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Iot System Based on Drones for Public Safety and Search and Rescue Missions

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ABSTRACT. *Drones have features including creditable accessibility, flexibility in applications, fast response and low latency, and easily deployable to achieve difficult missions. Better yet, with the immense improvement in Internet technologies over time, multiple drones can be connected and form an Internet of Things (IoT) system. In this paper, we propose an IoT system based on multiple drones which are connected with each other, therefore automatically monitor and take responsibility in various scenarios. Public safety is an important application of drones, in which drones can be equipped with HD cameras, face recognition system and non-lethal weapons, thereby monitor and react to emergencies. Searching and rescuing have long been a time-consuming and laborious job, but with the help of searching drones that are equipped with GPS location modules and thermal sensors, it's possible to effectively conduct search and rescue missions without regard to light and obstacles. Limited coverage of cellular and wi-fi signals restrict people's work at times. This is no more a problem with the help of drone base stations, which can be deployed separately, therefore, extend the signal coverage. By analyzing these three scenarios and related technologies, we show that the performance of the proposed drone-based IoT system is helpful.*

KEYWORDS: *Iot system, Public safety, Search and rescue, Capabilities of drones*

1. Introduction

Drone, unmanned aerial vehicle (UAV) is defined as a flying robot, which is unmanned aircraft.

UAVs are used to facilitate military initially; however, they are often utilized in a broader scope as civilian roles ranging from search and rescue, firefighting, police to personal videography, agriculture, and delivery service owing to their conspicuous advantages and capabilities. The first advantage is the flexibility of drones. They can appear once needed and suit various situations. Drones, for instance, can be used as cameras for searching in remote areas where fixed cameras are not necessary and costly or in areas where people are hard to reach. They could search for those regions when people need to find someone or something. They are able to survey parks and know where hikers are located. Besides, drones have the capability of quick response with low latency while emergency situation. They can survey disaster areas, such as earthquake, flood, or hurricane zones and lift the sufferer up to the hospital or safe region immediately when they find someone is in danger. With these two benefits, drones based on Internet of Things system will be taken advantage in various fields because they allow people to solve plenty of problems in an efficient and safe way.

In order to reach the applications with a fleet of drones, the Internet and IoT system are fairly indispensable.

IoT system allows drones to achieve the maximum of capabilities mentioned above. When every single drone is connected mutually, a network is established, which provides a drone system with the connectivity. It enables drones to communicate efficiently and take actions without human command. The drone is expected to recognize the target and response or rescue the person by itself with the technology of automation and Artificial Intelligence at the edge based on the IoT system.

The paper is going to discuss three use case scenarios of drones in public safety and research and rescue with IoT system on section II, functions of drone-based IoT system on section III, system design for the use case scenarios on section IV, and conclusion on section V.

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2. Use Case Scenarios

2.1 Public Safety

The first use case scenario of the IoT system based on drones is ensuring public safety in various ways. Government invests a lot with facilities and humans, such as policemen, in public safety. However, drones are able to achieve the mission done by humans with higher efficiency. Several examples are listed below.

The first example is to use drones for surveillance, especially in urban areas. Police vehicles patrol on the street for the purpose of safety and security within a certain area. Policing drones are able to be connected to the autonomous police vehicles and to supplant traditional police vehicles to patrol without human beings. Autonomous police vehicles and drones are connected based on IoT system, so that drones are expected to fly to blind zones, such as off-street, autonomously to help the police vehicle to see more clearly in every corner. They all use graphic sensors and multi-hop technology which is to regard every drone as a node to communicate information.

The second example is to monitor a crowd, track a target, or even take action. When a concert is held or in the central area of cities, a crowd of people are walking on the street during the rush hours. Police vehicles are restricted to get into the crowd and the number of policemen is limited. Policemen are not able to survey efficiently. If a criminal runs into the crowd, they are expected to be encumbered by a number of people and cannot trace the criminal. In this case, a fleet of drones is able to search for suspects and ensure the safety of the public. When they detect the chaotic scene via graphic sensors, they can recognize and take actions under the technology of automation, such as alarming and tracking the criminal or even shooting the criminal without hurting any bystanders. Besides, if the number of suspects is two or more, a fleet of drones can separate and trace each suspect respectively without human intervention.

Fig.1 Police And Law Enforcement Drones: Drones In The Field [1]

The third example is to monitor traffic and solve traffic problems. If a serious accident, for instance, happened on the street or highway, drones are able to present the sign, such as “accident ahead” or “keep right”, to the following vehicles, in order to enable people to know the accident ahead in advance and provide them time to slow down or change lanes with low latency. The sign presented by drones can not only inform the following people but also direct the traffic in case of traffic congestion. Besides, drones are able to lift the vehicle, if it obstructs the road, to a safe area to reach smooth traffic. In addition, drones based on IoT system can identify speeding vehicles and drunk driving. They can catch and stop them before the intervention of policemen, which is more efficient and safer for the traffic.

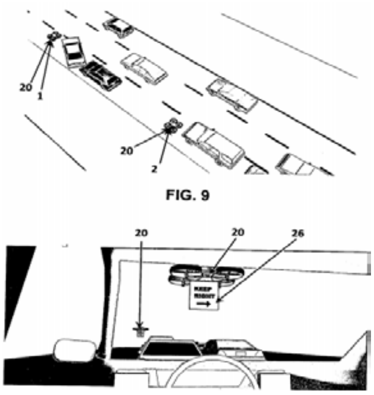

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Fig.2 Traffic Signs Presented by Drones

2.2 Search and Rescue

In this scenario, a set of drones are used to rescue missing targets. When humans or animals are trapped in a desert, a mountain, a forest or such wide-range and rural areas, finding and saving them became a significant problem. Sending a rescue team may spend days, or even weeks, regardless of the dangers that the rescue team may meet. The efficiency is too low, and the possibility of rescuing successfully is small. Also, using planes is not ideal, since pilots may not successfully find the destinations on such a big area. Also, when there is bad weather, or the area is covered by trees, the trapped targets can't be seen from the planes.

A network of drones greatly improves efficiency, reduces the danger and increases the possibility of finding the target. The system is formed with several drones. They are separated over the sky, communicating with each other through electromagnetic, so that each of them can fly in a certain area, which can improve efficiency and save energy. They are equipped with thermal sensors and GPS locating modules. When they sense the target, they go down to the target and take a photo, then immediately send the data to the database. The data includes location and images. Drones send messages through multi-hop. Considering the loss of wi-fi and cellular signals in rural areas, drones can use physical ways to transmit data. They fly back to the ground station. When the ground station gets the message, it immediately sends transportation drones to the target. The transportation drones have the ability to lift people up and carry them to the ground station.

Fig.3 Drone-Base Stations[2]

After combining with drone-based signal extending technology, the drones can also transmit data by multi-hopping. Several drone-base stations will be sent together with the searching drones. They are separated evenly, each of them is responsible for covering a given region. With the help of the drone-based stations, searching drones can easily transmit data through multi-hop. This greatly reduces the transmitting time and increases efficiency. Besides, with this technology, the trapped people can easily communicate with the ground station so as to help the operators confirm the situation.

In order to make sure that every drone is online, not losing the connection, every single drone sends a signal to the database and other drones every 30 minutes. Once the signal is lost, the database can let other drones to set out and look for the lost one, which has a GPS chip in it.

2.3 Drone Base Station

A complete network is always essential to remote communication among devices. In most of the modern cities or even suburbs, there is always sufficient infrastructure which can support the communication network, such as Wi-fi access points and cellular base stations. However, there are still a lot of conditions where infrastructure is totally absent, such as some remote areas like mountains or forests, or the places stricken by some disasters, where infrastructure is seriously destroyed. Traditionally, there may be little communication means. Some base station may be carried in by cars, which are not quite mobile. Which is more often happening is that searchers have to fix the damaged base station in the disaster-stricken area. Drone base stations can be a much better resolution. It can provide a better and bigger signal coverage, as it can be high in the sky. It can also provide good mobility, which can be quicker-response to the problem.

Here is the working process. First, a drone is sent to the target place. This drone is equipped with a high definition camera. After arriving at the certain place, the drone will patrol around the place in a pre-programmed way and continuously transmit video back to the database, and the database can analyze the information it

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gives(mainly the landscape), and transmit a request to the drone station, indicating the number of drones it will send.

Secondly, a fleet of drones is sent to the target area. These drones are equipped with multiple devices. Firstly, there is a mini base station on each of the drone, which enables them to spread cellular network in certain range. Secondly, they also have ad-hoc network interface, which can let them transmit data through the ad-hoc network composed of all these drones. Thirdly, a GPS system is equipped on them in order to get their positions.

After arriving in the target place, the drones are distributed in the pre-programmed way. With the mini base station on, they are able to spread the cellular signal. The drones can then adjust their positions in two ways. One way to adjust the position is according to the ad-hoc network connection between all of them. In this network, they can share their position information with each other. This can not only avoid physical collision of drones (when they go too close, they will change their direction), but also avoid jamming from each other (if the base stations are too close, there will be some interference from each other). The other way to adjust the deployment is directed by a special algorithm stored in each drone, which is called GTDMA. In a word, this algorithm enables the drones to make best use of its base station resource. As a result, the packet throughout in total can rise in a large scale.

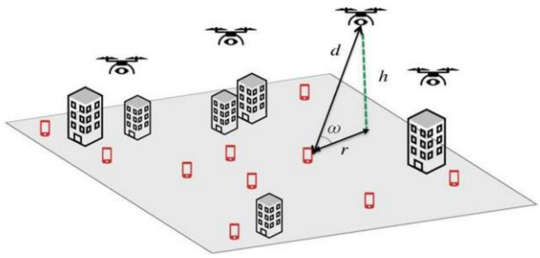

Fig.4 Rough Module for Drone Base Station [3]

3. Functional Description

In all systems and applications of drones, UAVs work in an identical procedure and use similar technologies. First, drones are expected to search and survey to collect data from the ground. Second, they send the data to the stakeholders through the communication of drones and the data will be solved to be ready for the response, or make decisions by themselves. Finally, drones are able to take actions according to distinguished situations autonomously. To achieve the process with a maximum capability of the drone system, the following technologies are required.

3.1 Drone Autonomy

The first generation of drone system has been designed with fairly limited abilities affecting its flexibility and effectiveness. Human authority over the mission execution has some weakness in the system. The communication link introduces latency that hinders the operator to provide feedback and reaction efficiently. UAV autonomy is a feasible way to overcome this problem. Autonomy allows drones to command and control themselves, which diminishes human errors and enable operators to concentrate on missions. It also reduces the susceptibility of ephemeral communication link loss, because the autonomy is expected to replan the mission in case of the loss of communication link.

The development of autonomous capability is significant to the IoT system based on drones. The autonomy allows drone system to take decisions by itself and to react with low latency. It is also an essential factor for long surveillance mission because the autonomy is able to reduce the operator workload and the data link bandwidth requirements.

Five levels of drone autonomy are distinguished. Level 1: Low automation --- humans are involved in the control of the operation and the safety of the drone, but the drone can take at least one fundamental function. Level 2: Partial automation --- pilot is still responsible for the control of operation but the drone is able to take over control of altitude, speed, and heading. Most of the drones are currently at this level. Level 3: Conditional automation --- the drone can fly itself and notify the pilot if the intervention is needed, so the pilot is the fall-back system. Level 4: High automation --- the drone is embedded in a built-in system and be able to sense and navigate itself. Level 5: Full automation --- the drone is able to control itself all the time without expectation of human intervention. It uses AI tools, autonomous learning system, to plan its flight and make decisions. [4]

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IoT system based on drones is reaching full automation. With a higher level of automation and less human interface, the drone system is expected to finish more convoluted missions.

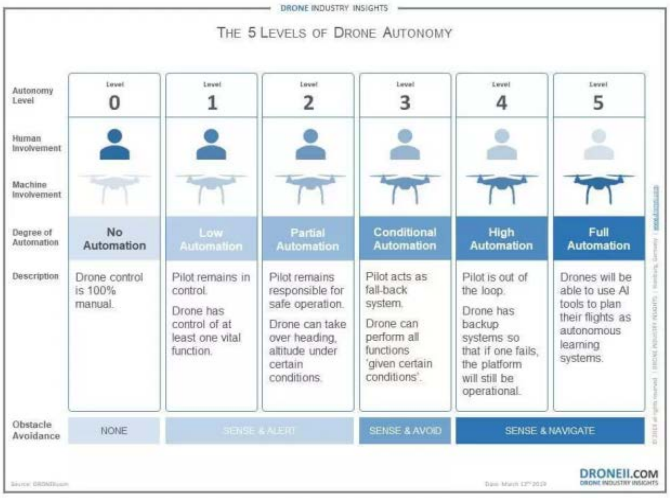

Fig.5 The 5 Level of Drone Autonomy [5]

3.2 Route Planning

A task allocation program will be used to give every drone an area to take care of, since it may take ages for a single drone to monitor a large region, and the data transmission may become hard as multi-hop isn't available. In order to increase the coverage area and the efficiency of observing, every drone should follow a certain route when patrolling or searching. Considering the regional topography and the sensing range of sensors, different drones should follow different paths in order to effectively and completely monitor the region it's responsible for.

A drone flight path is a set of waypoints that are sequentially linked up, which are shown in the form of coordinates. The drones can't be too far from the ground because of the limited sensing range, so their flight route depends on the change of landform in the mountain areas and the arrangement of buildings in the city areas. Considering the buildings or the mountains, the flight path of the drones should be three-dimensional so that the drones can avoid collision with those protruding structures. In order to construct the reasonable arrangement of these waypoints that can adapt to the given terrain, special small-sized drones will be sent. They are equipped with GPS locating modules, laser rangefinders, and HD cameras so as to sketch out a three-dimensional image with multiple layers.

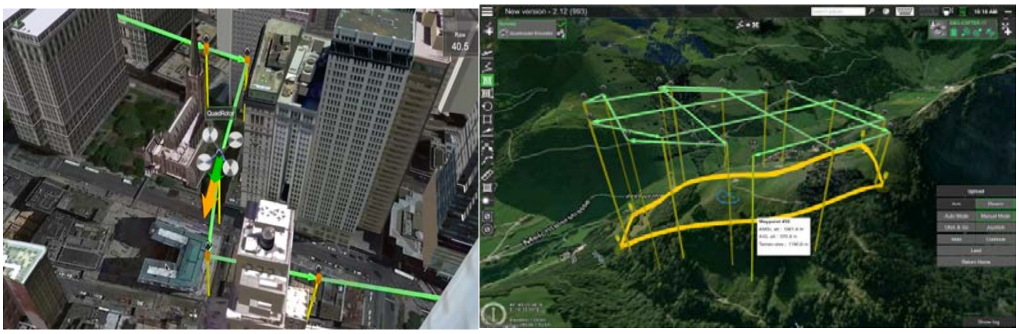

Fig.6 Drones First Detect the Local Landform [6]

Two drones need to be sent every time because they need to figure out the space coordinates of the obstacles. Each point in space is imaged in both two cameras, and the corresponding coordinates of the point in the two images are obtained separately. The data is transmitted to the ground computing station in real-time during the measurement. Through mathematical algorithms, the space coordinate of every point can be worked out. After the data is processed carefully, a 3D spatial model of the given region is formed.

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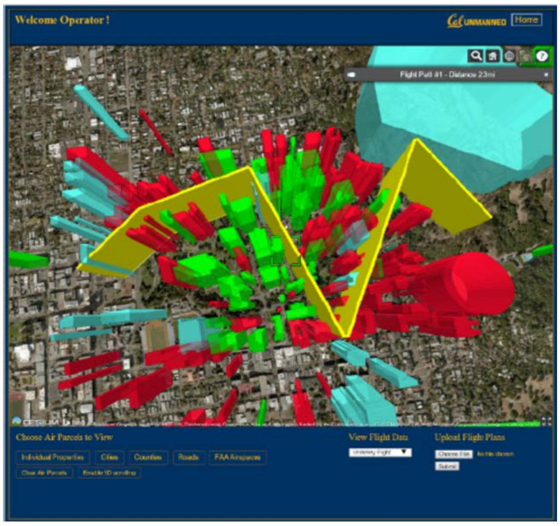

Fig.7 3d Spatial Models [7]

Using the 3D spatial model, the computing station can figure out the appropriate flight route of the drones. By going through the given route, the drones can cover every area in the region without colliding with obstacles.

Fig.8 Appropriate Routes Help Uavs Work [8]

The planning system is an important part of the drone system, since it greatly improves efficiency, and reduces the physical danger.

3.3 Ai Platform

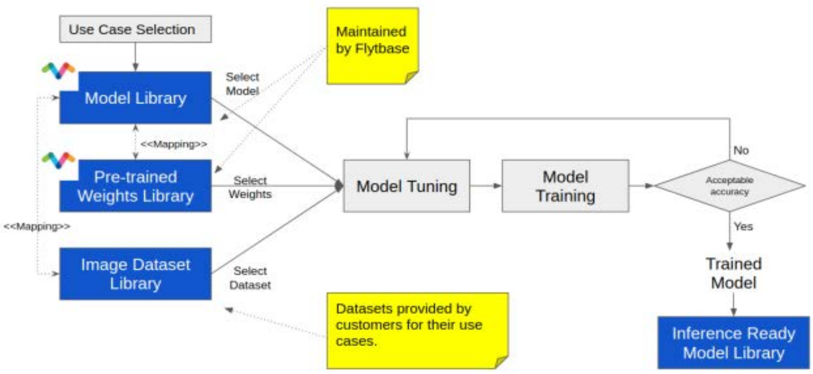

Fig.9 Workflow of Ai Platform [10]

The AI-based platform allows drone system to reach a higher level of autonomy. Drones collect a huge amount of data including videos and images. AI platform provides solutions to identify the objects and count

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them or detect change. The cloud-based training system allows the acceleration of training models and to suit various mission requirements. The trained model can be deployed in the cloud or on the edge for real-time analysis based on the use case. [10]

Flybase provides the AI platform which is based in the cloud and used for object detection, object counting, image segmentation, change detection, and image classification. The workflow of the AI platform, including preparing datasets, training models and deploying trained-models for inferencing, has been automated. It allows for fast response and low latency.

3.4 Wireless Mesh Network

Wireless Mesh Network allows data to be transmitted at a high speed and overcome the lack of communication infrastructure and maintain short-term communication in the disaster area for instance. Besides, it is able to increase the distance of communication via wireless mesh topology using a wireless LAN. Mesh nodes are connected to each other and each node is a host and router. Thus mesh network is able to enhance the communication capacity by increasing the number of nodes and hops by using hardware-based on IEEE 802.11. Drones are designed to provide high-speed Wi-Fi via a wireless mesh network. [11]

A scenario uses drones as hopping devices to provide wireless network shown in figure 10. A fleet of drones are dispatched by the base station to the area and distributed at

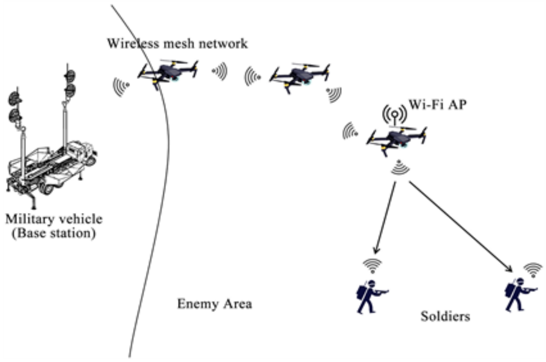

Fig.10 the Scenario of the Wireless Mesh Network (Military Environment) [12]

Regular intervals from the base station to the destination. They offer high-speed Wi-Fi to the region by searching surrounding drones to build a wireless mesh network automatically.

3.5 The Use of Cellular

Drones connected by cellular:

(1)Drones have been used in a wide range of fields, including policing, searching and rescuing, communication enhancing, etc. All the applications of multiple drones require communication methods, so as to form a completed network of drones. In order to fully establish the Internet of drones, perfect and efficient ways of communicating must be combined with the drone system. The aim is to realize high-capacity data transmission in a limited bandwidth. The key technology is cellular communication.

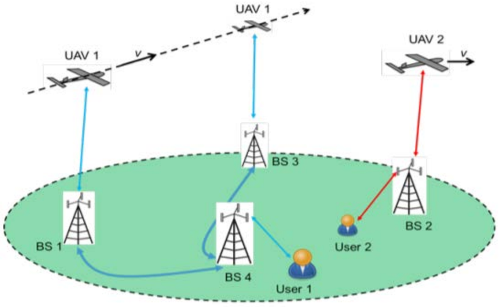

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Fig.11 Cellular-Connected Uavs [13]

The traditional method of controlling drones remotely is through radio wave. Owing to the improvements of LTE and 5G technology over time, cellular communications have a lot of benefits, including safety, high capacity, dependability, long range, quick response, etc.

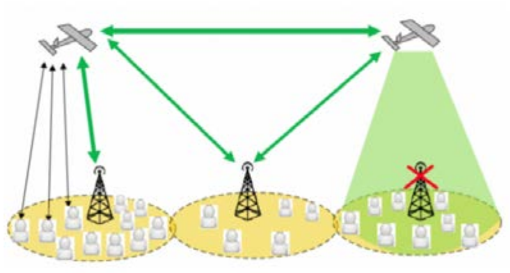

Fig.12 Uav-Assisted Cellular [14]

Better yet, drone-base cellular stations can be applied. Comparing to installed infrastructures, drone-based stations are cheaper, more convenient and more flexible. They can be connected to working drones and central databases. Therefore, it helps to establish an automated system consisting of drones.

(2)However, drones are deployed in three-dimensional space, but the current cellular network aims at serving the ground units instead of flying objects, so the existing cellular structure may not reach the goal of reliability and low latency. Related issues include spatial deployment, mission allocation and data transmission of drones.

To solve the problem, a three-dimensional cellular network has been proposed.

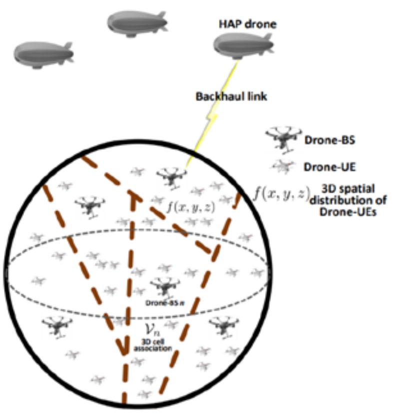

Fig.13 the Proposed 3d Wireless Network of Drones [15]

In the structure of the spatial network, there are several drone signal platforms at high altitudes, which offers responding connection to drone-based aerial stations. The separated multiple stations can form a complete three-dimensional network system with multiple layers. With the help of this spatial network structure, drones are able to establish communications of high capacity and low latency.

3.6 Types of Sensors

(1) Thermal sensors: Thermal sensors sense all kinds of thermal from people, animals, machines, plants, water, etc. They can figure out thermal images. The thermal sensor is of great value in searching, rescuing and firefighting, for they can detect signs of life at any time, regardless of the landform, temperatures, and light. They can also determine the current situation of the source of heat. For instance, it is used in estimating the situation of fire and reflecting the physiological signals of lives. Distance sensors

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(2) Distance sensors can sense the distance between drones and the targets, which is important in scientific research and 3D mapping. It is widely used in route planning, for it can avoid collision and help working out 3D spatial models.

a. Laser rangefinders

b. Radio detection

c. Magnetic field change detection

d. Sonar-pulse sensing: sending out sound waves at a certain frequency. The benefits of sound waves are strong penetration. They can transmit through long distances. Sonar technology is often used to sense underwater objects.

(3) HD cameras: HD cameras enable drones to take images with high quality. It is an important part in policing, since face recognition system, number plate recognition system, safety surveillance and emergency managing require images that show every little detail. drones with HD cameras can be combined with installed cameras to form a complete surveillance system with no dead angles.

(4) Chemical sensors: it senses certain types of chemicals in the environment. It is widely used in scientific research and working protection. It can go to an unknown environment and sense the potential chemical risks, therefore reduce the danger for people.

(5) Orientation sensors:

a. Accelerometers: sensing the movements made by the drone.

b. Inertial measurement sensors: it senses slight changes in the moving direction of drones.

(6) Temperature sensors

(7) Light sensors

4. Conclusion

In this paper, drones, as an important part of Internet of things, is mainly discussed. Three use case scenarios are proposed, consisted of public safety, search and rescue, and drone base station. Then, a general working process is presented, including information collecting, information analyzing, and reacting. In order to carry out the working procedure well, several functions have to be performed. This includes automation of drones, route planning, AI platform, wireless mesh network based on Wi-Fi, use of cellular, and multiple types of sensors. From the whole paper, great potential of drones IOT system has been shown. It not only has all the advantageous of the drones (accessibility, flexibility, fast responsibility, and good deployability), but also includes all the features of the IOT system (autonomous, flexible data exchange). Further studies of more use case scenarios of drones and more enabling technologies can be developed in the future.

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