Situation-Aware Conditional Sensing in Disaster-Prone Areas Using Unmanned Aerial Vehicles in IoT Environment

J. Sathish Kumar, Mukesh A. Zaveri, Saurabh Kumar and Meghavi Choksi

Abstract Environmental sensing is the most crucial task that needs to be performed in order to analyze the situation of a region during a disaster. The devices deployed in such regions are responsible for sensing and communication effectively. During a disaster, the operation of these devices may be affected by the environmental conditions and their respective power constraints. Moreover, the mobility of these devices in the network leads to a challenging task to perform sensing and communication in such an environment. The disaster recovery may need different sensor data at various points of time. In such cases, the selectivity of data from different sensors and its dissemination in real time are the most important tasks. In this paper, the proposed algorithm is based on the situation-aware conditional sensing for disaster-prone areas using unmanned aerial vehicles. The technique presented in this paper focuses on the control of way points of the aerial vehicles based on the events detected in the Internet of Things environment.

Keywords Disaster management · Unmanned aerial vehicles · Internet of things

1 Introduction

The disaster management is a crucial research problem that needs attention to address various critical problems such as environmental monitoring, real-time data collection,

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rescue recovery operations. It is reported that in the last two decades, approximately 400,000 lives were lost all over the globe in total [1]. However, due to the technological advancements, it is possible to handle the effects of the disaster to a certain extent. The most important challenge in such situations is the real-time surveillance [2] and communication [3]. In addition, the adversity faced in the case of a disaster demands that all the above-mentioned challenges must be solved intelligently, preferably using automation. The real-time support must be provided irrespective of the disaster type, i.e., natural or man made [4]. A glimpse of various disaster types such as fire and smoke in a building due to terrorist attack, extreme fire in the forest, road damages due to landslide, heavy flood, etc., is shown in Fig. 1 [5]. These situations need to be sensed both in pre-disaster and post-disaster cases. The sensed data in the disaster environment must be communicated to the rescue team for preparing the solution strategy, by bridging the gap between distance and time. The Internet of things (IoT) environment provides a mechanism, with which the real-time sensing can be communicated to any place at anytime from anywhere [6]. However, the IoT environment must be configured and organized in such a way that an optimized communication should result into automation of tasks, reducing the faults and failures in the system. During the disaster, the real-time data collection needs sensor devices, which are responsible to sense the situations under surveillance. However, these sensors are very low-powered and energy-constrained devices. Due to this limitation of the sensing devices, there is a need of IoT device to be computationally efficient ultimately making it energy efficient using Internet. The IoT environment provides collaborative processing among sensing devices and IoT devices that best suits these requirements [7]. The rescue operations and the response in the case of a disaster must be automated using these IoT devices, so that human lives are not lost in this process. Due to the adversity and danger in the case of a disaster, these IoT devices must be protected from the physical damage which is a precautionary requirement.

The unmanned aerial vehicles (UAVs) [8, 9] may serve a great purpose in such scenarios as discussed above. These vehicles may be operated from anywhere, at anytime, and to the distances that depend on the requirements of the situation under observation. UAV is a mobile device and can be controlled by an IoT device for fulfilling the requirements of real-time communication over the Internet from anywhere to the desired place [10]. Figure 1a depicts the fire and smoke situation in a building. In such a case, the sensor devices are deployed in and around this building. These devices sense different parameters and report the abnormality conditions to the ground control station. In this regard, the dynamic network is to be set up for the ad hoc data acquisition and on the spot monitoring from all possible directions. The UAV is responsible for monitoring and data collection using these deployed devices because of the hostile and restricted entry situations. It is mandatory to have knowledge of the safe distance of operation for the UAV as incidences of fire and smoke may affect the operations of the sensing and communication. Further, in the case of any abnormality observed by the UAV, it must be able to respond and rescue itself. Therefore, the two basic requirements that may be outlined in a disaster scenario are (1) for real-time response, the effective sensing, and communication operation and (2) the protection of UAV devices involved in the operation.

Fig. 1 A glimpse of various disaster types [5]

This paper focuses on the use of UAV with the help of an IoT device to collect the sensed data from the sensor devices in case of a disaster. The situation-aware conditional sensing mechanism is considered to address the problems as specified above. There is a necessity to communicate the information in real time, even in adverse situations instantly and protect themselves so as not to burden the operation in terms of cost. The validation of various situations under observation is performed by providing different conditions to the UAV device for enhancing its automation in total. The simulation is performed in IoT environment using DroneKit-Python simulation tool [11], and the experiments were performed on an actual drone.

The rest of the paper is organized as follows: Section 2 discusses the proposed algorithm that is used to validate the effectiveness of the UAV operation. Section 3 presents the implementation of the proposed algorithm and explains the situational awareness of the UAV in different scenarios. Finally, Sect. 4 concludes the work.

2 Proposed Algorithm

In this section, the proposed algorithm performs the sensing and communication using aerial vehicles by including various conditions. In this context, the problem is formulated using different notations. Let us assume a geographical region, R. This region may be a city, a forest, a rural area, a coastal area. Let us assume that the region R is subdivided into n smaller subregions such that $R = (R_1, R_2, \ldots R_i \ldots, R_n)$. Such divisions are needed to perform the area monitoring effectively and with ease. The division of the region depends on different factors related to the type of region or the type of disaster. In this context, the disaster may be a fire in a building [12], a flood [13], or a damage to structures such as flyovers, heavy machineries, highways [14] or rescue of a group of people lost in the forest [15]. The glimpse of various disasters is shown in Fig. 1. It is further assumed that the sensors deployed in the region R are for sensing different environmental parameters, such as temperature, pressure, humidity, stress, strain, atmospheric pressure, luminosity.

Under such circumstances, there is a need to identify the subregion R_i, where a critical situation has occurred. This is done based on the abnormality observed in the sensing parameters of the sensors operating in R_i. Next, for monitoring the situation specifically in the region R_i, the mission planning for UAV navigation at different locations within R_i is performed at the ground control station. A ground control station is a place where the trajectory planning and tracking of the UAVs are performed. For the real-time analysis, communication between UAV and ground station is performed using the Internet. In this context, the proposed algorithm works in two steps. In the first step, the UAV senses the situation of environment on the fly using various sensor devices. In the second step, the algorithm helps the UAV to make the decision dynamically based on the environmental conditions. After the surveillance and real-time communication of various parameters that are required, the relief response team is dispatched to the most required place in the disaster site.

In the second step, for the dynamic navigation of the UAV, various conditions are considered and incorporated in the UAV. To perform this dynamic navigation operation of the UAV, let us assume that there are m different parameters sensed in the region such that $P = (P_1, P_2, \ldots P_j \ldots, P_m)$. These values are collected by the aerial vehicle, and the collected values are sent to the ground control station. For instance, it may be possible that the temperature sensor shows more abnormality in its reading as compared to the other parameters. Let this be the jth parameter in the region where the disaster has occurred. Based on this gathering of the sensed data, two types of threshold can be determined viz maximum and minimum values of the parameter P_j. There are four different conditions that may be used to navigate the UAV successfully. If the value of P_j is greater than the threshold maximum, observed at the region, then an alert is generated. Similarly, if the sensed value of P_j is lesser than the threshold minimum, then there may exist two different scenarios. Scenario 1 may suggest that the region is not under disaster, whereas on the contrary scenario 2 suggests that there is a false alarm. In both the cases, the alert is generated. Once the alert is triggered, then the UAV may skip the remaining locations given in the mission plan and make an immediate decision to return back to its launch location. If the above-mentioned cases do not occur, then the UAV needs to continue the navigation through the planned path as per the mission to reach the next location for surveillance. The collected sensed information is communicated to the ground station in real time. Following any sensed anomaly, the relief operation at the site is executed. The relief operation can be initiated in two ways: either after complete monitoring of all the locations in the disaster region or at each and every location in the planned mission. In the second case, the UAV sends the recorded parameters continuously to the ground station in real time to prepare for the further solution strategy relevant to the problems faced at the disaster site. The proposed algorithm is explained in brief in Algorithm 1.

During a disaster, there are three most crucial operations that need to be performed. First, the real-time data must be sensed and communicated to the ground control station. This helps in formulating the strategy for the disaster relief. Second, the disaster site R_i must be isolated from the other regions of R, such that the operation surveillance is focused on only R_i. Third, the relief response must be provided in real time, with no loss of life. The proposed algorithm uses UAV as a part of the disaster response team to collect real-time data from the sensors deployed at the disaster site and communicate this data to the ground station using IP-based communication. Finally, the relied response may be provided in real time using UAV without causing a threat to human life. This process of situation-aware conditional sensing of the environment using IoT network may prove to be an effective mechanism in disaster situations. The implementation of the proposed methodology is discussed with different scenarios in the following section.

Algorithm 1: Condition-based Sensing Algorithm
Require: Sensing device, UAV, and m reading parameters
Ensure: Relief response at disaster site, protection of UAV during relief operation

Define a region R. Subdivide R such that $R = (R_1, R_2, \ldots, R_n)$.
for disaster observed in R_i region do
/*Define Thresholds */
Estimate max and min values of parameter P_m.
if $val(P_m) \geq max(P_m)$ then
/*Alert Is generated */
Navigate UAV to launch location.
else if $val(P_m) \leq min(P_m)$ then
/*Alert Is generated */
Navigate UAV to launch location.
else
Continue the navigation through the mission path.
end if
Communicate the data collected to ground station.
end for
Perform the relief operation.

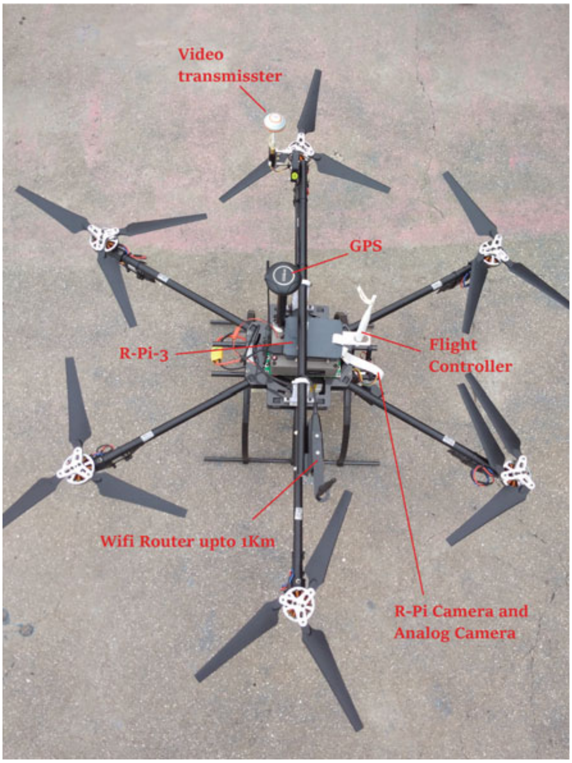

Fig. 2 UAV with its specifications

3 Scenarios and Results

In this section, for demonstrating the proposed algorithm using UAV, DroneKit-Python [11] is used and simulation is performed. DroneKit-Python is a simulation tool that allows the developer to control the navigation of the UAVs. Additionally, the mission planner tool [16] is used to track the navigation of the UAV in the region. After successful simulations, the scenarios are emulated using the actual UAV. As shown in Fig. 2, the Hexa Drone with high stability incorporated with GPS module, Raspberry Pi 3 onboard microcontroller with pi camera, high accurate flight controller, high-resolution video transmitter, analog video capture device, and lithium-powered battery of 20 min fly time is designed for the purpose of post-disaster management and surveillance. The glimpse of the drone on the fly for surveillance is shown in Fig. 3.

For the purpose of demonstrating the different scenarios, initially, a region of interest is defined as shown in Fig. 4. In the case presented in this paper, the region of interest, R is outlined using Google maps on mission planner, which consists of three department buildings, residential hostel, playground, health center, and few forest areas. Further, the whole region is partitioned into nine different subregions given

Fig. 3 Snapshot of on-the-fly UAV

by R = (R_1, R_2, …, R_9). These subregions are as shown in Fig. 5 with boundaries. Let us assume that a disaster occurs in region R_1 and the unnatural fire condition is considered as the disaster for experimental purpose.

In such a scenario, the unmanned aerial vehicle is dispatched to perform the surveillance operation, and at the same time, real-time communication of the sensed information is sent to the ground control station. The UAV is instructed to navigate through the region of disaster, which is shown in red color and performs the sensing and real-time communication operations at eight different locations, L = (L_1, L_2, …, L_8).

The planned mission with the waypoints of the UAV is shown in Fig. 6, and their respective locations are summarized in Table 1. These eight locations are the critical points from where the required parameters are needed to be sensed. In our case, the abnormality in temperature value needs to be sensed by the onboard system in the UAV. The basic mission plan instructs the UAV to start its flight from the home

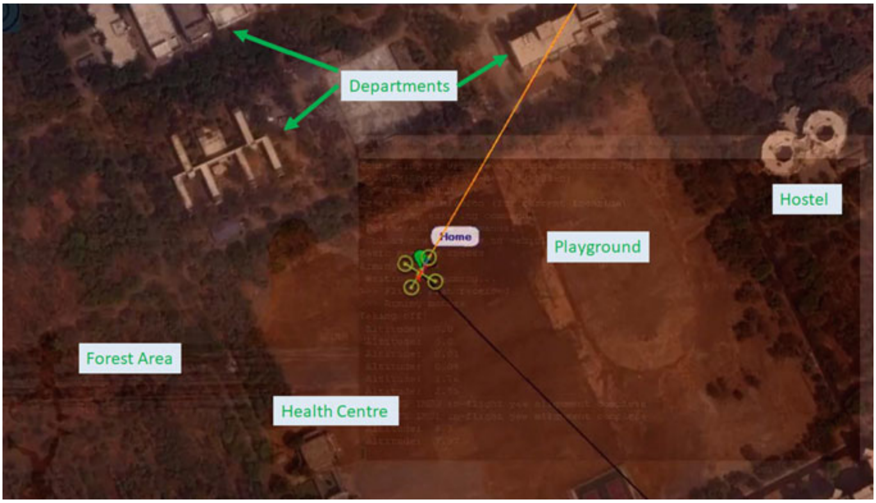

Fig. 4 A demonstration of region of interest in our campus

Fig. 5 Occurrence of disaster in region R_1

location and sense the parameters at eight locations before returning back to its home location again.

The ground station provides the UAV with an approximate maximum and minimum values of temperature in the disaster region. The threshold of the minimum and the maximum values is assigned during the experiment with 25 and 35 °C, respectively. During its flight from one location to another, the UAV senses the temperature value and communicates this information to the ground station. For the verification

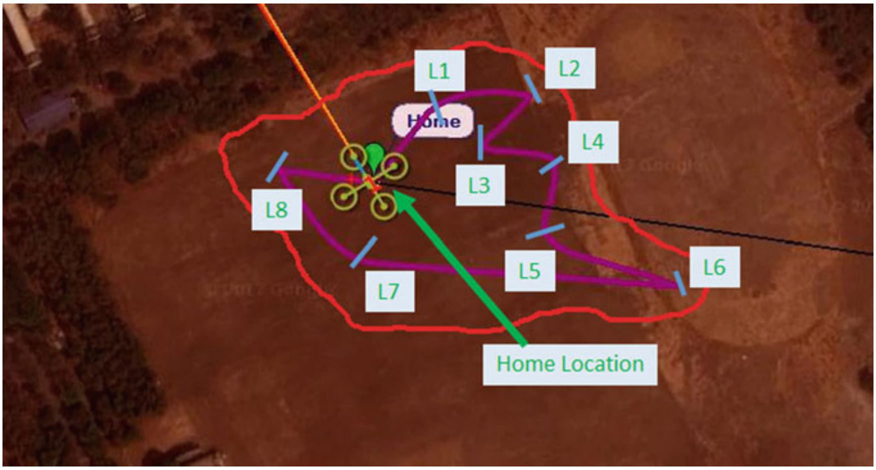

Fig. 6 Basic mission plan of UAV to sense the disaster region

Table 1 A summary of locations for navigation of the aerial vehicle

Location ID	Latitude	Longitude
Home location	21.161580	72.785524
L_1	21.161925	72.785813
L_2	21.161915	72.786162
L_3	21.161720	72.785974
L_4	21.161680	72.786280
L_5	21.161370	72.786210
L_6	21.161180	72.786776
L_7	21.161275	72.785417
L_8	21.161625	72.785132

of our proposed algorithm, three scenarios are demonstrated. In the first scenario, a false alarm is created by altering the temperature value in the code, i.e., by giving 23 °C, which is lesser than the minimum temperature threshold provided to the UAV. In such a case, the UAV generates the alert and returns to the home location at L_3, as shown in Fig. 7, where the UAV path tracking is depicted. Similarly, the second scenario is demonstrated as shown in Fig. 8, where the sensed temperature by the UAV is more than the maximum threshold. In this case, the UAV senses 39 °C at a location L_6 that is more than the maximum temperature range provided to the UAV. In such a scenario, again the UAV generates the alert and returns to the home location, as the UAV is vulnerable to get affected by the ambient condition and there is a possibility of crash. The UAV tracking in mission planner is shown in Fig. 8. In the third scenario, if the UAV senses the temperature within the specified range, then the UAV should navigate through each location of the disaster region. While navigation, real-time communication of the sensed information to the ground control

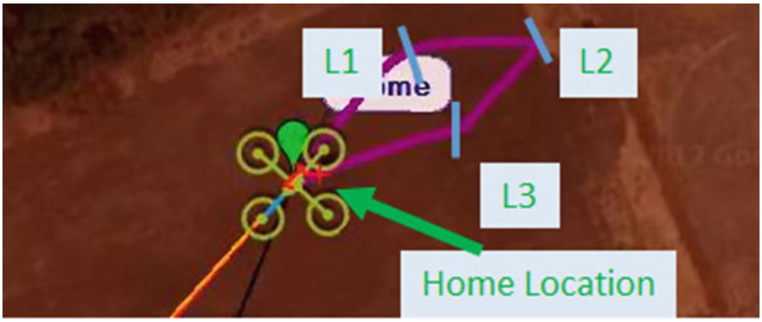

Fig. 7 UAV returns to home location in the case false alarm at L_3

station is performed. In this way, the control station knows the exact condition of the site through parametric sensing report received from the UAV. The full mission traversed by the UAV is as depicted in Fig. 9. Once the navigation area of the disaster site is decided successfully, there is a requirement to carry out disaster relief operation. However, the UAV performs the situation analysis by considering the various parameters and continuously evaluating the given conditions during the disaster. The disaster control and corresponding recovery are very crucial operations and need to be carried out with minimum risk of human lives. In this paper, the real communication using Internet enables the UAV to send the sensed data to the ground control station or to the cloud. Further, the real-time streaming of video using Raspberry Pi camera and analog camera is sent to the ground control station for accurate analysis. Therefore, the application of the IoT in such a scenario is efficient by using the automated devices as an integral part of the rescue team. This paper addresses these concerns by the use of the UAVs for relief operation and providing a mechanism for dynamic navigation, which is an essential requirement for such applications in order to save human lives.

4 Conclusion

The disaster management and the response are very critical that need to be performed in an effective way so that many lives can be saved. There is a need of real-time response in the disaster scenarios. Moreover, the sensing and communication tasks must be performed in such a way that the rescue can be carried out speedily. In this paper, the use of the UAV is demonstrated for strategy formulation of rescue team during disaster to sense the critical parameters at disaster site and accomplish the real-time communication to the ground station. In this context, the use of the UAV for real-time sensing and communication and an algorithm to protect these vehicles during extreme conditions is addressed. The implementation of the proposed work is performed using DroneKit-Python simulation tool and emulated the scenarios using

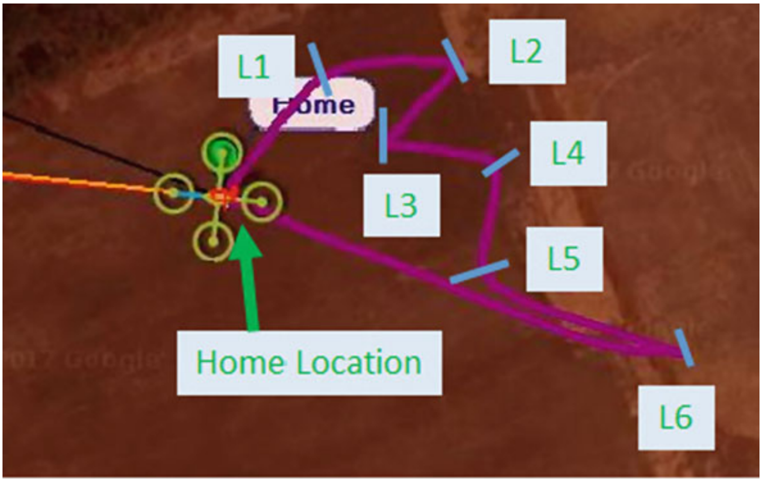

Fig. 8 UAV returns to home location while exceeding the threshold range at L_6

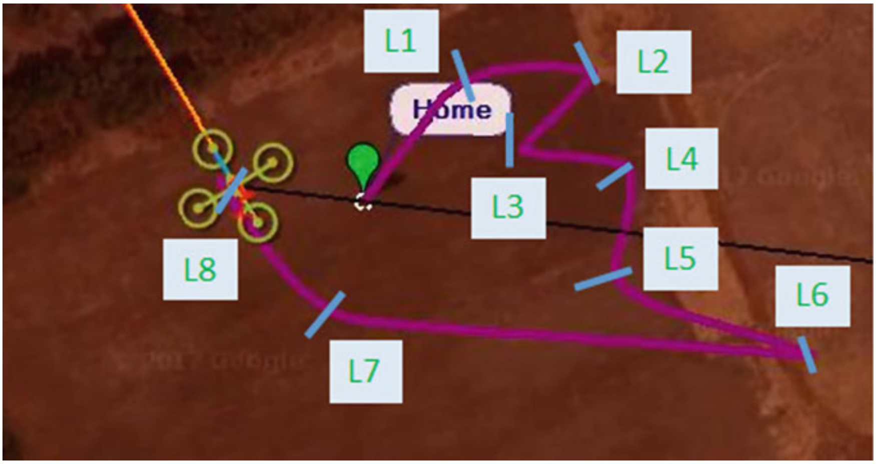

Fig. 9 UAV sensing values at eight different locations

actual drone developed for post-disaster management and aerial surveillance with the aid of mission planner tool. In the future, the proposed work can be tested for its efficiency with several parameters in extreme conditions.

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