Multimedia Imaging System of Data Collection and Antenna Alignment for Unmanned Aerial Vehicles Based Internet of Things

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Abstract

Because network of sensors gives a more accurate representation of remotely sensed environments, a network of wirelessly connected sensors is essential. Data packets must be routed to the base station hop by hop, which causes conventional network data collecting to use a lot of power. Unmanned aerial vehicles (UAV) were employed for hovering over the detected environment and gather data to solve this issue. The paper also aims to provide an automatic alignment for UAV antennas for tracking by utilising computer vision technologies. A directional antenna with high gain is used by a ground station that can operate by a pan-tilt to point towards the low-gain omnidirectional antenna carried by the UAV. To center the UAV's antenna's image in the frame, the antenna is equipped with a camera, and a computer detects the video and controls the pan-tilt. The antennas are aligned if there are no more than a few pixels between the UAV image center and the image center. The proposed imaging system exhibits fast data collection, thus attaining a high packet delivery rate and the minimum use of energy. With the suggested antenna auto-alignment approach, the antennas can be accurately aligned with an angle error of under one. UAVs must take the smoothest and shortest pathways possible to accommodate their motion and time constraints. As a result, the Traveling Sales Problem (TSP) is utilized to determine the shortest route, and Bezier curves are then employed to turn paths into a flyable path.

Keywords: unmanned aerial vehicle; antenna alignment, computer vision; Data gathering; Traveling salesman problem; Wireless sensor network; Path smoothing; Internet of Things.

1. Introduction

As an important IoT technology enabler, the Wireless Sensor Network (WSN) includes spatially spread self-governing sensory instruments that track changes in physical conditions [1]. In the literature, a number of approaches are being suggested for multisensor aggregation and fusion in heterogeneous sets of data. Multiple techniques have been created to accommodate the data and applications because of the various kinds of sensors used, as well as the heterogeneity of the information that must be combined. These techniques were taken from a variety of fields, such as pattern recognition, artificial intelligence, statistical estimation, and others. WSNs are now being used for a variety of purposes, such as environmental monitoring, disaster relief, and military surveillance [2]. Without the use of a centralized server, WSN performs operations collectively. Since the

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sensors in WSNs require an extensive amount of communication energy, energy efficient approaches take into account the required sensor nodes limited battery capacity [3]. The heavy utilization of the fundamental energy scarce nodes and fundamentally unstable wireless connections that arise from extensive data gathering using standard multi-hop forwarding will result in decreased network lifetimes and low rates of data collection, accordingly. However, energy-efficient data collecting and reliability could be offered by utilizing UAVs in an IoT framework [4,5].

Antennas that are Ground-directional usually employed to satisfy the UAV applications for recording video or relaying communication that necessitates an enormous quantity of non-wired data transmission, and real-time alignment of the receiving and transmitting antennas is crucial for achieving high-quality microwave communication. There are two main methods or a combination of them under investigation for automatic antenna alignment for unmanned aerial vehicles (UAVs)—automatic alignment using received signals and automatic alignment using the global positioning system (GPS) data—representing the majority of current research. The latter is easier and is more commonly used. However, GPS techniques depend on the GPS module's functionality, whose rate of updating position information is constrained. Short-distance tracking can experience significant tracking angle fluctuations and alignment failure due to limited update rates. Additionally, using GPS inside is ineffective. Moreover, antenna misalignment and GPS positioning errors are possible because of the atmospheric ionosphere and multipath effect. The use of computer vision technologies in industry has increased recently after decades of development. There, we attempt to utilize this technology to complete automatic antenna alignment and examine alignment performance.

UAVs are able for carrying a variety of instruments including cameras, sensors, and communication equipment. As a result of their energy constraints, they can help IoT and WSN devices that are typically unable to broadcast across long distances [6]. In these situations, UAVs can travel toward IoT devices on demand, collect their data, and send it to base stations or other devices that are outside of their communication range [6]. UAVs can be used for a variety of purposes, including military, civilian, environmental remote sensing, and agricultural ones. UAVs could be utilized for applications including monitoring severe storms, assessing pollution and air quality, observing the ocean along the coast, and managing forest fires. The UAVs serve as IoT network moving aggregators in this case. To employ UAVs for IoT communication effectively, however, several issues must be resolved, like the best distribution and energy efficient utilization of UAVs [7].

2. Related Works

This section examines recently placed approaches to the path planning problem that combine UAVs motion control to other planning techniques, fields of application, and so forth. There aren't many studies that take generality into account, though. The two key components that need testing are the sensor data collection and the path planning. In [13], the value of all sensors' Signal-to-Noise-Ratio (SNR) used on the UAVs aids in the information-gathering process. Instead of shortening the time of the mission, the researchers attempt to increase the data collection rate. In lots of studies, evolutionary algorithms were used to handle UAV path planning issues, like military missions [13] and route planning for UAVs navigating over specific terrain [14]. An additional latest work [14] relies on prospective path populations that are updated according to specific guidelines till the best route is found. This study on multi-UAV route planning was carried in offline as online conditions. For typical path planning issues, this study's convergence appears to be slower. The path was successfully predicted in this study, the UAV can follow it to gather data at the nodes. Collecting data from WSN utilizing the UAV is the major objective of Li et al.'s [15] research. In this study, the UAV is being utilized for cooperating data transfer due to the inability of sensor nodes to relay data to the cloud. The framework comprises a client side with a number of UAV-hosted components that selectively offload the data packets they have gathered to a cloud-based server. The server is housed within the cloud architecture and can offer the control center and the operator instantaneous processing of data and information feedback services. This approach is suggested in [16] for selecting the best flight path using Particle Swarm Optimization (PSO). The study depends on clustering and the UAV can reach the clusters heads. Prior to beginning the task, the UAV should be aware of the cluster heads' location. Path planning was primarily given consideration [17] in relation to WSNs for planning the data mules motion that can get information from stationary nodes of sensors. The Label-Covering Tour (LCT) problem was how defined the issue as a graph problem. Additionally, Gao et al. [18] solve the TSP [19] using the genetic algorithm as a common heuristic. There are additional approaches that take advantage of dynamic limitations [20], whereas Hanoun et al. concentrate on eradicating the buffering issue. As an example, every source loses data because nodes have a certain amount of storage space. The limitations on

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sensor buffer overflow times or delays caused by collecting data. Some restrictions on the use of UAVs for data collecting are primarily linked to motion and time restrictions. The earlier research did not take into account how UAVs not be used for real-time applications and cannot make sharp turns. One UAV's ability to do an observation is constrained. Additionally, the study [15] has sluggish convergence for issues involving regular path planning. Additionally, this work [13] made use of a simple UAV kinematic model. Path planning issues can be solved with decoupled equations of motion. Running fully interrelated equations of motion will produce simulations that are more accurate. In our design, every unmanned aerial vehicle can visit the gateways and collect data from each gateway, but using traditional network forwarding, every gateway node should build a connected network for the data transfer to the base station.

3. Materials and Methods

3.1 Unmanned Aerial Vehicles

Recently, UAVs have received a great deal of attention. Unmanned aerial vehicles (UAVs) are controlled vehicles without a human pilot aboard. Through microprocessors, electronic gadgets, and sensors, it is capable of autonomous control and operation of aerial vehicles [35]. Figure 1 illustrates a typical UAV system architecture and the communication channels that UAVs use to interface with computers, smartphones, ground control systems (GCS), and satellites. Remote control and operation of a UAV are performed by a human operator. In circumstances where human assistance would be challenging or dangerous, UAVs can complete autonomous tasks [36]. UAVs are currently a very practical method for logistics. Particularly, the demand for UAVs in the civilian sector has increased noticeably. UAVs are mostly used for remote missions including packages, delivery of airmail, disaster monitoring, search and rescue, environmental monitoring, and medical items. Figure 2 shows the USA's expanding commercial UAV market revenue in various sectors.

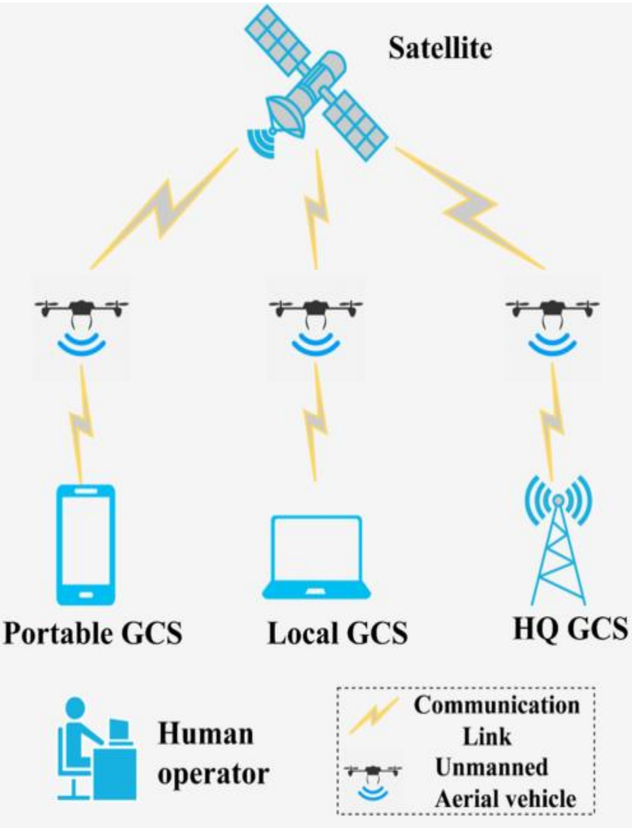

Figure 1: UAV system

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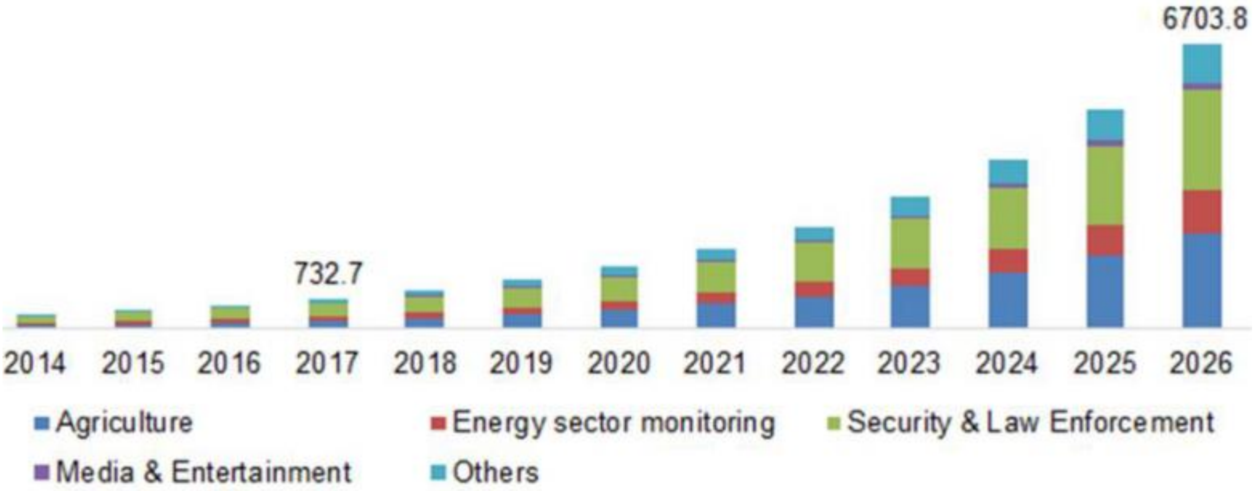

Figure 2: North American market for commercial drones

3.2 A System for Antenna Alignment Using Computer Vision Technology

Figure 1 depicts the automatic antenna alignment system's conceptual design. A ground-station utilizes a directional antenna with high-gain that is driven by a pan-tilt with two levels of point freedom towards the low-gain omnidirectional antenna that is carried by the UAV. The antenna is connected to a camera. When the antennas are lined up, the UAV image ought to appear in the middle of the image the camera takes. Via a cable, the camera transmits video data to a computer. The pan-tilt motion can be controlled by the computer while it processes the video. Figure 2 displays an illustration of the imaging system's principal sketch. The field of view (FOV) of a camera can only detect objects within an area that is H is height and V is width. There are h × v pixels in the composed digital image. We employ grayscale images in our system, and every pixel of an image has a corresponding gray value. With the help of current machine learning techniques, the target UAV on the image may be identified and tagged with a rectangular box. P and Q are used to denote the boxes' two center points, that correspond to A and B in the plane (FOV).

Figure 3: Concept for an automatic antenna alignment mechanism

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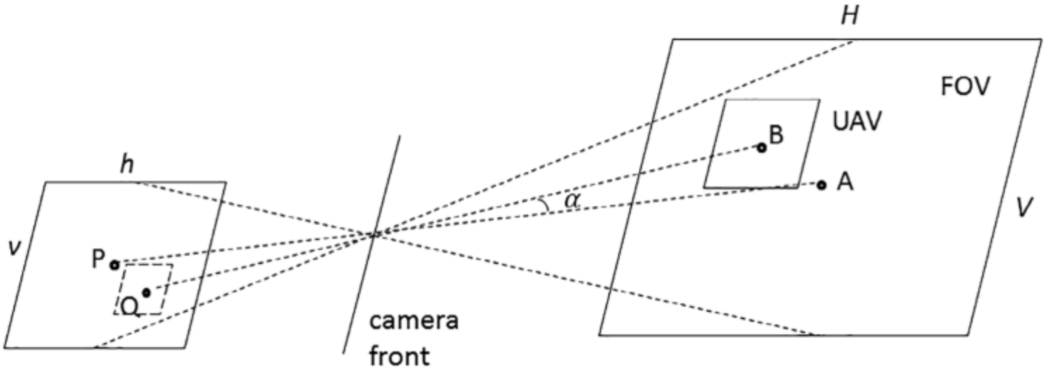

Figure 4: Basic diagram of an imaging system

4. Proposed Work

In this study, we suggest an innovative method of planning for UAV-aided data collecting. The sensory data that several UAVs gather can be shared and combined to create a complete view of the environment when they are deployed. To get to its goal, every unmanned aerial vehicle should travel a smooth and predetermined course in real-time. The UAV may gather data from numerous gateway nodes as the appropriate mobile sink. The UAV returned to the base station after gathering the data. We have developed a novel model that can gather information on the smoothest and shortest paths in response to this limitation. The high-level design is shown in Fig. 1, which also depicts the relationships between the research's suggested modules. When compared to current initiatives, our primary innovation is to design a path planning model that is smooth and efficient using WSNUAV systems. The shortest path is specifically planned using TSP. The motion limitations of UAVs, which are unable to make sharp turns, are then taken into account. We smoothed the pathways using Bezier curves for this reason. Additionally, we use the Kalman filter approach at the sensor nodes to delete data that is repeated. We list the following as the significant contributions of this study: • UAV movement under turning restrictions, we provide a novel path planning strategy that uses a brief and fluid data-gathering path. • Next, we use the Lyapunov function, which is locally implemented on every UAV, to regulate their motion. • To remove redundant data from the sensors and the gateway nodes, we employ the Kalman filter technique.

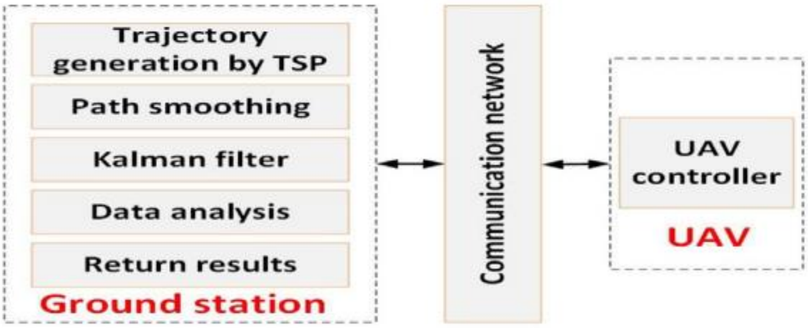

Figure 5. Proposed model Structure.

5. Performance Analysis and Results

Using optics knowledge, the following formula may be found.

$$\frac{l}{D} = \frac{h}{H} = \frac{v}{V} \tag{1}$$

D denotes the camera's front to the unmanned aerial vehicle distance; l denotes the image to the camera's front distance. Let α be the degree of alignment error, meaning the BQ and AP angle, while |AC| denotes A and B

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physical distance, and |PQ| be the pixel-based A and B image distance. Given that α is tiny, it may be concluded that

$$\alpha \approx \frac{180}{\pi}\frac{|AB|}{D} = \frac{180}{\pi}\frac{|PQ|}{v}\frac{V}{D} = \frac{180}{\pi}\frac{|PQ|H}{h}\frac{H}{D} \tag{2}$$

$$|PQ| = \sqrt{\Delta x^2 + \Delta y^2} \tag{3}$$

where | PQ|'s vertical and horizontal components are Δy and Δx, respectively. The system's alignment controlling error has been defined at e pixels. In our system, if Δx < −e or Δx > e, the pan-tilt motor ordered by the computer to rotate horizontally in the direction of the target. When e > Δx > −e, the motor shuts off. The computer will tell the motor to rotate vertically in the direction of the target when Δy < −e or Δy > e. The motor terminated and the automatic-alignment is finished when −e < Δy < e. often h ≥ v (and H ≥ V). For instance, | PQ|/v = 0.01381 if e = 10 and v = 1024, and

$$\alpha = 0.7913 \times \frac{V}{D} \tag{4}$$

The alignment angle error is shown by this formula to be inversely proportional to the distance of UAV (D). The error of alignment angle decreases with increasing distance. If someone wants to maintain the error below 1, D shouldn't be much less than V whenever the distance is short. Due to the reported inaccuracies being between two and three, it appears that this alignment method is more accurate than others.

If the speed of the UAV is s, this will require Δt time for the UAV to fly from the center far of FOV, as seen below:

$$\Delta t = \frac{V}{2s} \tag{5}$$

As an instance, if V = 10 m, s = 2 m/s, then Δt = 2.5 seconds. To complete the alignment in no more than 2.5 seconds, the motor must rotate quickly.

Using MATLAB's BL-TSP and TSP, that put into action, had the ability to compute the results. Additionally, using and the MiXiM and OMNeT++ frameworks, that offer an effective, adaptable, and discrete network simulator, we replicated communication between the WSN and the UAV. Every UAV(θ, v) sends its current position, track angle, and velocity to the network manager. The sequence of communication between the WSN and the UAV is depicted in Fig. 7. Ten nodes are represent the nodes of gateway and 1 node here that represents the UAV. We presumptively believed that each gateway already has its data when simulating 1500 m × 150 m area. As a result, the UAV will travel the BL-TSP path and stop at each gateway. All gateways in the conventional data collecting have data, while all nodes responsible for sending the data to the base station.

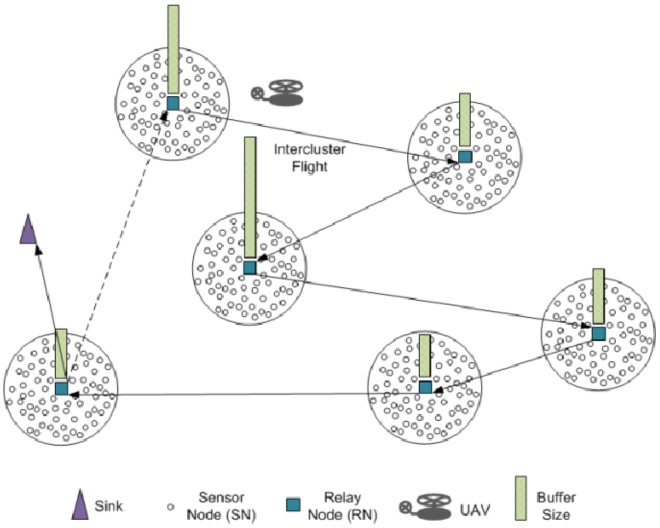

Figure 6: UAV and WSN Communication.

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We suppose that the UAV has a hub that continually searches for packets advertisements and entries of sensor node's coverage region. To communicate the sensor node with data before processing the connection event, central must first handle the advertisement event. There will still be sufficient time for collecting data while a UAV is flying slowly, but the region of coverage will be smaller. Therefore, it's necessary to lower the UAV to enhance its speed. The relationship between the connection time and velocity is depicted in Fig. 8. From what we see, the UAV may reach its best speed of 25 m/s when flying at a height of between 5 and 25 m.

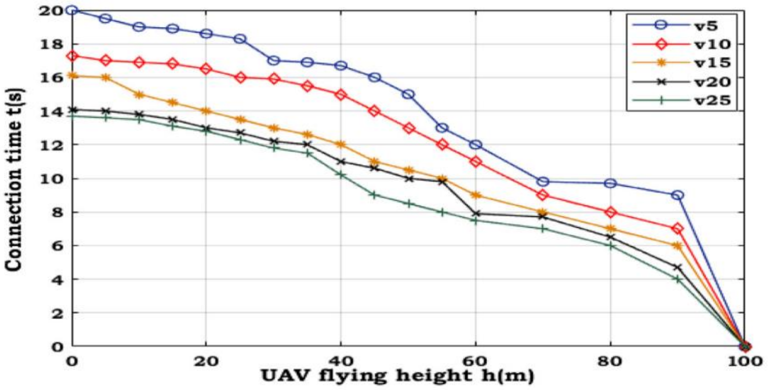

Figure 7: UAV flight altitude and data transfer rates for different UAV speeds.

The experiment was set up in accordance with the system concept, with an object used in place of the UAV for measuring convenience. See the image in Figure 3's upper right-hand corner for a pan-tilt with a pointing laser and digital camera installed on it. To reduce the interference from ambient light, an optical filter could be used before the camera lens. Set the following values: v = 1024 pixels, e = 10 pixels, and V = 1m. The object was randomly placed at eight different places between 1.5 and 6.5 m during the alignment experiment. Table 1 lists the errors that were measured, all of which are smaller than 1.

The experimental alignment system's temporal response curve is shown in Figure 3. The object representing the UAV was quickly moved to a different location at time t = 3 units (1 unit = 0.1 seconds), causing the system to be out of alignment at Δx = 160 pixels. The time it took for the system to regain alignment with x 10 was 1.6 seconds (16 units). The pan-tilt's rotation speed, which is what mostly limits response speed, can be increased by using a quicker one.

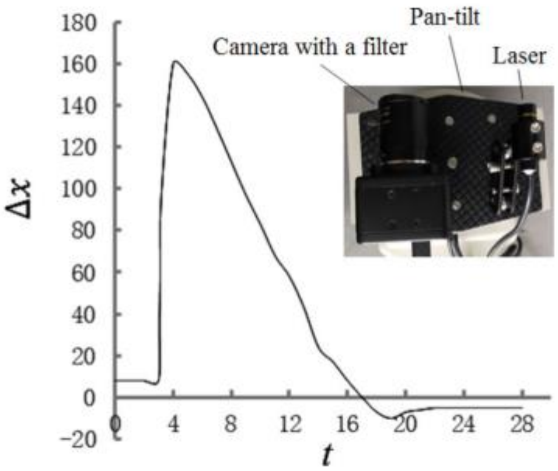

Figure 8: The experimental alignment system's time response [Color figure available at wileyonlinelibrary.com]

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