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On the development of an autonomous hexacopter drone for animal detection and collision avoidance system

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ABSTRACT

Traffic accidents caused by collisions with animals are a significant global concern for authorities. The economic impact is substantial, including costs for treating injuries, rehabilitating victims, repairing vehicle damage, and addressing fatalities. As a contribution towards finding a solution, a wireless sensor network (WSN) and an autonomous, power-efficient, and economically feasible drone are presented. WSN is responsible for acquiring relevant information from the farm and communicating the data to the aerial drone denoted as a hexacopter; which is functioning as a mobile roadside device for transferring the warning information to the passing drivers so as to avoid any collision with animals. The proposed system involves the design of a lightweight camel-based sub-system to trigger drones for monitoring herds, a drone-based sub-system for tracking and ensuring safety in agricultural areas, and a vehicle-based sub-system to communicate collision warnings where an alarming protocol has been developed. The whole system has been designed, implemented, tested, and verified in an actual flight test. Experimental results indicate that the system has a unique capability. It can mitigate the number of accidents involving vehicles and animals, especially camels, and thus reduce the economic cost of damages associated with the problem.

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1. INTRODUCTION

Traffic accidents resulting from the collision of vehicles with animals have been attracting massive attention from researchers. In the United States, hundreds of studies were conducted and the results indicated that 90 percent of animal-vehicle collisions involve deer [1]. Studies also indicated that vehicle-animal crashes occur on rural than urban roads. Regardless of the location of crashes in the United States, studies also indicated that collisions were estimated to cause 211 human fatalities and over one billion dollars in property damage every year [2]. Similar numbers are available from Europe, Canada, Australia, and the Middle East. Collisions in these countries usually involve deer, camels, and kangaroos, where animals die immediately after the collision. Historically, the problem of collisions between animals and vehicles has been addressed through several techniques such as warning signs. Such techniques are limited in number and appear to have only a limited effect on drivers. Recently, new alternatives have been tested and approved by several countries. Accident-avoidance systems, as an example, were designed using global positioning system (GPS) technology [3]. Such systems are divided into two types: animal detection systems and animal warning systems. Animal detection systems are located on the roads and used to detect large animals as they approach the road. When animals are detected; signs are activated and warn drivers. On the other hand, animal warning systems are also located on the roads and used to detect vehicles (not animals). When vehicles are detected, animals are alerted through audio signals.

Another alternative is to track and monitor animals by acquiring information about their status, movements, and activities in their natural habitat. The animal's position, velocity, acceleration, and heading are the primary forms of information that need to be obtained and tracked by the owners. In this regard, GPS technology [4], [5] was implemented to detect such information and then send it out to the dedicated global system mobile (GSM) servers. Such servers have the capability to warn the vehicle drivers through short message service (SMS) messages. The system warns the vehicle to slow down in order to avoid a collision with animals. Recently, GPS based collars [6] along with communication modules have been used a lot in monitoring an animal's movements and also in assisting engineers to identify where fencing should be constructed as well as in helping to decide the placement of crossing structures. The above technology requires an assistance system to help the drivers in applying the necessary action to avoid collision with an animal. Consequently, with the advances made in the development of unmanned aerial vehicle (UAV) technologies, drones are considered to have significant potential in monitoring animals in their habitat. Drones also have the potential to record their locations and then communicate them to their owners. The concept of such assistive technology is that a small drone equipped with an autopilot system, GPS, telemetry radio, and an additional computer system such as Raspberry Pi, is launched above the herd. The drone will fly a preprogrammed, systematic search pattern and then begin forwarding its data. Existing drones can be classified according to size, payload, control system, flight range, and altitude. Applications like the one we propose require the use of a small drone with a light payload which can cover relatively short distances and are only able to fly missions over short periods of time and at low altitudes. Such a solution could be revolutionary, in particular for farms that are very big and have a large number of animals.

The core objective of this research is to present the design and implementation of a pioneering system that can mitigate the number of accidents involving vehicles and camels. More specifically, this project is aimed at enhancing safety on the highways and it is aimed at limiting the number of accidents involving vehicles and camels. It is focused on reducing the fatality rate as calculated through assessing the economic cost of damages associated with this problem and by monitoring and controlling camel movements while crossing the highways using an aerial system. Lastly, exploring the effectiveness of utilizing drones that function as a mobile roadside device for transferring the warning information to the passing drivers using wireless communication technology. The main contributions of the paper are: i) the design and development of a lightweight camel-based sub-system that is able to process the data and trigger the drone to fly over the herd, ii) developing a drone-based sub-system that has the ability to track, monitor livestock across a large agricultural area and makes sure that camel herds are far away from any dangerous situations, iii) designing and developing a lightweight vehicle-based sub-system that has the capability to communicate with drone and warns drivers of the potential of collision, and iv) designating a wireless network that binds together technologies and unifies them into a single data gathering system.

The remainder of this paper is organized as follows: section 2 reveals some recent research on animal-vehicle accident-avoidance systems as well as drones. In section 3, we present the main scenarios of this research. Section 4, details the system description. A simulation of the dynamic model of the hexacopter and other modeling parameters are presented in section 5. Results and discussion in section 6. Finally, we conclude and discuss future work in section 7.

2. RELATED WORK

Many works have focused on identifying, detecting, and tracking animals with various electronic devices. As an example, radio collars, and GPS are being used by the scientific researchers for tracking and controlling the movement of animals relative to a selected area. Ragab [7] presents an intelligent camel vehicle accident-avoidance system that utilizes GPS. The system is used to detect camel position, direction, movement, as well as categorizing the dangerous zones for road users. On the other hand, in tracking animals it is very important for the researcher to have a better understanding of how an animal behaves and interacts with its environment. Kim *et al.* [8] developed a system for tracking animals with the help of sensor technologies, radio frequency (RF) identification, and GPS, where their system including identifying animals and zookeepers to keep tracking of animal locations and collecting sensor reading geared towards zoological garden users. Ting *et al.* [9] designed and developed a mobile system capable of identifying the targeted animal and its behavior. The system is also based on the radio-frequency identification technology.

Turner *et al.* [10] review the application of GPS for cattle monitoring on pasture, and how GPS data can be imported into a geographic information system (GIS) to assess animal behavior characteristics and pasture utilization. Hirota *et al.* [11] proposed the use of low-cost thermoelectric infrared imaging sensors to be attached to the vehicle. The sensor picks up heat energy from the animals and enable drivers to see well beyond the range of the car's headlights.

As the technology has progressed, drones have opened new opportunities in detection and monitoring animals [12]. Linchant *et al.* [12] reviewed studies in which wildlife populations were monitored by using drones. They focused on four main topics: i) the available systems and sensors; ii) the types of survey plan and detection possibilities; iii) contributions towards anti-poaching surveillance; and iv) legislation and ethics. The use of a small UAV carrying a GPS unit is proposed in [13], a low-cost television receiver dongle serving as a software-defined radio (SDR) unit attached to an omnidirectional antenna, and a programmable control board for command and data storage. In their work, the drone is flying an automated mission and is used to create a heat map that shows the collar's position. Thermal image acquisition as well as a video processing pipeline to perform object detection, classification, and tracking of wildlife was presented in [14]. The authors combine UAVs with the thermal imaging capabilities and artificial intelligence image processing to locate wildlife in their natural habitats. RF telemetry system for wildlife tracking using an autonomous UAV was also developed in [15], the system is targeting the ecological application where their ultimate goal is to design an intelligent platform to detect a movable object using UAV with optimized flight path.

Multirotor platforms were investigated in [16] to identify and count wintering water birds. Such platforms are suitable for such tasks because they can fly over terrain that is difficult for human to access. A low-cost UAV with a very high frequency (VHF) receiver and onboard computer was used in [17]. The authors presented a local search algorithm which drives the UAV toward the target. A novel autonomous aerial vehicle system to track and localize multiple VHF radio-tagged animals was presented in [18]. They employed the concept of a search termination criteria to maximize the number of located animals within power constraints of the aerial system. The use of small unmanned aircraft systems for wildlife tracking that are equipped with radio collars will offer many advantages such as cost reduction, and human effort reduction. Our focus in this work is to automate the whole process and thus mitigate this trend that faced authorities in many parts of the world.

3. METHOD

The system is designed to be portable. It consists mainly of three sub-systems: drone-based sub-system, camel-based sub-system (collar-based), and vehicle-based sub-system. The main scenario of this project is to employ a certain precautionary measure that aimed at mitigating the number of accidents involving vehicles and camels. In order to do so, we assumed that each herd of camels was equipped with an autonomous drone. Meanwhile, each camel also has a collar and communicates with the drone. Drones as well as collars are implementing a mesh network topology in which each collar relays data for the network. Vehicles by default, are also assumed to be equipped with the vehicle-based sub-system. During the normal situation, drone-based sub-system will do some measurements regarding the location and position of each camel in the herd. As soon as the measurements exceed some preset values, the drone will be switched on and take off autonomously. Drones will fly in front of camels and start hovering over the highway. During the movement of camels, the drone will calculate the distance between the camels and the highway and determines how much time the camels need to reach the highway. That information will be broadcasted to all vehicles on the highway.

Based on the information that is received from the drone, the vehicle-based sub-system starts warning drivers to reduce vehicle speed and send a report on their current speed back to the drone. The drone will continuously determine the distance and the relative speed between vehicle and camels. If the drone anticipates a collision may occur, it will command the vehicle-based sub-system to warn the driver with an audible alert to reduce the speed to the value calculated by the companion computer. If the driver does not respond to the drone (i.e., the speed of the vehicle received by the drone does not change) by braking the vehicle to avoid collision, the drone will command the vehicle-based sub-system to advance the alarming level, and as a future work, it will communicate with the vehicle's computer to automatically slow down the vehicle to prevent a collision with a camel. Drones have been developed to be compliant with a number of stringent safety and redundancy requirements for flying over highways with heavy traffic. In summary, our algorithm for collision avoidance system is shown below, and Figure 1 shows the sequence of events that will take place between drone, collar, and vehicle.

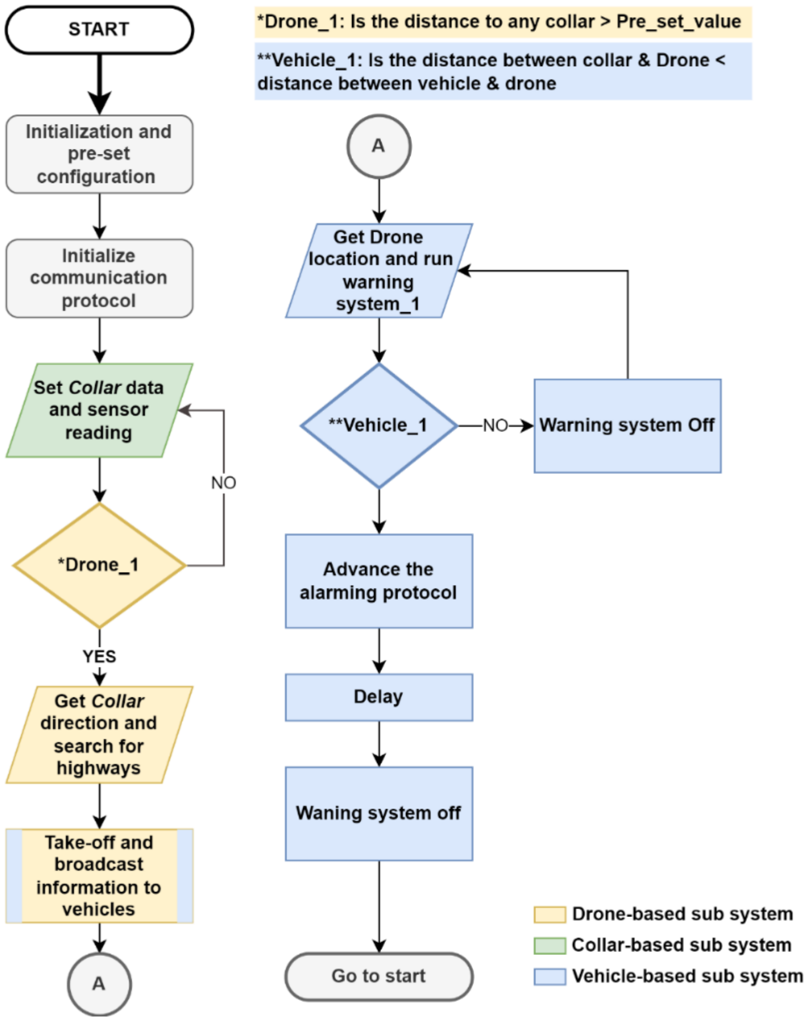


Figure 1. Flow chart of the whole system showing the sequence of events that will take place between drone, collar, and vehicle

4. SYSTEM DESCRIPTION

The system presented in this research is divided into three main sub-systems namely: a camel-based sub-system, a drone-based sub-system, and a vehicle-based sub-system.

4.1. Camel-based sub-system

The camel-based sub-system is simply a radio-GPS collar. The collar consists of an XBee module, a GPS module, an Arduino Nano board, an accelerometer module, three rechargeable lithium polymer batteries 1 S 3.7 v 750 mAh, a battery charger, and an organic solar cell (OPV), shown in Figure 2. The GPS receiver is used in this project mainly to capture camel behavior data such as position, velocity, and heading. Such data is then received by the Arduino Nano board which in turn passes it to the XBee module. The XBee module forwards the data to the drone-based sub-system. Since the GPS and XBee modules consume a lot of power, accelerometer module is used as an activity sensor to trigger both modules only when the camel is moving. All collars are organized in a low power mesh topology where each act as both a host and a router. Collar nodes cooperate in the distribution of data in the network, by relaying all the data they receive to all neighboring nodes. This arrangement could increase the range between camels since their behaviors are unpredictable. Figure 3 shows the actual design and implementation of the camel-based sub-system, featuring three key elements essential to the sub-system functionality. The radio collar module is represented in Figure 3(a), where all necessary components (discussed earlier) are integrated in a lightweight design compatible with the system. Emphasizing on the integration of renewable energy technology and to meet the system operational requirement, the radio collar is equipped with OPV to ensure efficient and reliable operation of the collar in the remote area, as shown in Figures 3(b) and (c).

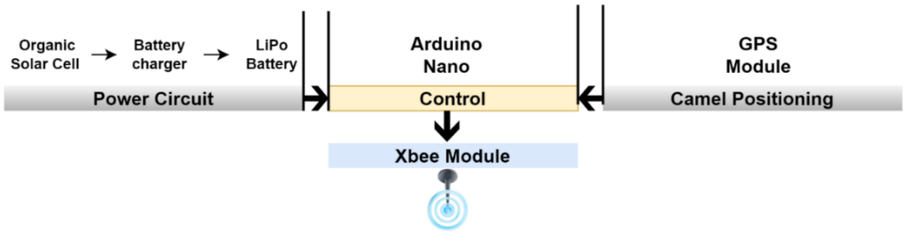
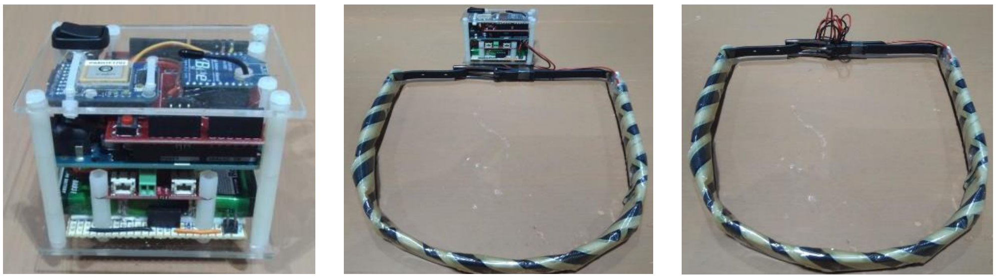


Figure 2. Functional block diagram of the radio collar module



(a) (b) (c)

Figure 3. Camel-based sub-system: (a) photo of the radio collar module, (b) photo of the radio collar with the OPV, and (c) photo of the OPV

4.2. Drone-based sub-system

Drone-based sub-system consists of a hexacopter drone with its onboard primary controller (Pixhawk 2.1 autopilot) and a secondary flight controller (Raspberry Pi 3 module), illustrated in Figure 4. Pixhawk 2.1 is a modified version of the oldest Pixhawk which allows for completely automated flight including take-off and landing. It consists of an inertial measurement unit (IMU), magnetometer, barometer, and a cortex-M4F microprocessor. The primary controller is attached to six Turnigy Plush 30 amp electronic speed controllers (ESCs). Brushless three-phase Tiger motor (MN2214) rated for 920 KV/251 W are used in this project. Six (9×45) inch propellers with fixed pitch blades are mounted on the motors, three pieces for standard rotation and three pieces for the right-hand rotation [19]. The hexacopter frame is made of carbon fiber material which features the high strength in carrying all controllers and other electronic components. In addition to all equipment used to feature the hexacopter drone, a secondary flight controller for the drone is linked to a companion computer running on Raspberry Pi 3, the GPS module, Arduino Nano board, and XBee module. The output power of the XBee module is 63 mW which enables the drone to extend its communication link with all collars up to 3.2 km. Drone works by the way of several propellers which lift the platform into the air, with the height, speed, and direction being controlled by the companion computer (Raspberry Pi 3). The Raspberry is used to replace the remote control and does all the flying, from auto take-off to landing. Guided mode is the main mode used in this project for flying drone autonomously without a predefined mission. It allows the Raspberry to control the vehicle on the fly and react to new events at any time of the day. Figure 5 shows a real photo of the drone-based sub-system.

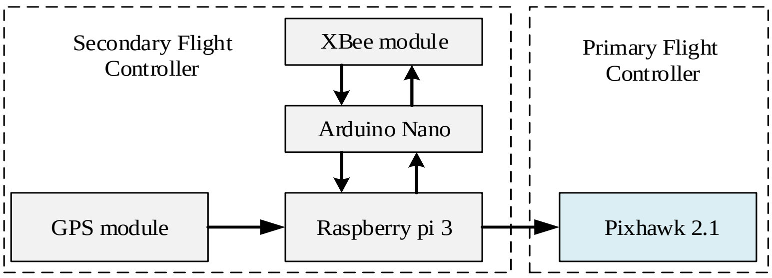


Figure 4. Functional block diagram of the primary and secondary flight controller

Figure 5. Actual photo of the hexacopter drone with the secondary flight controller on the top

4.3. Vehicle-based sub-system

The vehicle-based sub-system does not depend on the installation of any roadside equipment. Vehicles are equipped with a system that consists of Raspberry Pi, XBee, on-board diagnostics (OBD-II), speakers, and GPS (see Figure 6). The system is used to monitor a camel's movements through communication with drone using the XBee module and it warns the driver in case of possible collision. Raspberry Pi will process three tasks:

– Record the speed of the vehicle as transmitted by the OBD-II through built-in Bluetooth and pass it to the drone. The drone will calculate the distance between the camels and the highway. It will determine how much time the camels and the driver need to reach the dangerous zone on the highway. This information will be broadcast again to a vehicle-based sub-system (Raspberry Pi).
– Initiate a warning protocol to the driver with audible alerts to reduce speed.
– Advance the warning protocol level and as a future work to communicate with the vehicles' computer to automatically slow down the speed. The actual design and implementation of the vehicle-based sub-system is shown in Figure 7.

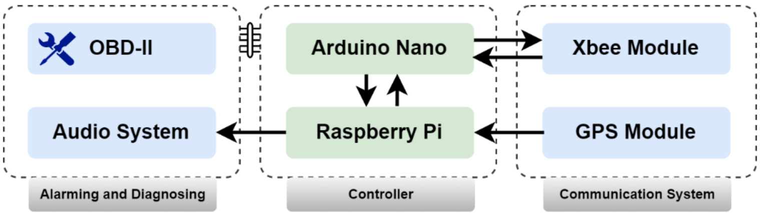


Figure 6. Functional block diagram of the main components of the vehicle-based sub-system

Figure 7. Actual design and prototype of the vehicle-based sub-system

5. MODELING

The proposed approach was implemented on the hexacopter drone with the sub-systems as described in section 4. The hexacopter drone weighs approximately 1.93 kg, including the airframe, motors, propellers, ESCs, power system, secondary flight controller, and the on-board primary flight controller. Based on this number, each motor should therefore be capable of providing $(1.93 \times 2)/6 = 0.64\ kg$ of thrust. From the data sheet of the MN2214 brushless motor; Table 1 [20], we can see that each motor can provide up to

$0.712\ kg$ of thrust with a 10×3.3 $inch$ propeller, that means six of these motors can lift $0.712 \times 6 = 4.272\ kg$ at maximum thrust. Therefore, hexacopter drone will take off at 89% thrust.

Table 1. Specifications of MN2214 brushless motors

Motor type: MN2214 KV920 11.1 volt						
Prop	Throttle (%)	Amps (A)	Watts (W)	Thrust (g)	RPM	Efficiency (g/w)
9*3 CF	75	4.3	47.73	381	6900	7.98
	100	8.1	89.91	605	8700	6.73
10*3.3 CF	75	5	55.5	448	6800	8.07
	100	9.2	102.12	712	8300	6.97

A simulation of the dynamic model of the hexacopter using MATLAB software was carried out in [19], [21]. Orientation of the drone is given by $\eta = (\Phi, \theta, \psi)$, while its position is given by $\digamma = (X, Y, Z)$. Therefore, the pose of the drone in the ground inertial reference frame can be written as (1):

$$\mathrm{P} = (\digamma^G, \eta^G) = (X, Y, Z, \Phi, \theta, \psi) \quad (1)$$

In addition, the linear and angular velocity of the drone can be described in the body fixed frame by $V^B = (u, v, w)$ and $W^B = (p, q, r)$. Accordingly, the velocities of the drone can be written as (2):

$$\mathrm{T} = (V^B, W^B) = (u, v, w, p, q, r) \quad (2)$$

In (3) to (14) determine the kinematic and dynamitic equations of the drone [22], where $c = cos\,()$, $s = sin\,()$, $t = tan\,()$, D_m is the thrust factor, m is the total mass of the drone, u_1 is the total thrust generated by all propellers $= \sum_{i=1}^{6} w_i^2$, (u_2, u_3, u_4) are the collective roll, pitch, and yaw, C is the force-to-moment scaling factor, and j is the rotational inertia around x, y, and z axes.

$$\dot{\Phi} = p + q.s(\Phi).t(\theta) + r.c(\Phi).t(\theta) \quad (3)$$

$$\dot{\theta} = q.c(\Phi) - r.s(\Phi) \quad (4)$$

$$\dot{\psi} = -q.s(\Phi)/c(\theta) + r.c(\Phi)/c(\theta) \quad (5)$$

$$\dot{x} = (c(\theta).c(\psi))u + (s(\Phi).s(\theta).c(\psi) - c(\Phi).s(\psi))v + \ldots \quad (*)$$

$$\ldots + (c(\Phi).s(\theta).c(\psi) + s(\Phi).s(\psi))\,w \quad (6)$$

$$\dot{y} = (c(\theta).s(\psi))u + (s(\theta).s(\Phi).s(\psi) + c(\Phi).c(\psi))v + \cdots \quad (*)$$

$$\ldots + (s(\theta).c(\Phi).s(\psi) - s(\Phi).c(\psi))w \quad (7)$$

$$\dot{z} = -s(\theta)\,u + (s(\Phi).c(\theta))v + (c(\Phi).c(\theta))\,w \quad (8)$$

$$\ddot{x} = (D_m u_1\, c(\Phi).s(\theta).c(\psi))/m + s(\Phi).s(\psi) \quad (9)$$

$$\ddot{y} = (D_m u_1\, c(\Phi).s(\theta).c(\psi))/m - s(\Phi).s(\psi) \quad (10)$$

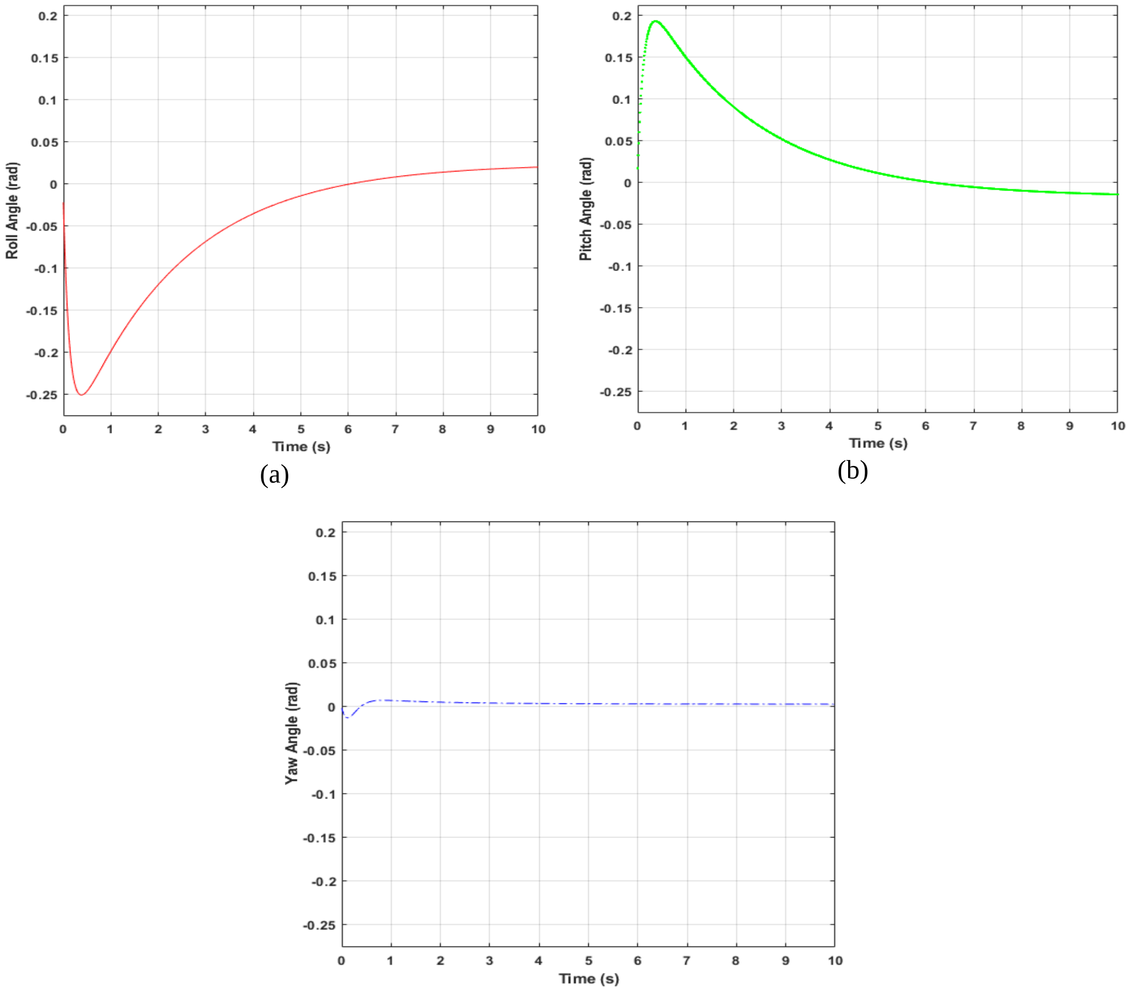
$$\ddot{z} = (D_m u_1\, c(\Phi).c(\theta))/m - g \quad (11)$$

$$\ddot{\Phi} = u_2 l D_m / j_x \quad (12)$$

$$\ddot{\theta} = u_3 l D_m / j_y \quad (13)$$

$$\ddot{\psi} = u_4 C / j_z \quad (14)$$

The most challenging part of this process is the tuning of the proportional integral derivative (PID) controller. The vehicle attitude was stabilized using this controller with $Kp = 7.7$, $Ki = 3.1$, and $Kd = 0.25$. Those parameters were the best in generating the desired control inputs to lift hexacopter from the initial position of 0 m to a set point of 15 m. Since the drone will be controlled through the Raspberry Pi, the control objective was to maintain the hexarotor in a constant altitude of 15 m. The MATLAB results for the roll, pitch, and yaw angles are shown in Figures 8(a) to (c). It can be seen that the controller was able to stabilize the drone with a steady-state error less than 0.025 rad for the roll and pitch angles, while it is almost zero for the yaw angles.



(a) (b) (c)

Figure 8. Response of the PID controller: (a) roll angle, (b) pitch angle, and (c) yaw angle

6. RESULT AND DISCUSSION

After successfully completing the flights in simulation environment. We performed several real-time tests on ground to experiment all modules separately to test their functionality and capability under different scenarios. The tests involve investigating the functionality of the drone-based sub-system, camel-based sub-system, vehicle-based sub-system, and the overall communication links between them.

6.1. Testing the communication with Pixhawk

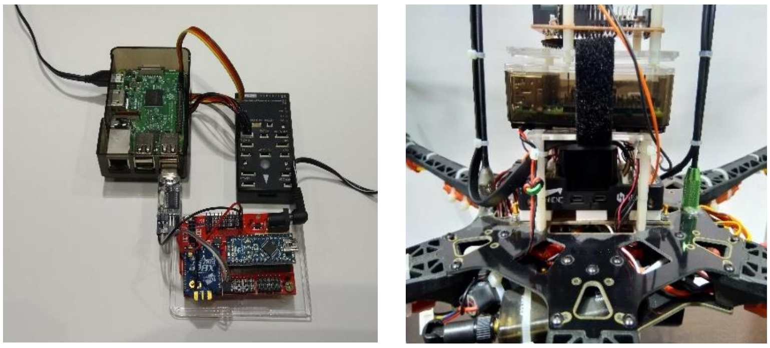
The first experiment was conducted to validate the communication link between the Raspberry Pi and the Pixhawk using the messaging protocol for drone (MAVLink) protocol over a serial connection as shown in Figures 9(a) and (b). A Python script was written to command the Pixhawk to switch the drone to the guided mode, then arm the motors, take off until it reaches 15 m, and last land to its initial position. In this experiment, tests are done without propellers, and the script is invoked one minute after booting the Raspberry Pi. Since the drone is autonomous, this test is essential to make sure that the software is running without any bugs. One more issue is the charging process for the drone's battery which is out of the scope of this paper. In the future, we will solve this problem so that the charging process will be automated.

(a) (b)

Figure 9. Communication link between the Raspberry Pi and the Pixhawk module: (a) physical connection between the two modules and (b) Mission Planner software's main view

6.2. Testing the XBee communication and overall drone setup

As shown in Figure 10(a), the XBee module in the second experiment is added to the test bench in order to examine mainly two features: i) scripts initialization and ii) capability of Raspberry Pi to run without any user input. In a similar way, the Python script is modified so that the Raspberry Pi will run the script as a result of receiving commands from the Arduino Nano board. Arduino Nano was placed between the two modules (Raspberry Pi and XBee) to read in the XBee's data and then communicate it via universal asynchronous receiver-transmitter (UART) to the Raspberry Pi. Raspberry Pi will process the MAVLink data and then put the drone into guided mode. Since the Raspberry Pi has only one hardware UART interface available in the general-purpose input/output (GPIO) header (14/15) that used to capture data from the Pixhawk module, a USB to TTL serial adapter was used to have the second UART and make it available to the Arduino Nano board. In addition to the two UART's, we used two GPIO pins on the Raspberry Pi as a software serial port to capture data from the GPS module (see Figure 10(b)). All tests were conducted successfully.



(a) (b)

Figure 10. XBee communication and drone setup: (a) connecting XBee module to the Raspberry Pi and Pixhawk through Arduino Nano board and (b) connecting all modules to the Pixhawk and Raspberry Pi including the GPS

6.3. Testing the vehicle-based sub system

In the third experiment, the communication link between the drone and the vehicle-based sub-system is tested (see Figure 11). The first test was conducted to check the connection between Raspberry Pi and a Bluetooth OBD-II adapter (Figure 11(a)). OBD-Pi software is used in this test [23]. It is an OBD-II compliant car diagnostic tool written entirely in Python to be read from the OBD scanner and monitor vehicle engine. For the time being, one parameter is recorded, which is the speed of the vehicle. A tiny script was written to encapsulate the location and speed of the vehicle and communicate these through the XBee module to the drone (Figure 11(b)). The drone-based sub-system successfully processed the data and sent back an alarm to the driver through the attached speaker.

(a)

(b)

Figure 11. Communication link between the Raspberry Pi and the Pixhawk module: (a) physical connection between the two modules and (b) Mission Planner software’s main view

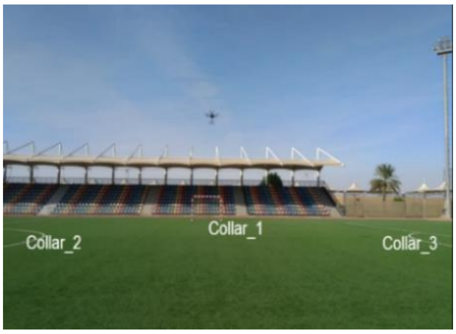
6.4. Real-time testing of the system

Since all standalone subsystems have been tested and verified, we have run a real-time test for the overall system including the communication link between collars and drone where three different demo collars are used in form of collars network and one flying drone, as shown in Figures 12(a) to (d). The Python script is again modified so that the collar's message is used to initialize the Python script. If we look at Figure 12(d), we can see that the communication link is actually between four XBee modules. All XBees were configured using the X-CTU software from Digi International [24]; one XBee is configured to act as a coordinator and others are configured to act as routers. For testing all modules with the GPS module, the test was conducted outdoor. The collars are programmed to capture the $GPGGA NMEA sentences (GPS fix data) [25], and extracted location, and heading. Location information and heading were sent to the Raspberry Pi. Based on this information, the drone will take immediate action and start its tasks. Due to the lack of space and regulation constraints; all tests were conducted without camels but with actual collars on ground.

(a)

(b)

(c)



(d)

Figure 12. Communication link between collars and drone: (a) testing communication link between drone and collar_1, (b) testing communication link between drone, collar_1, and collar_2, (c) testing communication link between drone, collar_1, and collar_3, and (d) landing the drone in between all collars

7. CONCLUSION

A high-level design of an intelligent system for animal detection and collision avoidance is presented in this paper using the latest technology. The use of drone technology in this kind of application can cut down the number of accidents involving vehicles and camels and reduce the economic cost of the damage associated with this problem. The drone detects camels as they approach the highway and sends warnings to the drivers traveling at speeds much higher than the posted speed limit. The warning protocol depends on camel position, velocity, acceleration, heading, and some commands to alert vehicle drivers to slow down in order to avoid a potential collision with camels being detected. On the other hand, if the drivers do not pay sufficient attention by breaking the vehicle within a short period of time (i.e. speed of the vehicle received by the drone does not change); the drone will command the vehicle-based sub-system to advance the alarming level, and as a future work, it will communicate with the vehicle's computer to automatically slow down the vehicle to prevent a collision with a camel. The system has been designed and implemented using the hexacopter drone and two attached technologies; a camel-based sub-system and a vehicle-based sub-system. Several tests were conducted to demonstrate the feasibility of this system. The results show that the system is promising and applicable. In the future, more advanced and interconnected warning protocol might be explored so that if drone anticipates a collision may occur, it will communicate with the vehicle’s computer through the Raspberry Pi to adopt some forcing technique mainly in case of near-accident scenario; such proposal needs the permission of vehicles company to access the on-board computer.

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