

Unmanned Aerial Surveillance System*

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Abstract

In this paper, one presents an Unmanned Autonomous Surveillance vehicle which has a wide range of applications in dangerous activities in the military or police. They are also frequently used in civilian areas for sports, social, or agricultural activities. The main reasons why one chose this topic are: the intersection of different research fields necessary for the realization of this project, such as aerodynamics, systems theory, electronics and programming, the usefulness of these systems in solving dangerous situations, autonomous drones represent the future in the development of human society and civilization.

Keywords: Drone, Microcontroller, Quadcopter, PixyCam2, PID, PWM Signal, UAV, UAS.

Introduction

Known by the acronym UAS (used to designate an aerial system without a human pilot on board), robotic aerial systems, in the general sense of the title, encompass both the vector itself and the equipment that is placed on board it. Together they execute the specific missions for which they were built and designed. They can operate either by remote control from a ground station or autonomously.

An unmanned aerial vehicle (UAV) is also known as an unmanned aerial system (UAS) or as a remotely piloted aircraft (RPA). As previously stated, it is an aerial machine that operates either by remote control by a pilot and/or navigator, or autonomously.

We live in a world where technology is advancing at an astonishing speed. Innovations in this field are experiencing exponential development. In this context, in recent years, the notion of drone has become an extremely popular term.

The term drone comes from the English acronym DRONE – Dynamic Remotely Operated Navigation Equipment. When we refer to drones, we are actually talking about aerial vehicles without a human pilot on board. In the specialized literature, drones are most commonly known as UAV – Unmanned Aerial Vehicle, UAS – Unmanned Aerial System, or RPAS – Remotely Piloted Aircraft System.

An unmanned aircraft (uninhabited aerial vehicle - UAV), also known as a drone, is an aircraft that lacks a human pilot, being guided either by a digital autopilot on board, or by remote control from a ground control center or located in another piloted aircraft. Drones are used in the military field, rarely in the civilian field. They carry a payload on board. Military drones are used for reconnaissance, surveillance, espionage or combat purposes. Depending on the purpose, their payload is reconnaissance equipment and/or weapons.

Types of Drones

In general, drones are classified by their flight mechanism:

- Fixed-wing. They have one wing or a pair of horizontal wings with a single engine and can fly at very high altitudes. Taking off and landing these types of drones is difficult and they cannot hover around a fixed point.
- Single-rotor. They are essentially helicopters and can only hover vertically in the air. They consume less battery power than multirotor systems.
- Multirotor. These are currently the most popular types of drones. They have multiple wings arranged radially with one engine on each wing. They are classified by the number of wings (tri-copter, quadcopter, hexa-copter, octocopter) and are much more stable and easier to control than single-rotor drones, but their energy consumption is much higher.

Similarly, we can categorize drones by the mission they perform:

- Military. They perform very dangerous attack missions and are known as Unmanned Aerial Vehicles. Structurally, they are like airplanes and are loaded with air-to-ground missiles to eliminate their target.
- Logistics. They are used by companies like Amazon for package deliveries.
- Surveillance. They collect information in a guided or automatic manner and usually return to base. Most of these drones are quadcopters or tri-copters equipped with a high-resolution camera.
- Civilian. These drones are for general use in construction, agriculture or in various scientific fields for data collection.

Drones Today

Operating a drone in flight is done either autonomously, using navigation equipment and equipment installed on board, or by an operator on the ground who transmits commands via satellite or radio frequency.

UAVs are fixed-wing and rotor-bearing. Usually, the devices are used in special military operations. But, nowadays, they are also used in an increasing number of civilian activities: surveillance missions carried out by law enforcement, perimeter security, detection of illegal hunting, assistance in extinguishing fires, securing borders, landslide measurements, monitoring incidents involving crowds of people, inspection of large-scale industrial facilities of strategic interest, large buildings and constructions, oil and gas pipelines, inspection of continuously operating flow equipment in quarries (in order to monitor temperatures in the area of high-friction bearings, by using thermal imaging cameras), inspection of petrochemical facilities (in order to detect cracks, fissures, leaks that may occur in pressure vessels, by using thermal imaging cameras), etc.

Remote sensing functions of drones include sensors from the electromagnetic spectrum, gamma ray sensors, biological sensors and chemical sensors, as Towaha S. O. F. (2018) said.

Electromagnetic sensors include the visual spectrum, infrared or near-infrared cameras, as well as radar systems. Other electromagnetic wave detectors, such as microwave sensors and ultraviolet spectrum, can also be used. Biological sensors are sensors that can detect the presence of various microorganisms and other biological factors in the air. Chemical sensors use laser spectroscopy to analyze the concentration of each element in the air, according with Patric P. C. and Popa I. F. (2021).

Currently, the development of UAVs is redefining the concept of geo-intelligence (information products resulting from the analysis and exploitation of aerial and satellite images of the Earth's surface) as well as the concept of air power. Today, in an active military environment, a UAV can record over 2,000 hours of operation per year, while a fighter jet with a human crew on board records a maximum of 400 hours of operation, and the difference is growing exponentially.

Today, a UAV possesses almost all the strengths characteristic of a manned aircraft, to which is added the overcoming of some physiological and physical limits of the pilots. Also, the risks to which humans are exposed are completely avoided. The absence of a pilot in the cockpit allows UAVs to reach the highest level of performance, increasing the size of the payload carried on board (camera, sensors, weapons), the flight ceiling and maneuverability.

In a research study by Stamate M. A. (2020), the components of a Quadcopter are:

- The frame. The battery, motors, propellers and electronic components are attached to this. Preferably, it is a frame made of a light but very resistant material. A commonly used material is carbon fiber, but a plastic frame can also be used for a budget.
- Lithium-Polymer (LIPO) battery of 11.1V (3 cells in series) or 14.8V (4 cells in series). A cell of this battery uses polymer-based electrolyte making this type of battery very light and releasing a much higher current at a nominal voltage of 3.7V than that of conventional Nickel-Cadmium batteries. Due to the chemistry of the elements from which it is built, the LIPO battery is very volatile and can cause a fire or explosion if it is pierced and comes into contact with oxygen in the atmosphere or water.
- Four brushless DC motors. These are usually made up of a stator with electromagnets electrically switched by an external circuit and a rotor composed of a permanent magnet. A Hall effect sensor is usually found on the stator to determine the position of the rotor.
- Electronic Speed Controllers (ESC). It is an electronic circuit that allows the switching of electromagnets in a brushless DC motor using MOSFET transistors that function as switches in the current path. An ESC is usually controlled by a PWM signal with a frequency of 50 Hz with 1000 and 2000 microseconds meaning the throttle is at 0% and 100%, respectively.
- Flight controller. It is a microcontroller that controls all aspects of the drone's flight. Its main role is to implement in software the program that will stabilize the vehicle in the air (using the sensors provided) and to guide the drone via GPS to the destination given by the human or artificial operator. It must have at least a gyroscope to measure angular velocity and an accelerometer that measures linear acceleration to determine the attitude (orientation) of the drone relative to the direction of gravity.
- Radio receiver/transmitter. It usually uses the 2.4 GHz radio band to allow commands to be transmitted by a ground control station. Frequency hopping is usually used in the transmission of this radio signal to eliminate the possibility of interference with other operators using the same radio band. The command is transmitted from the receiver to the flight controller through multiple PWM signals (for each channel), a single PPM signal, or serial communication through an IBUS or SBUS bus, .

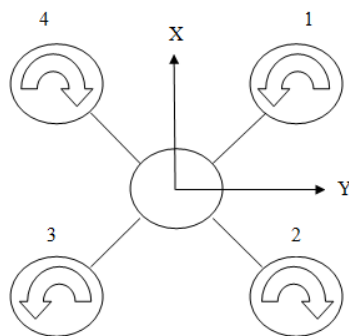


Fig. 1. The "X" configuration of a Quadcopter

Finally, for the drone to stabilize around a fixed point, a position control block must be implemented (so that the drone maintains its position in the XY plane in the event of external atmospheric forces) and an attitude and altitude control block, as one present in Fig. 1 from above. Because we can control the lift, roll, pitch, and yaw motion independently, we can create a set of four decoupled controllers for the second control block to control these system states. The pitch and roll controllers must be cascaded with the position control block because the drone must perform a roll, pitch, or a combination of these movements to oppose external forces that deviate it from the reference position, as Rajesh R. and Baranilingesan I. (2020) mentioned. It is necessary for the position control block to estimate the yaw because the reference position is given according to the Earth's inertial position system and the only rotation that controls any direction in the x and y coordinates regardless of the drone's position relative to its own system is the yaw. This together with the reference position is used to generate the first roll and pitch command which will be cascaded with the estimated system states, as Katsuhiko O, (2003) mentioned.

Below, in Fig. 2 is presented the control diagram of a drone:

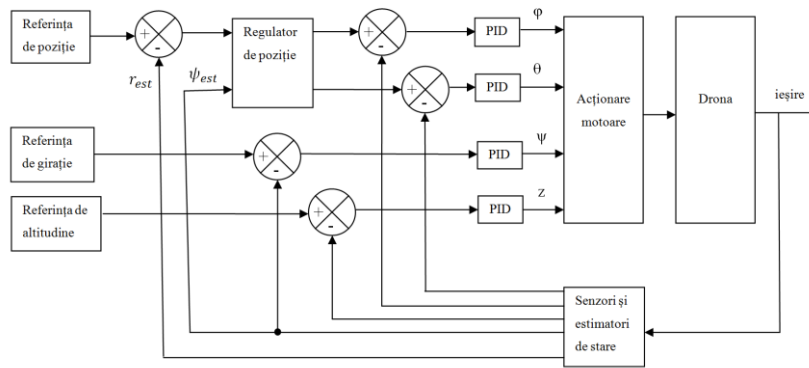


Fig. 2. Control diagram of a drone

Quadcopter Implementation - Electrical Schematic and Components Used

In a research study by Burlea I. E.. (2021), it shows the main component of this scheme is the Arduino development board to which the devices necessary to make the quadcopter operational are connected. The development board is powered by a 12V battery whose positive terminal is connected through a protection diode to the Vin pin of the Arduino. The 12V voltage of the battery is reduced to a working voltage of 5V by the internal voltage regulator. In parallel with the battery is attached a voltage divider which is connected to A0. This is used to transform the battery voltage range from [0.12] to [0.5] V in order to be able to measure the battery voltage through the A0 pin which accepts a maximum of 5V. The value of the resistors that make up the voltage divider are 1.33k Ω and 1k Ω which, when we consider the diode voltage drop, will reduce the maximum battery voltage to 5V. The user is warned when the battery needs to be recharged by the indicator LED in series with the resistor R1 and connected to pin D9 of the Arduino, as one presented in Fig. 3.

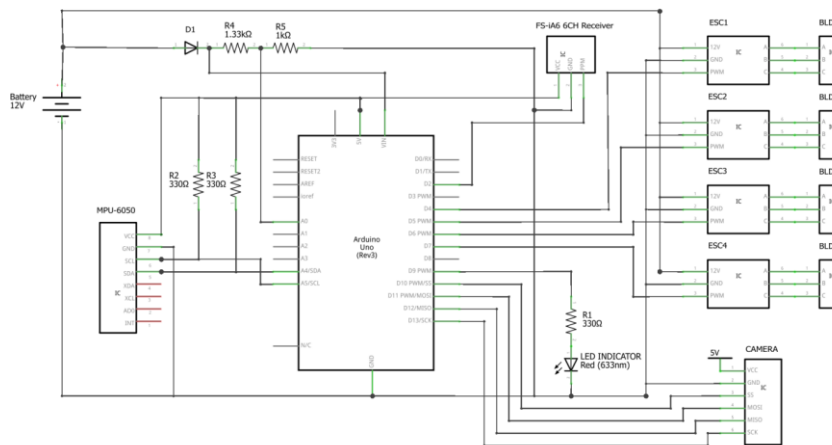


Fig. 3. Electrical diagram of the quadcopter components

The MPU-6050 module is powered by 5V from the Arduino through the Vcc pin. Communication with this device is carried out through pins A4 and A5 which are connected to SDA (Serial Data) and SCL (Serial Clock) on the sensor. The I2C bus specifies that the communication lines must be pulled up through resistors because bit 0 is transmitted when the voltage on SDA is high and SCL is pulled to ground by a transistor. To transmit bit 1, both lines are pulled to ground.

The receiver and the camera are powered by 5V from the Arduino. The receiver is connected to pin D2 to communicate with the development board via a PPM signal. Communication with the video camera is carried out through an SPI (Serial Peripheral Interface) interface. Pins D10, D11, D12 and D13 on the Arduino correspond to the SS (Slave Select), MOSI (Master Output Slave Input), MISO (Master Input Slave Output) and SCK (Slave Clock) inputs and outputs of the SPI bus.

List of components used in the assembly of the quadcopter:

- Frame: DJI 450
- Power supply: Gens Ace 3S1P 2700mAh 35C
- Motors: A2212 1000 KV
- ESC: 30A panel / 2A BEC Brushless Control
- Propellers: 1045 L/R
- Flight controller: Arduino Uno
- Transmitter/Receiver: FlySky FS-I6 with FlySky FS-IA6 receiver
- Inertial measurement module: MPU-6050 gyroscope/accelerometer
- Camera: PixyCam2 with object detection integrated circuit

Assembly of the Drone

The drone components are mounted on a DJI 450 frame with a weight of 394 grams and dimensions of 5.08 x 15.24 x 25.40 centimeters. This frame contains a power distribution board (PDB) for the 4 motors and the electrical components used, according with Fig. 4.

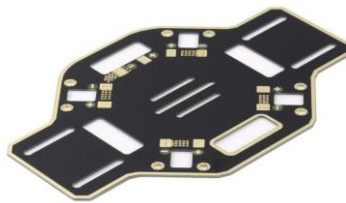


Fig. 4. Power distribution board

Power is provided by a Gens Ace 3S1P 2700mAh 35C battery which is fitted with two wires containing T-type power plugs (the wires have a relatively large diameter to withstand high current intensities) and a set of 4 plugs with small diameter wires to measure each cell individually (for n cells $n+1$ plugs are needed). It is connected to the PDB via a T-type plug/pin pair. The battery is charged with a special IMAX B6 Lipro Balance charger which uses the BALANCE function to ensure the maximum voltage of 4.2V on each cell, as one shows in Fig. 5 and Fig. 6. When not in use, the battery must be discharged using the STORAGE function to reduce the voltage on each cell to approximately 3.8V. If this long-term storage voltage is not ensured, the battery can quickly deteriorate, as Liang O. (2020) said.

The BLDC motors are mounted on the frame arms along with the ESCs, and gold-plated plug/pin connectors are soldered onto their wires to make it easy to replace these motors if necessary. Before mounting the propellers, they must be balanced to prevent the center of gravity from shifting and the propeller from generating large amplitude oscillations. These oscillations can cause erroneous data readings in the inertial sensor module. The propellers are then mounted on the motors in the “X” configuration shown in Fig. 1. The direction of rotation of each propeller must also be checked, usually symbolized by the L/R symbol that corresponds to a CW/CCW propeller (clockwise or counterclockwise, respectively). If this symbol is not written, the curve on the propeller that creates the air pressure difference must be followed to discover the direction of rotation.



Fig. 5. LIPO battery



Fig. 6. Charging the battery using the BALANCE function

After mounting the propellers, the correspondence of the motor's rotation direction with that of the propeller is checked. If these do not match, the motor's A and C power wires can be twisted to reverse its direction of rotation, as one present in Fig. 7.



Fig. 7. Motor and propeller assembled on the arm

I2C communication is a type of half-duplex synchronous serial communication (non-simultaneous bidirectional communication) that requires two transmission channels, SCL (Serial Clock) and SDA (Serial Data). When the channels are inactive, they are pulled high by pull-up resistors. To achieve this configuration, two resistors are connected separately from SCL and SDA to VCC.

The microcontroller used as the flight controller is the Arduino Uno. The microcontroller is powered by power cables from the 12V battery in the Vin pin of the device, according to the Fig. 8 and Fig. 9.

The battery voltage must be known by the program in order to warn a human operator when the battery is depleted and the drone must stop its activity to avoid damaging the battery. The battery voltage must also be known in order to compensate for the speed of the motors when the battery is very low. The battery voltage reading is done through a voltage divider that brings the maximum working voltage of the 12V battery to a value of 5V that the Arduino can read through the A0 pin. The value of these resistors should be approximately 1.3k and 1k ohms to take into account the voltage drops due to the protection diode.

<p>Fig. 8. MPU-6050</p>	<p>Fig. 9. Arduino, MPU-6050 and FS-IA6B receiver</p>	<p>Fig. 10. PixyCam2</p>

According with Burlea I. E.. (2021), a prototyping shield is attached to the microcontroller to make the connection with the MPU-6050 sensor easier. The flight controller is placed in the center of the drone on the frame platform. The power wires and the SDA and SCL connections with this sensor are soldered to the A4 and A5 pins of I2C serial communication, respectively. It is necessary to take into account the resistors that are attached to the I2C lines to pull these lines to voltage when they are inactive. For this project I chose to use PPM (Pulse Position Modulation) communication because it requires only one communication line, unlike PWM where one line is required for each channel. Another reason for using PPM communication is that it is simpler to

implement in this project than the serial IBUS/SBUS. To complete the connection to the receiver, the receiver's PPM signal wire is placed in pin D2.

After all these arrangements, in Fig. 11 one shows the entire assembled drone, before its first flight (Fig. 12).



Fig. 11. Assembled drone

Flight Controller Implementation - Source Code Analysis

This program is written using the C++ programming language in the Arduino IDE. The responsibilities of this program are to manage the electronic devices and stabilize the drone manually (via user commands from the transmitter) or automatically (using the image processing camera (showing in Fig. 10) to stabilize around an object). Next, we will analyze this program step by step.

```
void setup()
{
  // Activates external interrupts
  sei();
  // Listen for external interrupt INTO
  EIMSK |= _BV(INT0);
  // Trigger INT0 on rising edge
  EICRA |= _BV(ISC00) | _BV(ISC01);
  // Setting pin 9 like output pin
  DDRB |= _BV(1);
  // Starts I2C communication as master
  if (!imu.Init())
  {
    PORTB |= _BV(1);
    // Do not start if the IMU is not working
    while (1) delay(250);
  }
  // Initialize the camera
  pixy.init();
  // Starts UART serial communication with the computer at 57600 baud
  Serial.begin(57600);
  // Wait until the receiver is active and the speed is initially set to minimum.
  // Channel 3 must be approx. 1000
  while (ppm.GetChannel(3) < 990 || ppm.GetChannel(3) > 1020)
  {
    // Turns off the ESCs' audible alarm while waiting for the signal from the receiver
    SendESCPulse(1000, 1000, 1000, 1000);
    delayMicroseconds(3000);
  }
}
```

```
    // Read the battery voltage
    batteryVoltage = analogRead(0) * BATTERY_SCALE;
    // Start the loop timer
    loopStartTime = micros();
}
```

The above code comes from the main.cpp file and presents the setup() function which is called only once when the Arduino starts.

The data from the receiver must be decoded using the PPM signal which is read through the D2 pin. We cannot use a polling read because the microcontroller has to process other data during this time and cannot wait for the receiver signal each time. To solve this situation, an interrupt-based read is used by activating external interrupts using the sei() macro which sets the corresponding bit 7 in the SREG (Status Register) register.

To activate the external interrupt INT0 (which listens on the D2 pin) bit 0 must be set in the EIMSK (External Interrupt Mask Register) register. This is done by a logical OR operation and a bit shift operation to the left using the INT0 macro (which is actually the value 0).

The reference quantity is expressed in degrees per second. If the autopilot lever is not activated, then we will calculate the difference from the center of each channel and subtract from this value the determined angle that is converted to the appropriate size. This causes the drone to self-stabilize. The final value is divided by 3 for each active PID so that the motors do not reach saturation.

If we are on autopilot, then we will use the camera to determine if the object we want to track is in front of us. The object is set up in advance through the PixyMon program that helps configure the camera and view this object. The image captured by the camera is 320x200 pixels.

System Testing

During the first flight test of the quadcopter, I noticed that it had major oscillations around the reference point due to the PID coefficient values that were not optimal. Because of this, I built a drone stability testing platform, which reduced the system's mobility to a single rotational movement imposed by me. In this situation, the Arduino Serial Plotter program can be used to display the graph of the system's response over time. Oscillations are usually caused by the large value of the proportional coefficient that leads the system to overshoot. Calibration can be achieved by gradually increasing the value of the coefficients from 0. The proportional coefficient introduces a fast response (by reducing the transient period) with the disadvantage of the appearance of an overshoot in the system response. Increasing the differential coefficient makes the response anticipate the error to reduce the overshoot (it is said that it slows down the system), and introducing the integrator quantity reduces the stationary error to zero, thus allowing a controllable flight of the drone.

After testing on the platform and setting the appropriate coefficients, you can proceed to testing the quadcopter outdoors, with the mention that this can be very dangerous and flying over crowds of people should be avoided. Also, testing the autopilot mode should be done in the field at a good distance from the quadcopter or by using protective equipment.



Fig. 12. The quadcopter in flight

Conclusions

The main tasks of this project were successfully completed. The assembly stages of the drone and the design of the electrical circuit proceeded without major problems. The control program was written simultaneously with the assembly of the system. Before mounting the motors, they were mechanically balanced and tested with the part of the program responsible for issuing the PWM signal to the ESCs. Similarly, the inertial module was tested before mounting it on the drone frame to improve the estimation of state parameters using the Arduino Serial Plotter graphical visualization program.

The system can be improved by using a Raspberry Pi microcomputer that allows running artificial intelligence algorithms for decision-making without the intervention of a human operator in surveillance activities. Also, the sensor module can be improved by adding a barometer and GPS to introduce altitude, respectively the horizontal position as state parameters in the control loop. Without these additions, the quadcopter deviates from its horizontal position relative to the Earth when external forces, such as wind, act on it. Obstacle avoidance can use ultrasonic sensors or video cameras that use image processing algorithms to detect the distance to potential obstacles in each direction.

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