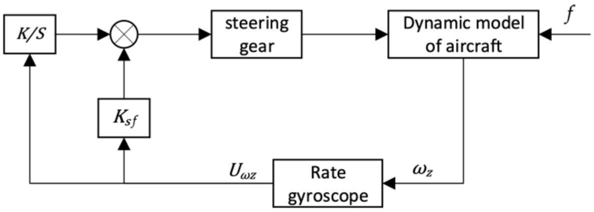

FIGURE 4. **Schematic diagram of pitch channel control for attitude control mode.**

and the elimination of complex photoelectric mechanisms in the strapdown seeker, the cost of the aircraft is significantly reduced.

3) CONTROL SCHEME OF SWCM

Autonomous flight is a key technology of an intelligent micro air vehicle. The integrated design of guidance and control is adopted to realize navigation control, flight stability control, Intelligent flight control (especially the control of gust mitigation and task discrimination) [15].

In addition, the autopilot is used to achieve the software realization of the control strategy. The guidance system and rudder system of the aircraft are installed in the same cabin with compact layout. It is especially important for smart aircraft with small tracking field of view strapdown imaging seeker to adopt small control surface design and small angle of attack design.

In the control scheme of the aircraft, due to the accuracy of strapdown inertial measurement, the angle of attack feedback is not introduced into the attitude stabilization control loop of the pitch channel. The principle block diagram of the existing attitude stabilization control loop is shown in Figure 4, and the mathematical expression of the control signal is shown in formula (1).

$$U_p = \frac{K\omega_z}{s} + K_{sf}\omega_z \tag{1}$$

In the above formula, f is the disturbance torque, U_p is the pitch channel control signal, K and K_{sf} are the control parameters. The research shows that the attitude stability control loop of pitch channel controlled by classical PID method cannot eliminate the attitude deviation caused by interference [16], [17].

This scheme is modified and innovated on the base of the existing control method, and a dedicated automatic stability increasing balance instrument is designed. Considering the realizability, reliability and real-time performance of the project, an improved PID method is adopted to design an attitude control loop based on Active Disturbance Rejection Control (ADRC). In this attitude control loop, the unmeasurable state variables are regarded as internal disturbances of the system [18]. In order to estimate the disturbance in real time, an appropriate state observer is constructed, and the mathematical expression of the control signal is improved by · choosing the observer parameters and using the idea of feedforward control for reference. The mathematical expression is formula (2).

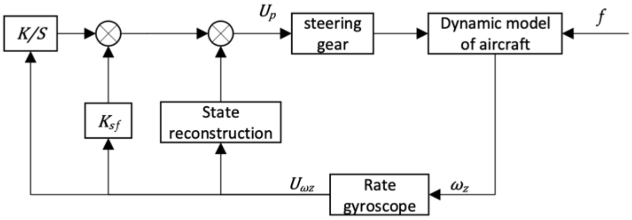

FIGURE 5. **Schematic diagram of attitude control loop based on ADRC.**

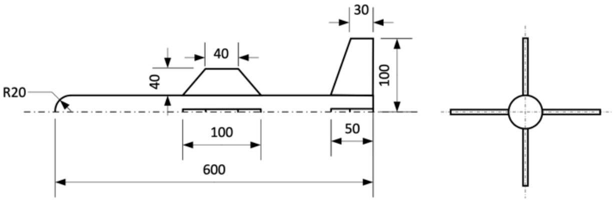

FIGURE 6. **Aerodynamic scheme of the aircraft.**

$$U_p = \frac{K\omega_z}{s} + K_{sf}\omega_z - \frac{z_1}{b} \tag{2}$$

In the formula above, Z_1 and b are parameters of state observers. The control law designed in this way can automatically detect and compensate the unmeasurable state, the unmodeled characteristics of the system and the influence of disturbance on the system performance, thus realizing the ADRC technology. The principle diagram of attitude control loop based on ADRC is shown in Figure 5.

The control actuator adopts a micro brushless electromechanical actuator based on MEMS. The receiver on the aircraft controls its ascent, descent and course according to the instructions received. The control device consists of flight control components (including inertia components, computers) and actuators (steering gear, rudder) to adjust the flight direction of the aircraft through the actuator according to the requirements of the command signal.

4) AERODYNAMIC SCHEME OF SWCM

The aerodynamic structure optimization design is adopted in this scheme. The normal full-motion rudder layout with high lift-drag ratio is also adopted in the aircraft. The lift of the aircraft is mainly generated by wing deflection and rudder deflection. The aircraft has a high stability and relatively small adjustment. The length of the aircraft is 600 mm. The diameter is 40 mm [19]. The aerodynamic shape of the aircraft is shown in Figure 6. Its main view is shown on the left and its side view is shown on the right. Dimensions are in millimeters.

By adopting digital design technology, the aerodynamic design of the micro catcher has a large lift coefficient, which ensures that the aircraft will not fall when flying with a small angle of attack or rudder angle during the launch stage (such as 50m/s). At the same time, it ensures that the seeker has a larger tracking and searching angle. At a higher speed near the

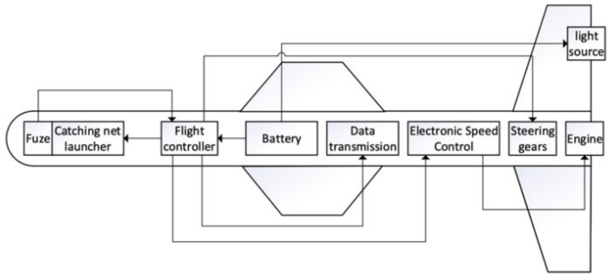

FIGURE 7. Structural layout Scheme of the aircraft.

sound speed, the position of the aerodynamic pressure center will not change dramatically, and the flight stability will not be lost. The full-motion rudder surface has a small adjustment ratio to meet the requirements of MEMS electric steering gear. The aerodynamic design of the head should meet the requirements of both drag reduction and optical guidance.

5) STRUCTURAL SCHEME OF SWCM

The integrated molding method is adopted in this scheme. Lightweight materials such as polyethylene are used as additive materials for additive manufacturing. Solid parts are manufactured by layer-by-layer accumulation of materials based on the aerodynamic and structural CAD data of the aircraft. The information-based micro flight-catcher in the virtual space is first realized to complete the aerodynamic-structural-general integration design and simulation. Then, the digital technology is adopted to integrate key areas or components [20]. In this way, the total weight of the aircraft can be less than 2 kg and the safety of SWCM can meet the requirements of the scheme design.

The aircraft scheme is designed as a high-speed micro flying net-catcher, which is formed in one piece without being division. The aircraft consists of a guidance part, a control part, a fuse, a warhead and an engine. The structural layout scheme of the aircraft is shown in Figure 7.

There are several parts to illustrate below:

a. The flight controller receives the guidance instruction from the instruction receiver and adjusts the angle of steering gears to change the flight direction of the aircraft.

b. The battery supplies power for flight controller, steering gears, engine, data transmission and other devices.

c. A high-energy rocket engine is installed at the tail of the aircraft.

d. In the image instruction guidance mode, the guidance equipment on the aircraft is composed of guidance light source and data transmission.

6) DAMAGE, POWER AND ENERGY SCHEMES OF SWCM

A net catcher made with nylon is used to deal with MUAV targets. In the power part, ejection launch is used to avoid the bad aerodynamic characteristics of the aircraft in low speed flight. Smokeless safe high-energy rocket engine is used as the main power, requiring specific impulse of more than 200s, engine mass ratio of less than 0.7. Propellant, which is not being ignited or exploded by open flames, is smokeless, environmentally friendly. A micro fuel cell with light weight and high energy conversion efficiency is adopted in the energy part. Due to limitations of specialization development costs, choices are made only based on the existing equipment or technical schemes in the market, or suggestions on research and development according to the specific needs in the future to require the manufacturer to make adjustment supply adaptively.

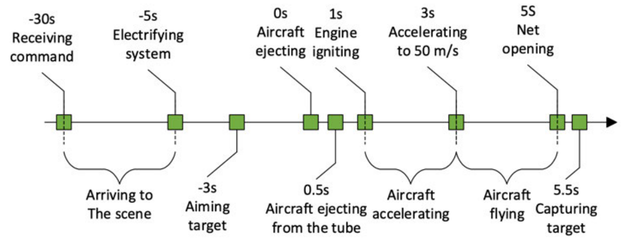

FIGURE 8. Time flow of SWCM to execute tasks.

V. TASK FLOW PLANNING AND EXPERIMENTAL VERIFICATION

A. TASK FLOW PLANNING

The time process of anti-MUAVs weapon system performing work tasks is planned as shown in Figure 8:

At -30th second, the operator receives command and arrives to the scene. After the operator finds the target visually, the intelligent micro flying net-catcher is put on the shelf and the system is de-insured and started-up. The seeker starts to work and transmits the target and interference image from the CCD camera to the sight. After the aircraft self-checks and revises the initial state parameters, the system returns the ‘‘good state’’ signal enters the standby state.

At -5th second, the operator searches, aligns and confirms the target more accurately through the optical sight. And then the operator displays the capture contour of the target and displays the launch aiming ring on the sight.

At 0th second, the operator points the launch aiming ring at the target and presses the launch button. The aircraft leaves the launch tube at a speed of about 6 m/s and 30° from the horizontal angle. After launching the aircraft, the operator uses the hand-held detection equipment to continue illuminating the target, guides the aircraft to the target and observes the shooting effect.

At 0.5th second, the aircraft is ejected out of the launch tube and flies by inertia for 0.5s, waiting for the engine to ignite.

At 1st second, after the aircraft is 6m away from the operator, the main engine ignites, and the aircraft accelerates. The seeker measures the angular velocity of the line of sight of the target and outputs the control command to make the aircraft fly to the target according to the proportional guidance law.

At 3rd second, the aircraft accelerates to a speed of 50 m/s and flies to the target under guidance.

At 5th second, when the aircraft is close to the target, the net will be ejected to capture the target.

At 5.5th second, the net captures the target.

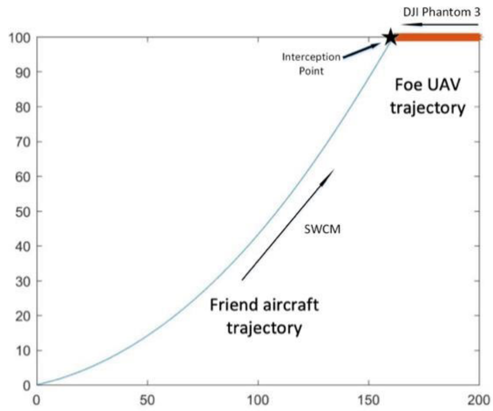

FIGURE 9. The simulation with proportional guidance coefficient = 3 of a head-on interception of MUAV.

B. NUMERICAL SIMULATION AND EXPERIMENTAL VERIFICATION

The numerical simulation of SWCM intercepting MUAVs is used to verify the experimental design. The proportional guidance method is adopted in these simulations. The basic expression of proportional guidance is shown in formula (3).

$$\dot{\theta} = k\dot{q} \tag{3}$$

In the above formula, $\dot{\theta}$ is the rotational angular velocity of the velocity vector of the missile, $\dot{q}$ is the rotational angular velocity of the line of sight, and k is the proportional coefficient. The launch positions of the friend UAV are both set at the coordinate origin. The proportional coefficient (k) of proportional guidance are both 3. The distance is in meters, and the time is in seconds.

The head-on interception simulation is shown in Figure 9. In this simulation, the foe UAV is set to fly horizontally from east to west (the right side is East), with a speed of 10m/s, a starting height of 100m and a horizontal starting distance of 200m from the launch position of SWCM. As shown in the Figure 9, the red track is the foe UAV movement route, the blue track is SWCM interception path, and the five-pointed star is the interception point.

Similarly, the tail-chase interception simulation is shown in Figure 10. In this simulation, the foe UAV is to fly horizontally from west to east (the right side is East), with a speed of 10m/s, a starting height of 100m and a horizontal starting distance of 100m from the launch position of SWCM. The marking method is the same as that in Figure 9.

In the above two interception simulations, when the SWCM is 0.1m away from the foe UAVs, the capture net is opened to capture the enemy UAVs. As shown in the above figures, the reasonable intercept trajectory curves are obtained by simulation. The SWCM intercepts the foe UAVs successfully. Through the above simulations, the correctness of the proportional guidance algorithm in the scheme is proved.

In addition, the experiment of intercepting a MUAV is designed and implemented to verify the feasibility of the scheme. The pictures of the experiment are shown in Figure 11 and Figure 12. In the experiment, the aircraft is launched and opened the capture net to intercept the foe UAV successfully. As shown in Figure 11, the SWCM is flying toward the DJI Phantom 3, which acts as a foe UAV. The captured DJI Phantom 3 is shown in Figure 12, and its body is wrapped by a red capture net. The successful interception test of the real aircraft verifies the feasibility of the scheme.

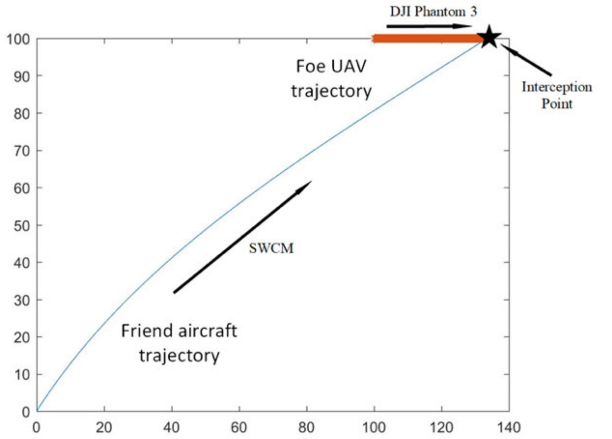

FIGURE 10. The simulation with proportional guidance coefficient = 3 of a tail chase interception of MUAV.

VI. TECHNICAL CHARACTERISTICS AND APPLICATION PROSPECTION

A. TECHNICAL CHARACTERISTICS

This scheme aims at anti-MUAVs and benefits from the development of MUAVs technology. The technical characteristics of this scheme are analyzed and listed as follows:

1) Cheaper than the equipment with similar function. Compared with the laser defense system with the same function, this scheme has lower cost, and can be equipped in large quantities on this basis, which reduces the general security cost.

2) Lightweight and portable with less restrictions on use conditions. The product of this scheme can be carried by a single person, which is convenient for storage, transfer and use. Meanwhile, it can be carried with the operator to deal with random emergencies that cannot be predicted in time and place. This scheme is applicable to multiple platforms and various places. The equipment can be launched from concealed objects, vehicles or helicopters, and then can pursue targets from these places, which cannot be achieved by similar products.

3) Able to defend against multiple targets at the same time. The program can simultaneously defend against small-UAVs, MUAVs and armed personnel, and can also be used to defend against more targets after function expansion. Compared with laser defense system, it has the advantages of less preparation time, anti-saturation attack and anti-parallel attack.

4) Suitable for soft-killing design of net-catching type. Soft-killing design is used in this scheme, which maximizes

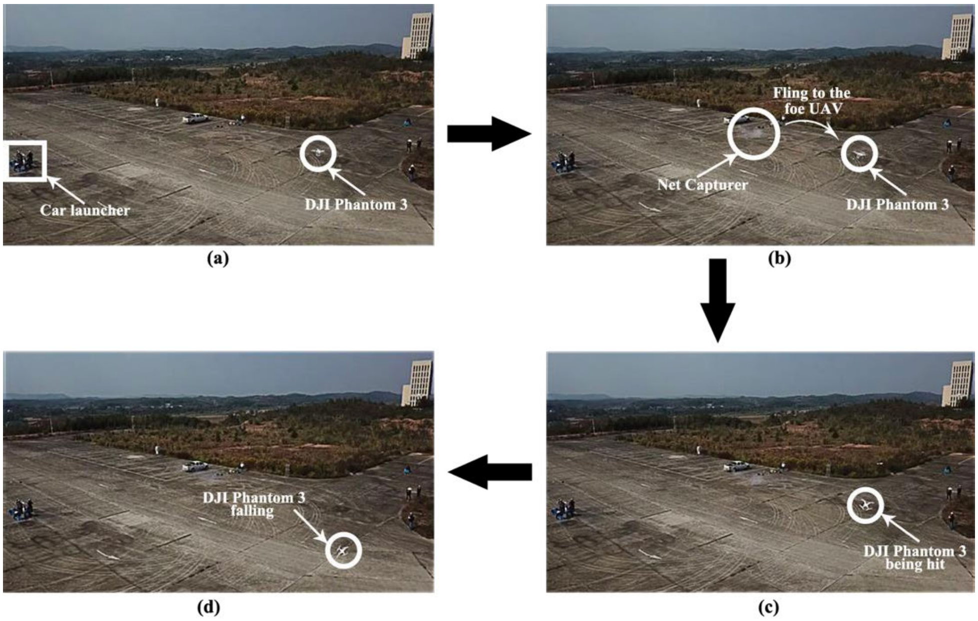

FIGURE 11. Experimental scene of intercepting UAV.

FIGURE 12. The intercepted foe UAV.

the integration of military and civilian dual-purpose tasks and minimizes the possible damage to the target UAVs and surrounding objects.

B. APPLICATION PROSPECTION

The technical essence of the portable security defense system developed in this scheme is to deliver precisely and quickly at low cost in various complex environments. Its main purpose is national security defense and public security defense. The main applications include:

1) It can be used for the security defense of major event venues such as various sports games, major conferences or crowd opportunities.

2) It can be used for security alert, patrol and emergency handling of airport defense against MUAVs.

3) It can be used for daily patrol and alert at low altitude and sea, and can be equipped randomly in re-vehicles, ships or helicopters.

4) It can be used for dealing with emergencies in public security, fire protection and urban management.

5) It can be used for high-end security and defense services of other private or corporate units.

6) It can be used for precision delivery business in other special environments such as some toxic, unmanned and geographically inconvenient places, including precise cable throwing, forest fire extinguishing, and dissemination of important items.

In particular, for the multi-coordinated UAVs system, the multiplexing technology of UAV, namely time multiplexing technology and space multiplexing technology, is considered to solve the defense problem of multiple MUAVs. The time multiplexing technology is to consider separating the guidance device from the disposable warhead and installing it on the surveillance UAV which can stay in the air for a long time. In this way, the multi batch interception task can be guided. Spatial multiplexing technology, that is, consider launching multiple capture nets at a time to intercept clusters of MUAVs. The combination of time and space multiplexing technology can effectively address the problem of multi-coordinated UAVs to a certain extent [21].

VII. CONCLUSION

In view of the severe demand that MUAVs targets such as consumer-grade UAVs frequently threaten urban low-altitude security, this article analyses the technical necessity of the development of anti-MUAVs, and then proposes an engineering, dual-use low cost technical scheme of the anti-MUAVs weapon system.

The security system based on a high-speed smart weapon is handy, low-cost, precise guidance and flexible to perform multiple tasks. The technical characteristics of the smart weapon are determined by the highly integrated information and equipment of the micro-aircraft and the special application scenarios. Main technological innovations include:

1) A low-cost smart anti-MUAVs scheme being realized by using four-quadrant image guidance in a micro-aircraft (40mm in diameter).

2) The automatic stability control design is adopted to satisfy the stability of the aircraft at low speed.

3) The soft killing scheme of net-intercepting being adopted, which is optimized and integrated into a space less than 40 mm in diameter to realize smart capture of MUAVs.

Lastly, the effectiveness of SWCM scheme is proved by simulations and experiments. The results show that the scheme of SWCM has unique advancement and good feasibility. It can be widely applied to national defense and public security defense.

In the future, based on the SWCM scheme, the research on the defense of MUAVs cluster will be carried out, which is a promising direction for future work. Through the research of MUAVs cluster defense, the scheme is optimized to deal with the complex anti-MUAVs mission requirements.

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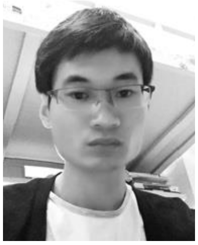
CHENG DONG was born in Yancheng, Jiangsu, China, in1995. He received the B.S. degree in mechanical design, manufacturing, and automation from the Nanjing Institute of Technology, in 2018. He is currently pursuing the M.S. degree in mechanical engineering from the Shanghai University of Engineering Science.

In graduate period, he studies UAV system and its application with the Shanghai University of Engineering Science. His research interests include anti micro UAV system development, UAV system integration, and application.

He has obtained three practical new patents, and another invention patent is being accepted.

CHAOFENG LIU was born in Hainan, China, in 1978. He received the Ph.D. degree in fluid mechanics with Fudan University.

He is currently an Associate Professor and a Master's Supervisor with the Shanghai University of Engineering Science. He has been involved for a dozen years in fluid-solid-thermal coupling calculation, mechanical and electrical equipment manufacturing, and aircraft design.



JIE LIU is currently pursuing the M.S. degree in aircraft design from the Shanghai University of Engineering Science, Shanghai, China.

His current research interests include aircraft design and urban defense systems.

NIMIN ZHOU received the B.S. degree in mechanical engineering and automation from the Liaoning University of Science and Technology, Anshan, China, in 2014. He is currently pursuing the M.S.Eng. degree from the School of Mechanical and Automobile Engineering, Shanghai University of Engineering Science, Shanghai, China.

His research interest includes the development and application of high-rise curtain wall cleaning robot.

HANG ZHANG is currently pursuing the M.S. degree with the Shanghai University of Engineering Science. His major is mechanical manufacturing and automation.

He is committed to mechanical manufacturing and automatic control system. His current research interests include cleaning robot and dynamic load analysis.

TONG FANG received the B.S. degree in fashion design and engineering from the Shanghai University of Engineering Science, in 2018, where he is currently pursuing the M.S. degree with the School of Mechanical and Automotive Engineering.

His research interests include high-rise curtain wall cleaning robot and airborne bullet continuous launching devices.

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