Development of an Embedded System-Based Dropper Payload for Drones

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***Abstract*— Echinococcosis hydatidosis is a chronic disabling disease of parasitic origin that constitutes an exemplary case of one-health. According to data from the national epidemiological bulletin, is one of the most important zoonoses in terms of the number of cases, severity, and economic costs in Italy. This paper aims to contribute to the prevention of the spread of this infection by proposing the development of an embedded system on a drone that can release decoys containing canine medicine. To this aim has been chosen a microcontroller, which is responsible for interfacing and controlling the different peripherals required to accomplish the release of decoys from the custom payload. In addition to the hardware part of the embedded system, has been implemented an ad hoc program that is able to coordinate all the elements, satisfying the proposed purpose. In particular, suitable software architecture has been implemented by means of an ARM-Cortex microcontroller not only for the advantages related to size, cost, and power consumption but also to exploit their high-performance and safety requirements.**

Keywords*— Echinococcosis, canids, GPS, UAV, drone embedded system, dropper payload.

I. Introduction

Echinococcosis hydatidosis is a complex infection caused by the larval stage of a tapeworm belonging to the genus Echinococcus granulosis. It is a small, flat, ribbon-like worm whose head may be characterized by hooks and suckers that are used to adhere to the intestinal walls during infestation [1]. The tapeworm has no digestive system and feeds by osmosis, absorbing nutrients already digested by the infested organism. To develop, these parasites need hosts. Two types can be distinguished: definitive and intermediate. Definitive hosts are those in which the parasite becomes an adult, while the intermediate hosts are those in which the larval form develops and generates fluid-filled cysts (hydatid). In the first, the adult form settles in the small intestine, and in Italy, the infection mainly affects dogs (especially herding dogs or stray dogs) but also foxes and wolves. In intermediate hosts, on the other hand, the hydatid is localized mainly in the liver and lung and affects mainly sheep, cattle, pigs and buffaloes [2]. Man is also an intermediate host. Certain human activities, such as the rural practice of feeding the entrails of slaughtered animals to dogs, have caused the parasite's biological cycle to be prolonged over time. Once ingested, the cysts hatch, giving rise to the parasite that develops to the adult stage. The latter will produce eggs that are then excreted by the infected dog through faeces, contaminating the external environment (water, food and soil). Consequently, intermediate hosts become infected by ingesting contaminated food. Here, the larvae penetrate through the intestinal mucosa and reach the circulatory system, which enables them to reach the liver and lungs (80% of cases), or the organs in which the cyst will develop [3].

The disease is transmitted to humans from definitive hosts (dogs) either directly, through close contact, or indirectly, by ingesting infested food. If for animal species the infection is asymptomatic, for humans the symptomatology is variable: from the absence of symptoms, it can reach very serious form (in 1-3% of cases the outcome is fatal) and this depends on the organ in which the cysts are localized. Their sudden rupture can also cause anaphylactic shock and in children, patients most at risk, cause intracerebral damage. The treatments that are necessary in case of an established disease are often long and costly, affecting the economy of the health care system and the families caring for their loved ones, and the quality of life of individuals with Echinococcosis (EC) is severely compromised [4], [5].

According to statistical data, Echinococcus granulosis is the most widespread species: it accounts for over 95% of human cases with estimates of 2-3 million affected worldwide and is the second most common zoonosis in Italy in terms of hospitalization [6].

Similar dropping systems have been developed in the literature and find application in various fields. For example, in [7] an ambulance drone capable of dropping any type of rescue kit, i.e. not only defibrillators as is the case in the current scenario [8], has been realized by exploiting the dropper system. Another example is shown in [9] where such technologies have been applied for precision agriculture through the use of an Autonomous Multifunctional Quadcopter drone [10] that can monitor plantations, spray water and plant new seeds with the aim of reducing human effort [11]. In [12] has been used an application of a dropper system on drones for the pick-up or delivery of small items (4-6 kg) from/to the homes of people quarantined due to diseases such as Covid-19 [13]. This solution makes it possible to completely avoid contact with infected persons and at the same time ensure what they need.

Reducing the spread of EC infection is therefore of great importance. To this end, in addition to complying with hygiene regulations and carrying out strict controls on sheep farms and slaughterhouses, an embedded system mounted on a drone, which allows the controlled release of baits containing the medicine for stray canids, was developed with the department of veterinary medicine of the University of Naples Federico II. This is advantageous because it makes it possible to cover large areas, even those that are difficult to access.

The system implemented involves using a DJI Flame wheel F550 drone equipped with a mechanical part (dispenser) made by 3D printing and suitably mounted to the drone frame. The system is then connected to a servo motor, which enables its rotation, controlled by a microcontroller (STM32F401 Nucleo-64), which has been appropriately programmed to perform the required operations:

- Step 1: control of the drone's power supply for safety reasons;
- Step 2: servo motor position correction for correct alignment of the dispenser with the discharge window;
- Step 3: payload loading in the appropriate sectors of the device;
- Step 4: drop payload in flight.

II. Hardware Architecture

The terminology embedded system tends to refer to the set of hardware and software dedicated to specific purposes whose elements are all integrated and embedded [14].
This section provides a detailed description of the hardware components used to realize the architecture of the proposed system.

A. DJI Flame wheel F550

The drone on which the embedded system is installed is the DJI Flame wheel F550. It is a hexacopter characterized by a flight time of 25 minutes, a maximum speed of 80 km/h and a range of 2km at 500m height. Its structure is made of carbon frame with an optimized frame design, in fact there is plenty of space for the assembly of autopilot systems. The 6 arms are made of ultra-strong material, specifically PA66 +30GF (semi-crystalline thermoplastic material derived from polyamide 66 with 30% glass/graphite fibre added) providing high impact resistance [15].

Thanks to the multi-axis control platform, Naza M-V2, there is excellent flight stability and maneuverability. In fact, its design integrates inner damping, controllers, 3-axis gyroscope, 3-axis accelerometer, and barometer. In addition, it can measure flight attitude and thus can be used for autopilot/automatic control [16].

B. Radio control and receiver

What allows the drone to be steered in control is the radio control (with its receiver), which uses radio waves as the transmission medium. Usually, a radio control is of the proportional type, and to transmit the signal, among the various existing systems, is used a pulse width modulation (PWM), which is a particular technique of transmitting electrical or electromagnetic signals that makes it possible to obtain a variable average voltage dependent on the ratio between the duration of the positive pulse and the entire period (duty cycle) [17]. In practice, a train of pulses is transmitted, one pulse for each available channel, the duration of which depends on the position of the relevant control lever. The number of channels, i.e. controls, available varies depending on the complexity and cost of the type of radio control [18].

The model used for the proposed project is the FrSky Taranis X9D Plus with X8R mode receiver, with a 2.4 GHz band. It has 24 channels with a faster baud rate (variation per unit time of the signal on a transmission channel) and lower latency. Moreover, due to the presence of the spectrum analysis function, it is possible to check radio waves for inference [19].

C. STM32F401 Nucleo-64

STM32 is a family of microcontrollers created by STMicroelectronics based on ARM M profile cores, whose peculiarity is that they have high performance and are extremely versatile, making them widely used in embedded system projects. In this work, the STM32F401 Nucleo-64 electronic board was used.

The STM32F401 is the brain of the entire project and simultaneously coordinates all components that are part of it via the various connection interfaces.
The main features of the series are:

- Header compatibile con Arduino UNO V3;
- Header Morpho, ST extension for full access to STM32 I/O;
- USB 2.0 port that has three main functions:
    - Programming/debugging with ST-LINK/V2.1;
    - Virtual COM port;
    - Mass storage (USB disk drive) for drag-n-drop programming;

- Flash memory of 512 kb and 96 kb SRAM;
- Input/Output:
  - 50 general purpose I/O pins (GPIOs);
  - 12 bit ADC (Analog-to-Digital Converter) with 16 channels;
  - 7 general purpose timers;
- It has one user-programmable LED (LD2), one LED for power supply (LD3) and one LED to monitor USB communication (LD1);
- Has a user-operable button (USER BUTTON) and a reset button [20].

The heart of the board is the ultra-low-power ARM Cortex-M4 core with 32-bit ARM (Advanced RISC Machine) architecture and a frequency of 84 MHz. It is an integrated electronic device on a single chip that interacts with the outside world via a programmed residing in its internal memory and through the use of specialized or programmer-configurable pins. This type of MCU offers advanced performance in digital control; in fact, it makes it ideal for DSP (Digital Signal Processing) applications and is characterized by low power consumption, high speed and operational simplicity [21].

D. Servo C5077 Graupner JR and dispenser

A 4.8V Graupner JR C5077 servomotor capable of 3.60 kg-cm torque with a speed of 0.15 sec/60° was used to allow the rotation of the dispenser and, consequently, the 'drop' of the baits [22]. This device therefore controls the rotation of a motor through a control circuit that regulates the angle. Again, the control is done via a PWM signal by adjusting the length of a square-wave pulse sent to the servomotor. Depending on the duty cycle, the angle of rotation will vary with a duty cycle of 50% the motor pivot will be positioned at 90° (which is exactly half the possible rotation range) while with a duty cycle of 100% we will have a rotation of 180°.
Figure 1 shows the dispenser connected to the servo in which the payload is inserted. It consists of 10 sectors, each 18° wide, and is made of 3D printing [23], [24].

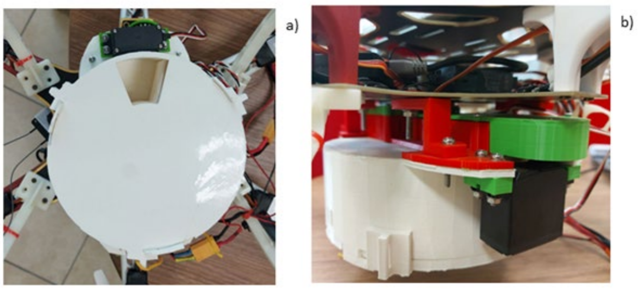

Figure 1 a) Dispenser top view; b) Dispenser side view

Figure 2 shows the entire embedded system developed. In particular, it is possible to observe the servo motor connected to the dispenser in the lower part of the frame. On the side there is the radio control and, the one circled, is the button that allows the rotation of the servo and consequently of the dispenser.

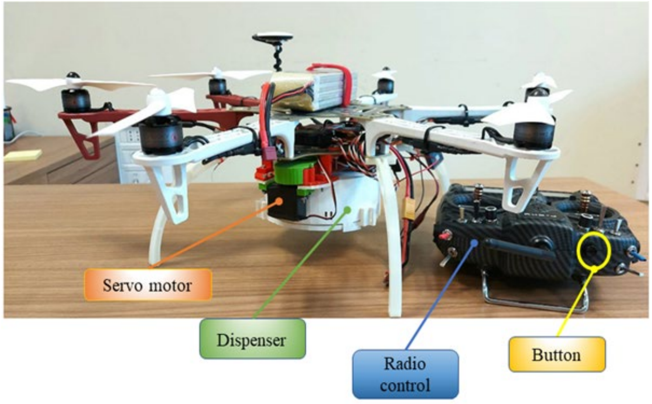

Figure 2 Embedded system on drone

III. Software Architecture

This section illustrates the development of the operating software that enables the STM32F401 Nucleo-64 micro-computer to coordinate all the hardware components connected to it, as described above, and to manage all incoming data by exploiting the connection technologies at its disposal.

A. Integrated development environment

An integrated development environment (IDE) is used to write the programme. This environment is designed for building applications that aggregates common development tools into a single graphical user interface. It is generally composed of a text editor in which the software code is written; tools that allow the automation of simple processes such as the compilation of source code into binary code (automation of the local build) and, finally, a tool that allows any bugs in the code to be identified (debugger) [25]. Among the many development environments that STMicroelectronics makes available, the online Mbed compiler was used, which is an IDE in C/C++ that allows you to write, compile and download code and run it directly on the board quickly. Moreover, being online, it has the peculiarity of being a lightweight but at the same time very powerful software as it uses the professional Arm-compiler engine [26].

B. Code implementation

The software code developed for the realization of the "*Dropper payload*" mission consists of four main steps:

- Checking drone powered off;
- Trim mode;
- Charge mode;
- Drop mode;

1) Checking drone powered off

For safety reasons, the first phase of the code is dedicated to checking the system's power supply. In particular, it is necessary to check that the drone is powered off and that, therefore, only the part relating to the microcontroller is powered in order that the subsequent phases, trim and payload, take place without the risk of accidental activation of the device. To achieve this control, a cyclic command is used in the implementation of the code: until the system detects the drone in the ON state, the LED1 (red LED) blinks repeatedly. As soon as the drone is switched to the OFF state, the loop is exited, LED1 lights up steadily and it is possible to proceed to the next step.

2) Trim mode

Due to the accumulation of small errors during dispenser rotation, the first sector of the latter may not be perfectly aligned with the payload unloading window. This mode therefore allows the position to be corrected by increasing or decreasing (depending on the position of the switch) the angle of rotation of the servomotor by a very small amount (relative to the width of the entire sector). In this regard, the code takes care of reading the state of the switch: having verified that it is not in the "*run*" state (center position), one can have either the "*trim plus*" state (top position) or the "*trim minus*" state (bottom position). In both cases, if input from the local button is detected, there is a shift of +0.005° (trim plus) or -0.005° (trim minus) respectively. This can be repeated until the correct alignment is achieved.

3) Charge mode

At the end of trim mode, if the switcher is in run mode, both LEDs light up, indicating that you are in charge mode. At this point the code again checks to detect the signal coming from the local button: each input corresponds to an 18° displacement (sector width) of the dispenser, which allows the payload to be inserted within the sector. Loading ends when the last position, i.e. the maximum position of the servomotor (180°), is reached.

4) Drop mode

This phase consists of releasing the payload in flight. In order to do this, however, it is necessary to check the drone's power supply again, which this time must be set to ON, so a cycle is used in which LED 1 flashes until the drone is turned on. Once the device is switched on, the code must then check for the presence of the signal from the radio control (RC) and simultaneously the input signal from the unlock button (sbl). Each time the RC button is pressed, there is a rotation of the dispenser by 18° in the opposite direction to that carried out during the charging phase, resulting in the load falling to the desired point. When the servomotor reaches the minimum position (i.e. from 180° to 0°) both LED1 and LED2 flash, indicating the end of the drop phase and, consequently, of the entire mission. At this point, the drone is ready for re-entry, and it is possible to restart the entire cycle, starting from the first phase.

For sake of the clarity in Figure 3 is shown the software flowchart, which is a graphical representation of the sequential operations that the microcontroller must perform in order to execute the developed algorithm.

IV. Conclusion

This work aims to develop an integrated drone-based system capable of releasing baits containing medicine for canids on command, which represents an innovative solution to combat the spread of Echinococcus infection. In fact, the proposed system is able to cover large areas in less time, even those that are difficult to access. In this work, we focus attention on the realization of the electronic circuit and the programming of the microcontroller chosen, creating an algorithm capable of coordinating all the components connected to it.

As STMicroelectronics is a global leader in semiconductors, the choice of the microcontroller belonging to this family has brought many advantages to the system. In fact, the STM32F401 Nucleo-64 board guarantees higher performance, in terms of microprocessor, RAM memory and energy consumption, and is capable of handling applications of greater complexity [27], [28]. In addition, the code developed for this type of micro-computer has the advantage of being suitable for all STMicroelectronics microcontroller families that include an automotive and aerospace version, such as, for example, the Stellar integration MCU family. These not only have higher-performance characteristics, but also meet the requirements in terms of safety and security so that they can also be used in new-generation autonomous vehicles such as drones [29], [30]. This paper presents a preliminary architecture design for Unmanned Vehicles used for filming in GNSS-challenging scenarios. A tactical-grade MEMS IMU can be used with a RTK unit to allow the drone to perform self-localization with centimetric accuracy, implementing a Kalman Filter prediction-correction algorithm for data fusion [31]–[33]. A 5G radio-modem can be used during GPS outage periods or in case the signal is partially degraded.

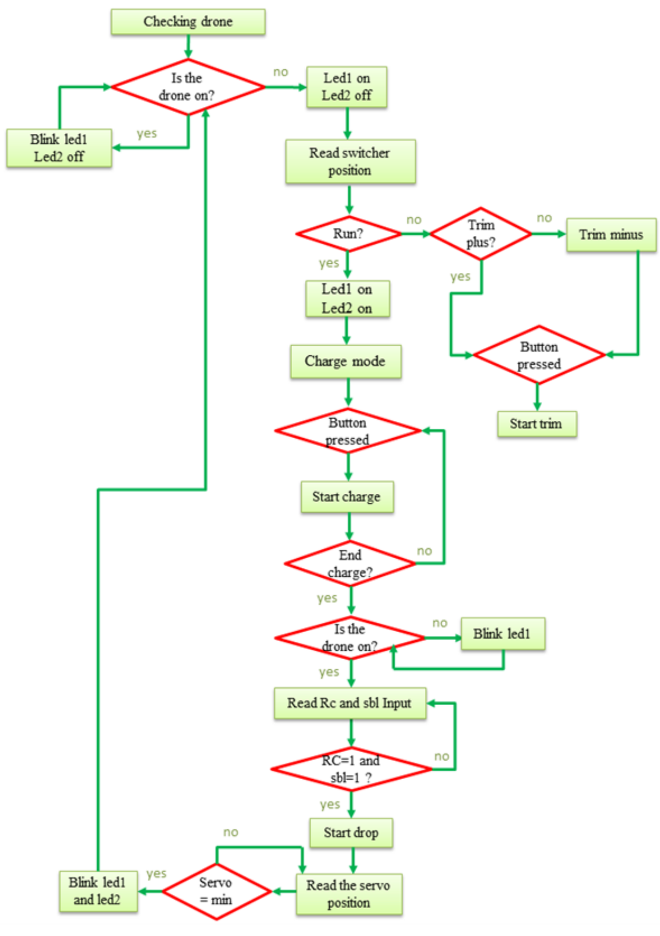

Figure 3 Flow chart code

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