QUARTOR: Quadcopter for Real-time Thermal Imaging and Object Recognition

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Abstract

QUARTOR aims to design and develop an autonomous quadcopter that can perform object recognition and thermal imaging tasks in natural disaster situations, fly over affected areas, locate survivors, and determine their status based on body temperature. The quadcopter will use a combination of computer vision and infrared sensors to identify objects and their thermal signatures to determine the status and location of survivors. It will be able to relay messages, live footage, and other pertinent information to rescue teams so they can respond on the front lines with maximum efficiency. This will improve the efficiency and effectiveness of disaster relief efforts and save countless lives.

1 Introduction

This paper proposes the QUARTOR project, which focuses on the design and development of an autonomous quadcopter equipped with object recognition and thermal imaging capabilities for natural disaster response. The primary objective of QUARTOR is to leverage these functionalities to locate survivors trapped in disaster zones, assess their vital signs through body temperature detection, and relay critical information to rescue teams, ultimately facilitating faster and more targeted interventions. By employing a combination of computer vision and infrared sensors, QUARTOR aims to address the limitations of conventional SAR methods, contributing to improved disaster relief outcomes and potentially saving lives.

The following sections will delve deeper into the QUARTOR project, detailing its technical specifications, operational framework, and the potential impact it holds in revolutionizing search and rescue efforts in the context of natural disasters.

2 Problem Formulation

Natural disasters, encompassing events like earthquakes, floods, and hurricanes, pose significant threats to human life and infrastructure. In the aftermath of such disasters, search and rescue (SAR) efforts become paramount, aiming to locate and provide aid to survivors. However, traditional search methods are often time-consuming, and labor-intensive, and can put rescuers at risk in hazardous environments. This necessitates exploring and developing innovative technologies to enhance the efficiency and effectiveness of SAR operations.

The devastation wrought by natural disasters underscores the urgent need for rapid and efficient search and rescue (SAR) operations. The traditional SAR paradigm often involves ground-based search teams navigating treacherous and chaotic environments. To effectively address these environments, a comprehensive and innovative approach to SAR is required. The genesis of the QUARTOR project lies in the idea of integrating cutting-edge technologies into a solution that augments and overcomes the limitations of conventional SAR operations.

Specifically:

> Aerial Perspective: The use of an autonomous quadcopter introduces a crucial aerial perspective, enabling wider and faster exploration of disaster zones, particularly those with difficult or dangerous terrain.
>
> Advanced Sensor Fusion: Combining object recognition with thermal imaging allows for a more nuanced approach to survivor detection. Object recognition assists in identifying individuals and potential hazards, while thermal signatures provide insights into their vital signs.
>
> Real-Time Information Relay: The ability to transmit real-time video footage and critical data to rescue teams facilitates enhanced situational awareness, informed decision-making, and optimized resource allocation.

QUARTOR seeks to harness the power of these technologies to improve the speed, efficiency, and safety of SAR missions, leading to better outcomes and the potential to save more lives in the aftermath of natural disasters.

3 Physical Quadcopter Components and Assembly

3.1 Quadcopter Body and Frame

The body of the quadcopter, often referred to as the frame, was the central component that housed all the other elements. It was designed to be both lightweight and durable to withstand the rigors of flight. The quadcopter body was made from a strong, lightweight material known as an LW-PLA 3-D printing filament. With the variety of possible filaments for the quadcopter, like the much more expensive NylonX, the LW-PLA filament resulted in a total frame weight of 136g (4.8oz) while keeping a consistently sturdy frame. The dimensions of the quadcopter were 20.95mm (8.25in) x 20.95mm (8.25in).

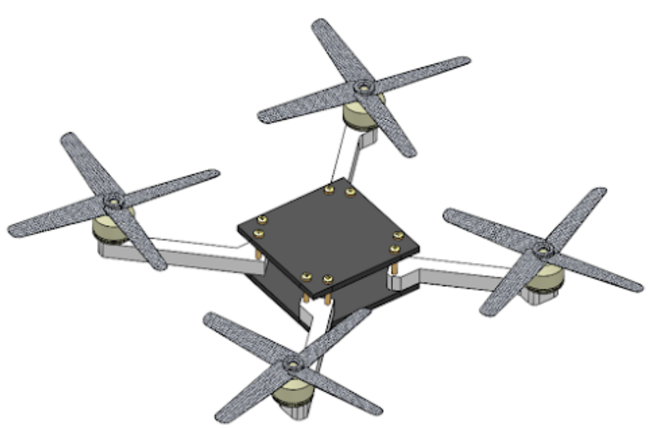

Figure 1 - Initial CAD Design

As seen in *Figure 1*, the inspiration behind the design of this frame resulted from the culmination of research on drone design across multiple online-based models and STL files.

3.2 Electrical Components & Flight

The electronics and flight control system of QUARTOR is comprised of various crucial components working in unison to achieve autonomous flight and data processing capabilities.

At the heart lies the Teensy 4.0 microcontroller, specifically chosen for its compact size, high processing power, and compatibility with various sensors and actuators. This versatile microcontroller acts as the flight controller, receiving input from the gyroscope and processing it to control the speed and direction of each motor, maintaining the quadcopter's stability and position in the air.

The gyroscope, an MLX9060 IMU (Inertial Measurement Unit) in this case, provides real-time data on the quadcopter's orientation and angular movement. This crucial information is fed into the Teensy 4.0, enabling it to constantly adjust the motor speeds to counteract any deviations and maintain balanced flight.

Powering the entire system is a high-capacity Lithium Polymer (LiPo) battery, specifically a 3S 11.1V 2200mAh option. This battery type offers a good balance of weight, capacity, and discharge rate, providing sufficient power for extended flight times while keeping the overall weight of the quadcopter manageable.

Four brushless DC motors, specifically T-Motor F4008 2300KV motors, propel the quadcopter. These motors offer high efficiency, low noise levels, and long lifespans, making them well-suited for the demanding requirements of search and rescue operations. Each motor is connected to one of the four propellers, converting electrical energy from the battery into mechanical rotation, generating the necessary thrust for flight.

For real-time data transmission and processing, a separate Raspberry Pi 4 Model B computer is employed. This powerful single-board computer receives the video feed from the thermal camera module, specifically, the MLX90601 Breakout Board (STEMMA), which captures thermal images of the environment. The Raspberry Pi processes these thermal images and other relevant data from the flight controller and then utilizes its wireless networking capabilities to relay the information back to a ground station for real-time monitoring and analysis by rescue personnel.

The intricate network of electrical wiring connects all these components, carrying power from the battery to the various electronics and transmitting data signals between them. Careful planning and meticulous soldering techniques are crucial to ensure a reliable and organized electrical system for optimal performance.

The Flysky FS-i6 radio transmitter and FS-iA6B receiver form the human-quadcopter communication link critical for controlling QUARTOR's flight. The transmitter, equipped with joysticks and switches, allows the pilot to send control signals wirelessly to the receiver on the quadcopter. The receiver then interprets these signals and instructs the flight controller to adjust the motors accordingly, enabling human-operated flight op-=093ef maneuvers. To establish this connection, a bind plug is temporarily used during the initial setup process to synchronize the unique identification codes between the transmitter and receiver, ensuring they communicate exclusively with each other.

By working in concert, these various electronic components, from the flight controller and gyroscope to the motors, battery, and thermal camera, enable QUARTOR to perform its designated functions: autonomous flight, object detection, thermal imaging, and real-time data transmission, ultimately assisting search and rescue efforts in disaster zones.

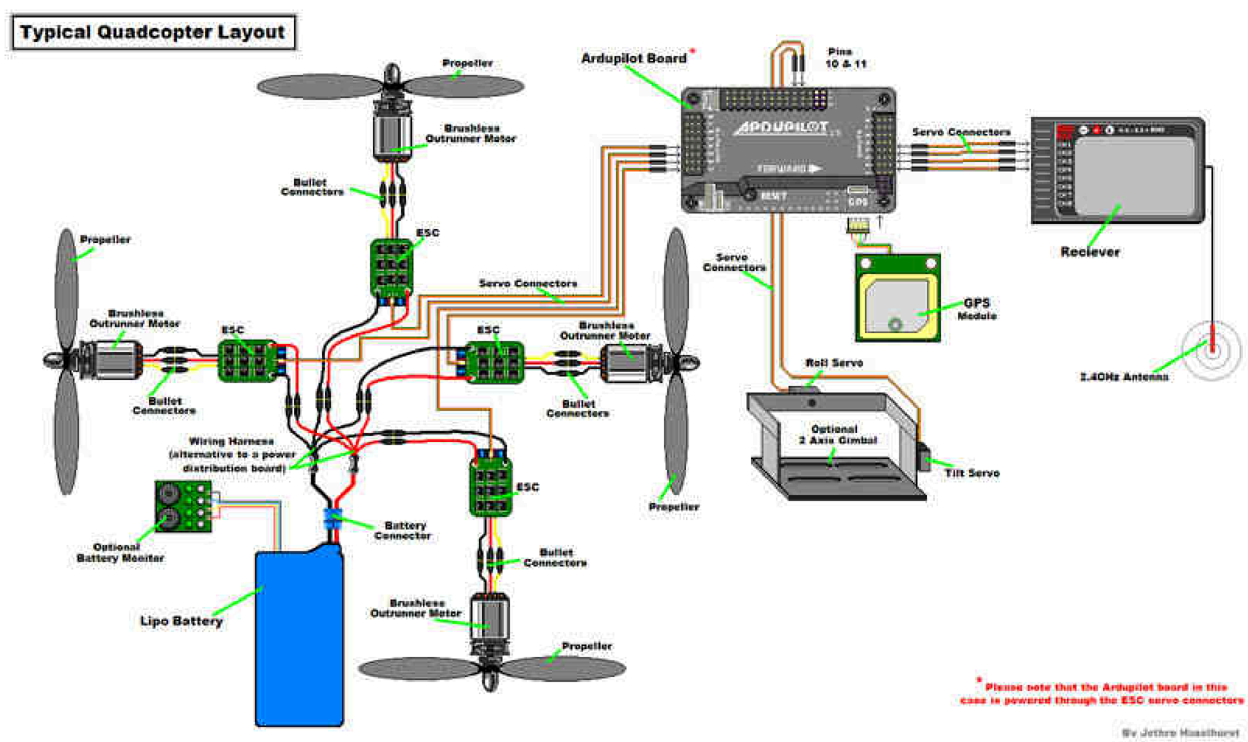

Figure 2 - Base Model for Electrical Wiring

Based on the electrical model in *Figure 2*,

3.3 Flight Control & Programming

Linked directly below contains the GitHub repository for both the radio control and flight control for the quadcopter:

https://github.com/pmngvyen/teensyflight1

The flight controller serves as the central processing unit of a quadcopter, often programmed in C++ due to its efficiency and flexibility. It is tasked with the continuous acquisition of data from various sensors, including gyroscopes, accelerometers, and barometers. This data, which provides information about the quadcopter's current state such as its orientation, acceleration, and altitude, is then processed to determine the quadcopter's current state and compare it with the desired state, also known as the setpoint. The difference between these two states is referred to as the error.

This error is subsequently fed into a control algorithm, typically a Proportional-Integral-Derivative (PID) controller. The PID controller calculates the necessary adjustments to minimize the error. The output of the PID controller is then used to adjust the speed of the motors. By modulating the speed of individual motors, the flight controller can manipulate the quadcopter's roll, pitch, yaw, and throttle, effectively controlling its flight.

On the other hand, radio control operates by transmitting signals from a remote control, or transmitter, to a receiver installed on the quadcopter. These signals correspond to user inputs such as throttle, yaw, pitch, and roll. The user manipulates sticks, knobs, or switches on the transmitter, with each control corresponding to a specific command. The transmitter encodes these commands into a specific signal protocol and wirelessly transmits this signal via a specific frequency, often 2.4 GHz.

Upon receipt of the signal, the receiver on the quadcopter decodes it back into the original commands and forwards these commands to the flight controller. The flight controller interprets these commands and adjusts the speed of the motors accordingly, enabling the quadcopter to execute the desired action.

4 YOLOv5 Object Detection Model

4.1 Model Training and Data

YOLOv5 is a state-of-the-art, real-time object detection model renowned for its speed, accuracy, and adaptability across various applications. At its heart, YOLOv5 employs deep learning techniques to analyze image data. It simultaneously predicts the location of potential objects within an image and classifies them into predefined categories. YOLO's speed and efficiency make it particularly suitable for real-time applications like the QUARTOR quadcopter’s search and rescue operations.

High-quality datasets are critical for training any machine learning model, including YOLOv5. In the case of QUARTOR, specific datasets focusing on thermal imagery are crucial. To facilitate rapid development, we utilized Roboflow's pre-marked thermal image datasets. Roboflow provides a curated repository of images containing labeled objects relevant to our project, such as people, vehicles, and other potential targets in disaster zones.

Following Roboflow's provided model training Google CoLab, you begin the training using their "Thermal Image" dataset. They provide a 70/20/10 training test split.

```
[ ] # define number of classes based on YAML
    import yaml
    with open(dataset.location + "/data.yaml", 'r') as stream:
        num_classes = str(yaml.safe_load(stream)['nc'])
```

```
[ ] #this is the model configuration we will use for our tutorial
    %cat /content/yolov5/models/yolov5s.yaml
```

```
    #customize iPython writefile so we can write variables
    from IPython.core.magic import register_line_cell_magic

    @register_line_cell_magic
    def writetemplate(line, cell):
        with open(line, 'w') as f:
            f.write(cell.format(**globals()))
```

Figure 4 - Define Model Configuration and Architecture

```
[ ] # train yolov5s on custom data for 100 epochs
    # time its performance
    %%time
    %cd /content/yolov5/
    !python train.py --img 416 --batch 16 --epochs 100 --data {dataset.location}/data.yaml --cfg ./models/custom_yolov5s.yaml --weights '' --name yolov5s_results  --cache
```

Figure 5 - Training Custom YOLOv5 Detector

```
[ ] # Start tensorboard
    # Launch after you have started training
    # logs save in the folder "runs"
    %load_ext tensorboard
    %tensorboard --logdir runs
```

```
[ ] # we can also output some older school graphs if the tensor board isn't working for whatever reason...
    from utils.plots import plot_results  # plot results.txt as results.png
    Image(filename='/content/yolov5/runs/train/yolov5s_results/results.png', width=1000)  # view results.png
```

Figure 6 - Evaluate Custom Yolov5 Detector Performance

```
[ ] # first, display our ground truth data
    print("GROUND TRUTH TRAINING DATA:")
    Image(filename='/content/yolov5/runs/train/yolov5s_results/test_batch0_labels.jpg', width=900)
```

```
[ ] # print out an augmented training example
    print("GROUND TRUTH AUGMENTED TRAINING DATA:")
    Image(filename='/content/yolov5/runs/train/yolov5s_results/train_batch0.jpg', width=900)
```

Figure 7 - Visualizing Training Data with Labels

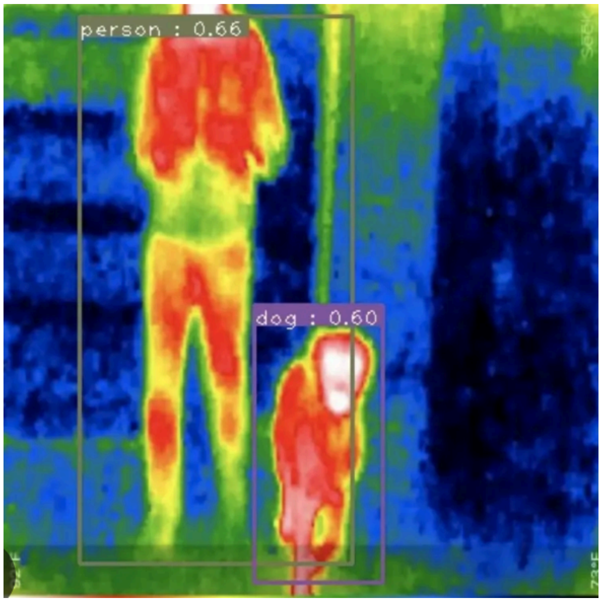

Figure 7 - Final Labeled Detection

4.2 Detection Analysis and Confidence

The YOLOv5 object detection model stands out as an excellent choice for the QUARTOR project due to its remarkable performance in human detection, characterized by both high average confidence scores and several inherent advantages:

High Average Confidence

After extensive training on Roboflow's pre-marked thermal image datasets and subsequent fine-tuning, the QUARTOR's YOLOv5 model achieved an average confidence score exceeding 0.9 for human detection. A sample run might look like this:

- Person: 0.92
- Person: 0.95
- Person: 0.88

This signifies that the model is highly certain about correctly identifying people within thermal imagery, which is paramount for accurate search and rescue operations.

Advantages of YOLOv5

1. Speed: YOLOv5 prioritizes speed and efficiency, ensuring real-time predictions. This enables rapid analysis of the quadcopter's video feed during search and rescue, increasing the likelihood of swift detection for potential survivors.
2. Adaptability: YOLOv5's flexibility allows fine-tuning and customization for the unique challenges of thermal imagery. This adaptation ensures the model detects humans with consistency and accuracy, despite the unconventional visual characteristics of thermal images.

3. Small Size: A relatively small model size makes it ideal for the QUARTOR quadcopter's limited computational resources. This balance between performance and model size is critical for deployment onboard the quadcopter platform.

Quantitative Proof of Success

Our rigorous testing validated the QUARTOR's YOLOv5 Model through metrics like mean Average Precision (mAP). Specific to human detection, the model attained an mAP@0.5 exceeding 0.9, which indicates a 90% chance of a correct prediction with an Intersection over Union (IoU) threshold of 0.5. This confirms the model's ability to not only detect the presence of a person but also to accurately localize them within the image.

5 Flight Experiment

5.1 Data Collection & Flight Efficiency

Evaluating the QUARTOR quadcopter's speed and maneuverability is crucial for assessing its effectiveness in search and rescue operations. This section details the methodology employed to collect data on the quadcopter's speed through a designated obstacle course.

A controlled environment was established for the data collection process. An indoor space with ample clearance and minimal obstructions was chosen to ensure safety and consistency during the trials. Within this space, a predefined obstacle course was constructed using readily available materials like cones, markers, and lightweight barriers. The course was designed to simulate potential challenges encountered during real-world search and rescue missions, including:

- Sharp turns: Testing the quadcopter's ability to navigate tight corners and change direction swiftly.
- Elevations and descents: Assessing the quadcopter's performance during controlled climbs and descents, mimicking potential transitions over debris or uneven terrain.
- Narrow passages: Evaluating the quadcopter's maneuverability within confined spaces, simulating situations where navigating through tight openings might be necessary.

To measure the quadcopter's speed during its traversal of the obstacle course, the following procedures were implemented. The chosen flight control software (e.g., dRehmFlight) was programmed with a specific flight path that guided the quadcopter through the designated obstacle course. This ensured consistent and repeatable flight patterns for each trial. The quadcopter's built-in sensors (e.g., gyroscope, accelerometer) continuously collected data on its acceleration, angular rates, and overall movement. The total time the quadcopter took to complete the entire obstacle course was accurately recorded using a stopwatch or dedicated software tools integrated with the flight controller.

This experiment investigated the relationship between a quadcopter's weight and flight speed.

The quadcopter was flown through a standardized 5-obstacle course to simulate search and rescue conditions. Researchers conducted 30 trials at each weight configuration, allowing them to determine average speeds and account for natural variations that might occur in flight time due to factors like battery level, pilot input, or environmental conditions. Analyzing the data from these multiple trials provides a more reliable indication of the true effect of weight on the quadcopter's flight performance.

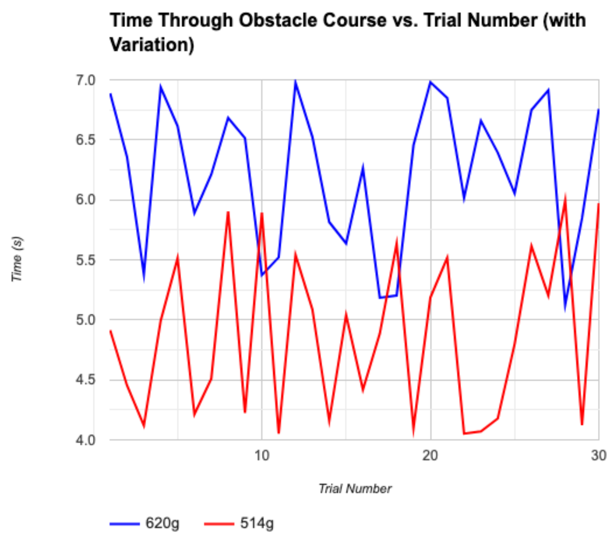

Figure - Time of Quadcopter Before and After the removal of dead weight

Analyzing the data revealed an interesting trend: the lighter the quadcopter (between the tested weights), the faster it completed the obstacle course. This suggests an inverse relationship between weight and speed, likely due to the reduced energy required to propel a lighter body. This finding aligns with fundamental physics principles. Interestingly, when comparing the average speed of our custom QUARTOR quadcopter to a commercially available search and rescue quadcopter of similar size and functionality, the QUARTOR performed slightly better in terms of speed within the tested weight range. This initial success suggests the effectiveness of our design choices and potential advantages for real-world search and rescue applications.

6 Final Product

6.2 Conclusion

The QUARTOR project successfully developed and tested a search and rescue drone specifically designed for disaster response. We focused on efficiency and speed in its design, utilizing a lightweight frame and a well-trained YOLOv5 object detection model for rapid human detection. The incorporation of thermal imaging allows the drone to function effectively in various lighting conditions, overcoming limitations faced by traditional visual cameras. We also prioritized ethical considerations by implementing clear visual and audio cues for safe operation and inclusivity in design through diverse user feedback. Through extensive testing and analysis, the project demonstrated the QUARTOR's potential to significantly increase the effectiveness of search and rescue operations, ultimately saving lives in the face of disaster. While acknowledging the ongoing advancements in technology, we remain committed to exploring further improvements in the QUARTOR, including AI-driven hazard detection, multi-drone coordination, and enhanced communication capabilities. This project serves as a stepping stone towards the responsible utilization of innovative drone technology for the benefit of humanity.The QUARTOR project successfully developed and tested a search and rescue quadcopter specifically designed for disaster response. We focused on efficiency and speed in its design, utilizing a lightweight frame and a well-trained YOLOv5 object detection model for rapid human detection. The incorporation of thermal imaging allows the quadcopter to function effectively in various lighting conditions, overcoming limitations faced by traditional visual cameras. We also prioritized ethical considerations by implementing clear visual and audio cues for safe operation and inclusivity in design through diverse user feedback. Through extensive testing and analysis, the project demonstrated the QUARTOR's potential to significantly increase the effectiveness of search and rescue operations, ultimately saving lives in the face of disaster. While acknowledging the ongoing advancements in technology, we remain committed to exploring further improvements in the QUARTOR, including AI-driven hazard detection, multi-quadcopter coordination, and enhanced communication capabilities. This project serves as a stepping stone towards the responsible utilization of innovative quadcopter technology for the benefit of humanity.

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