Review Article

Internet of Things (IoT)-Enabled Unmanned Aerial Vehicles for the Inspection of Construction Sites: A Vision and Future Directions

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Today people are witnessing the rapid evolvement in every area. This is because of the emerging trends in communication technology and autonomous unmanned vehicles. These trends have led us towards the high standards of health, energy, transportation, monitoring, and surveillance of huge domestic and industrial projects. Thus, this review paper presents the integration of the latest trend in communication technology, i.e., Internet of things (IoT) with unmanned aerial vehicles (UAVs). This manuscript not only reviews the use of IoT-enabled unmanned aerial vehicles for inspecting the several construction sites but also emphasizes the utilization of such IoT-enabled autonomous aerial vehicles for ensuring the health and safety measures at the site. It discusses the major limitations and shortcomings of state-of-the-art techniques for the same purpose, i.e., optimization issues in path planning, lightweight artificial intelligence (AI) and computer vision algorithms, coordination in communication using IoT, and scalability of IoT network. Thus, this paper shall help the reader to explore different open research problems in-depth.

1. Introduction

It is observed that the population of this planet is rapidly increasing, and it is an intellectual guess; this number is likely to double by the 2060s. Today's modern facilities of metropolitan cities have attracted and even compelled many of the families and individuals to migrate from their native rural places to these urban and smart cities. This movement from rural areas to smart cities has brought several challenges for the local city government to ensure the standard and quality of life. In such conditions, one of the options for administrative staff is the effective and smart use of the Internet of robotic things (IoRT) [1]. Apart from managing the resources, these IoRT strategies will be used effectively in monitoring the progress of various online and offline construction sites. The terms online and offline construction sites illustrate the nature of site such that the sites where material for development is purchased from other out-sources that are far, are known or labelled as online construction sites whereas the sites where the material is produced, i.e., concrete, are known as offline construction sites. Such utilization of IoT-enabled drones or IoRT will enhance the level of updating the progress to the supervisor or site manager within a short time. There are several IoT-oriented applications that one may find in the previous research work [2]. These applications have been proposed to improve several domains, i.e., public health sector, mobility of goods, water resource management, waste management, smart environment, and government [3].

In this paper, the authors performed a deep review of the published works regarding IoT-enabled drones and shall discuss the technical shorting comings of the topic. Furthermore, this manuscript covered different strategies (latest and futuristic) that will support the use of IoT-enabled UAVs in applications. While studying the different research papers, it has been observed that these UAVs are utilized in several applications as shown in Figure 1. Historical background shares that such drones were initially used by military services, but nowadays these UAVs with IoT add-on also used a lot in civil applications such as infrastructure inspection, public safety, traffic control, agriculture, and crop health surveillance, leading us to enjoy several perks. The usage of UAVs in the construction industry will be a cost-effective solution [3] because of the flexible manuovers of UAVs at most of the dull, dirty, difficult, and even dangerous locations. This makes the proposed solution one of its kinds. These IoT-enabled drones can fly over the objects with accurate altitude and acquire the best quality pictures using a high-resolution camera to further process it via machine algorithm and IoT like applications to update the progress of any construction site either it is connected or not connected. For nonconnected sites, the number of drones can be increased and may work in master-slave combination [4] to update the results whereas for connected sites, the update can be obtained using the proper flight schedule [4].

The modern standards for the quality of life demand improvement in utilizing the resources smartly, increasing sustainability, and reducing the negative effects on the environment. This led us to the innovations in the field of information and communication technologies, which includes smart environment, smart living, smart economy, smart people, smart mobility, smart governance, and smart tourism. Such trends are witnessed in various cities of the world, i.e., Malta in the Republic of Malta, Dubai in UAE, Kochi in India, San Jose in California, the United States (US), and several others in Europe. Many other countries are also focusing ongoing with the flow; for example, Dubai has planned the same way of evolution [4]. A similar type of project is also initiated by the government of Saudi Arabia named "Vision 2030" [5]. In such modernization, IoT-enabled drones have got lots of popularity except for the construction site where the usage of such drones can be exceptionally fruitful in detecting the issues that matter for construction site performance. A site engineer always wishes to have sustainability of site work while managing the number of resources to get the maximum efficiency [6]. Certain defects can never be estimated quickly and with conventional methods, i.e., defects in the envelopes of pillars of a building, air leakages, moisture/humidity, and damage of thermal insulations that lead to degradation of site performance [7] and increasing the greenhouse gases. Currently, it has been observed that approximately 65% of energy is dissipated from modern housing schemes [8] and 72% from the industrial area in central Europe [9]. Thus, a novel method should be introduced to monitor and control this loss. Drones in this regard may provide comprehensive results such that with the help of thermal cameras, they can detect infrared (IR) radiations [10]. This detection of IR radiations is known as thermography which is prescribed in several research works for identifying the energy-efficient buildings within the site [11].

One may see several research works based on thermographic mapping and imaging techniques where a dense image is modelled to conclude the thermal energy loss from any site or building [12]. Such algorithms produce quality thermal resolution-oriented images, as shown in Figure 2 to minimize the long hours that are required to check the quality and assess the defects, specifically the CO_2 emission as illustrated in Figures 2(b) and 2(c) whereas Figure 2(a) is the normal figure. The only constraint technique is the time consumption in acquiring the 3D model of the site due to the terrestrial scanning method. Apart from this limitation, the technique can be utilized for monitoring the damages, i.e., missing insulation in building, types of cracks, moisture defects, and heat losses.

In order to present a comprehensive way to monitor the construction sites, this paper shows the support for IoT platform and addresses the shortcomings of computer vision techniques specifically the huge time consumption for thermal image acquisition, and researchers derived various digital image processing algorithms, i.e., elimination of noise interference using the Butterworth low pass filter. This leads to fast processing and fine enhancement of image quality with any external noise. After studying these research contributions, the paper suggests the amalgamation of such techniques with unmanned aerial vehicles to provide speedy and accurate surveillance of construction sites. Various papers have highlighted the same need [11, 13–16]. Despite all, the proposed review paper presents the major limitations of already derived techniques for smart surveillance at the construction site. In addition to this, it emphasizes the combination of Internet of things, computer vision, and an area of unmanned aerial vehicles to evaluate the progress of any offline or online construction. The paper provides a feasibility study to integrate the multidisciplinary and trending areas to inspect the progress, and, in this regard, many research manuscripts were studied and highlighted here for readers. This paper shall be surely one of the ways to transform conventional surveillance methods.

The paper has been divided into several sections such that computer vision techniques for the inspection of construction sites in modern era. The next section is about the utilization of UAVs for the safety of workers. This paper also focuses on Internet of things and its boom in today's world. The next immediate section addresses the brief survey of IoT-enabled unmanned aerial vehicles used so far in the inspection, and it seems that their usage is still at the stage of infancy. This paper provides a broader picture and future directions for using IoT-enabled UAVs for inspection purpose. Lastly, this also motivates the research community to see the research issues and findings within the same area for future provisions.

The organization of the paper is divided into mainly six sections. In Section 1, reader may find the introduction to the paper theme and some significance of recent research contributions. The study of current inspecting methods and techniques are discussed under Section 2 along with major

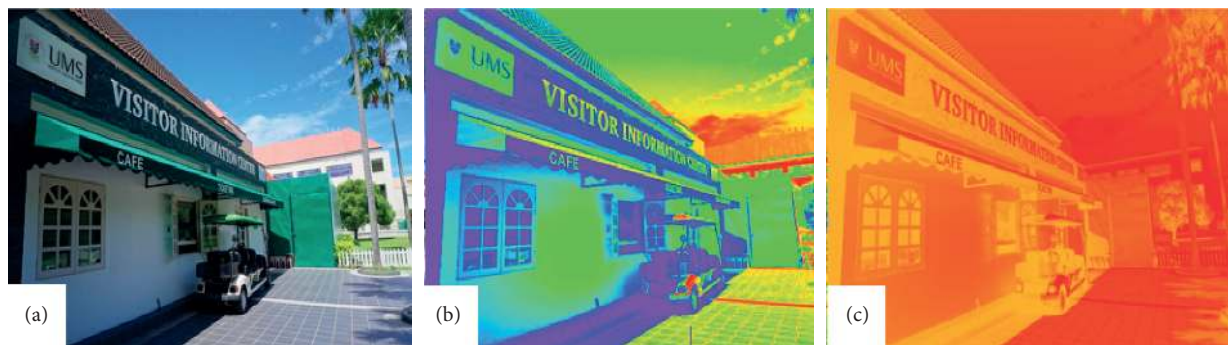FIGURE 1: IoT-enabled UAVs for different applications.

FIGURE 2: (a) RGB Image, (b) thermographic image, and (c) orthothermogram image.

limitations or constraints. Similarly, in Section 3, one may study the strategies followed and proposed for the surveillance of worker's safety at various construction sites. The diversity and importance of IoT-enabled drones and other applications have been highlighted under Section 4. The reader may study the limitations of IoT-enabled drones for the surveillance of construction sites under Section 5. The theme for this vision along with future directions is mentioned in Section 6. Last but not the least, the comprehensive conclusion is mentioned as Section 7 of this review manuscript.

2. Inspection Techniques

This section will discuss the techniques and modern computing algorithms that are utilized for the inspection of either construction or any building site. The proper advantages and shortcomings will be discussed in this section. The idea of discussing these techniques is to motivate researchers to use them with an IoT-enabled UAV to have better update from the site in less time.

2.1. Model Construction via Laser Scan. This technique is among the most popular ones in the literature whereas the 3D model is obtained using thermographic imaging of a

specific building or site. This provides an easy way to see the exact defects of the site. For a decade, researchers have proposed optimized mapping using the LiDAR sensing method. This LiDAR-based optimization strategy involves the reproduction of accurate elevation of several buildings and structures [17]. Moreover, the farmlands and waterways can also be identified using the technique. The images derived from such a technique are presented in Figure 3 where Figure 3(a) is the normal image and Figure 3(b) is the thermographic image. The author has taken the thermographic images of more than 85 positions using the terrestrial laser scan method, and this took more than five working days.

This terrestrial scan needs huge processing time due to preprocessing; thus, to reduce this computation, researchers have proposed the creation of geometry using the thermal simulation method [18] before the actual results. A similar strategy has been followed in [19] where more focus was set on deriving efficient results with a smaller number of scans known as light detection and ranging (LiDAR). Furthermore, the time constraint for laser scan had been addressed in [20] where authors proposed parametric-based 3D model reconstruction [20] whereas they extended the same technique to acquire the volumetric 3D model. So far here, the scans were of normal resolution; thus, some of the researchers also put
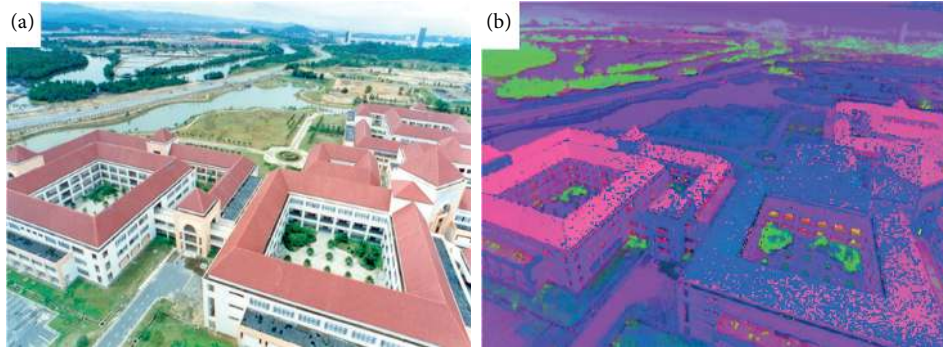
FIGURE 3: (a) LiDAR sensing image; (b) images of the entire site based on LiDAR scan.

some efforts to improve the resolution by using the optical diffraction element (DOE)-structured light [21]. This DOE-oriented technique is based on laser patterns and over the application of a convolution neural network (CNN). This approach improved the resolution, but still, it consumes huge processing time. To reduce the motion distortion, one may see [22] where continuous-time simultaneous localization and mapping (CTSLAM) is proposed. This research provided a cost-effective solution with less but efficient continuous scans. Laser scan-based identification and monitoring of construction site involves the high-density outcomes [23] and high demand in real-world for providing efficient and accurate results. The only drawback is the time consumption during scans of the positions. Thus, for identifying something, i.e., during the energy audit of a large-scale area that requires a speedier and reduced memory-oriented solution, this technique is preferred a lot by many researchers.

2.2. Model Reconstruction through Photogrammetry. The procedure that involves certain recordings, measuring photographic information, i.e., patterns, is known as photogrammetry [24]. In the last few years, several advancements occurred in computer vision and control area. This provided ease in three-dimensional model reconstruction for construction sites [24]. Structuring from motion (SFM), stitching, and overlapping of images are the most popular among the low-cost and high-resolution 3D model reconstruction techniques. Photogrammetry is divided further into three types depending on the type of method, i.e., RGB-D, monocular, and stereophotogrammetry. Mostly, the RGB-D photogrammetry technique was performed using Kinect RGB-D sensors [25–27], where a real-time Kinect fusion algorithm is processed to merge the maps into one. This strategy resolves multiple issues and provides an optimized solution by integrating the machine learning algorithms in real-time. This technique is most of the cases, observed in the mapping of large indoor environments using simultaneously localization and mapping (SLAM)-based mapping [28]. In this entire procedure, the important thing is the graphical processing unit (GPU) that performs the SLAM algorithm, and it requires the support of a thermal camera for monitoring the large-scale indoor building or construction site.

The 3D model reconstruction is performed using a regular camera, and later combining the photos from different angles [29] is known as monocular photogrammetry. The most common software used for this purpose is a two-DOF turntable. In this technique, several steps are executed such that masking photos from the respective background, photo mesh analysis, and lastly texturing step. This was so far static image and object approach but later in [30], and image-based model reconstruction was introduced using a single moving camera that led to the real-time 3D mapping of surroundings as shown in Figure 4. In this figure, Figure 4(a) is the original RGB image whereas Figure 4(b) is the mapped image based on thermal 3D model reconstruction methodology.

This monocular photogrammetry does not consist of any extra sensor, i.e., infrared or LiDAR; therefore, it provides efficient results with less memory usage and faster processing. These features have high potential to be equipped within any unmanned aerial vehicle with an on-board processor, i.e., National Instrument's myRIO controller to perform the computational tasks and provide the right outcome that is essential for the surveillance of any construction. This entire work is speedy enough as it can be executed using the general processor unit (GPU) of a smart mobile phone in real-time [31]. The literature shares that such algorithms and strategies are well enough for the indoor sites, whereas for the outdoor adaptability, it still produces 3D orthothermogram image showing the extensive inspection but not practically demonstrated still.

The construction of a 3D model based on stereo images is known as stereophotogrammetry. This technique is used for creating several models such that the human face [30]. This approach involves with spatial-temporal stereo-matching algorithms with noise rejection. It provides more promising results so far [31]. These techniques must be embedded with unmanned aerial vehicles for time-efficient results [32] with SLAM-based approach.

The approach for deploying a camera, inertial measurement unit (IMU), and integrating SLAM [33] algorithm may provide better time-efficient and cost-effective results for monitoring any sort of large ongoing construction site [34]. The images based on stereo reconstruction are comparatively better understood, as shown in Figure 5. These images are compared with the ground truth images, and the
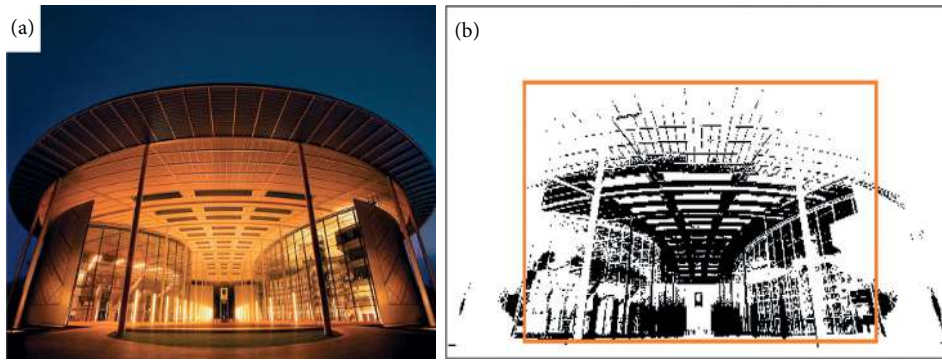
FIGURE 4: (a) Ori0067inal RGB image; (b) mapping based on thermal imagery onto the reconstructed 3D model.
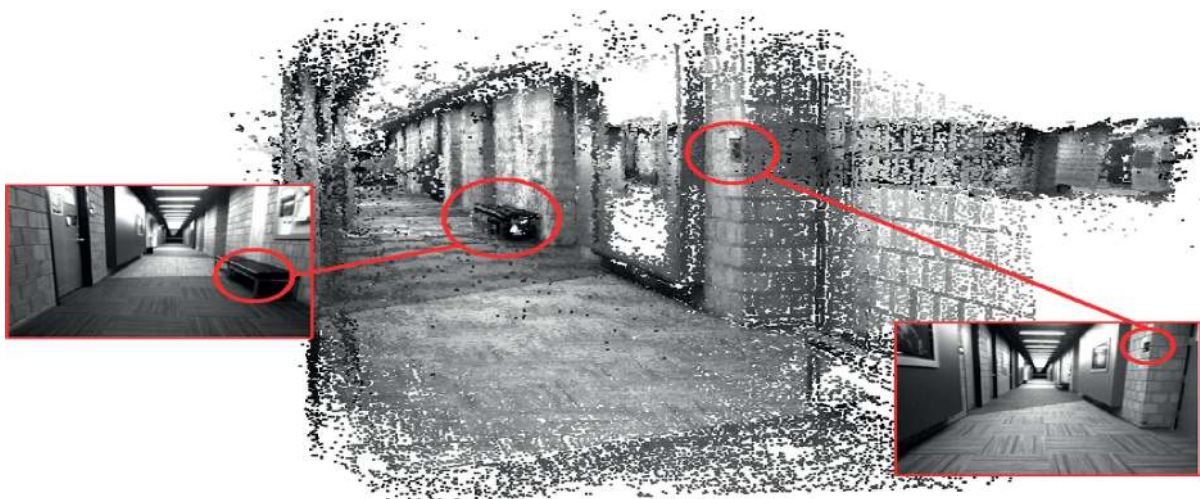

FIGURE 5: Dense 3D model reconstruction of a building model [35].

results are validated with an experimental setup too [36]. Moreover, the mentioned experimental technique and this high-resolution disparity maps along with the algorithm are applicable even for both indoor and outdoor environments, no matter for any online or offline site.

Concluding the entire photogrammetry topic, the monocular strategy is the most cost-effective approach [35] but consumes lots of postprocessing time and computing [37]. However, the stereo imaging technique can reduce this heavy computation and processing time. This means stereo imaging can provide the same results as produced by photogrammetry in various real-world applications. Since this approach is limited by nonmatching pairs within a nonplanar environment; thus, to resolve this shortcoming, RGB-D sensor technique is used [38]. By integrating the RGB-D sensor technique, the results are not only improved, but this is the only low-cost solution so far 3D mapping and may replace most of the techniques in the construction industry [27, 32].

2.3. Simultaneous Localisation and Mapping (SLAM).

The use of camera and active sensors integrated within the autonomous robots to locate itself in any space is known as simultaneous localization and mapping (SLAM). This technique has been frequently utilized in the 3D model mapping of indoor as well as outdoor environments [39]. Mostly the sensors used in this field are laser scanner, global positioning satellite, and thermal sensor. The SLAM algorithm embedded with such autonomous mobile robots helps us to locate such areas that are dangerous or difficult [39]. In the literature, researchers have proposed multiple camera vision-based SLAM techniques that integrate multiple images and track the navigation of micro aerial vehicles (MAVs) [40]. This SLAM algorithm embedded with autonomous vehicles consumes some time hence to have high-speed navigation and to map a low-drift odometry technique is proposed in [33] known as inertial SLAM. To boost up the accuracy at high-speed, researchers added more cameras and included the geometric features [41]. Simply, after going through the detailed evaluation of SLAM-based frameworks, one can use it for acquiring promising results, i.e., 3D mapping, producing thermographic 3D models, and defect analysis of any site.

One of the variants of SLAM is introduced as point and lines using the RGB-D algorithm where 3D point constraint errors are also tackled and even lines are constructed [42]. In addition to this, one may see the S4-SLAM algorithm used

for outdoor ground and water surface multiple scenario-based applications. This algorithm is mostly proposed for unmanned vehicles and ships and is amalgamated with odometry function [43].

2.4. Surveillance Using Drones and UAVs. The aerial surveys were introduced in the early 1980s [44]. This was the first time when fixed-wing aircraft and helicopters were used to monitor the sites in case of a natural disaster. In today's era, people from various fields opt for multirotor drones known as unmanned aerial vehicles (UAVs) for several applications due to their flexible and aggressive maneuvers [10, 45–50].

The main constraint of using drones for the inspection of such sites is the unawareness of the environment; thus, this review paper focuses on computer vision and other mapping techniques too. Apart from this, there are several research contributions, i.e., use of infrared technology-based inspection using quadrotor craft [15]. Almost more than 100 literature resources from the last 35 years have witnessed and emphasized the use of drones for several techniques, i.e., using a drone for inspection of site work on the local street [51] and drones for auditing the energy drawbacks [52]. One of the major reasons to recommend drones for such surveillance is because they can fly over a large area and may hover at one place too. Several quadrotor-type UAVs can perform vertical take-off and landing (VTOL) that may help in capturing the high-quality images of any site, i.e., bridge inspection [52]. Furthermore, it was seen that an abutment in Dakota was monitored using the DJI Phantom drone and provided an effective analysis of overall defects in real-time. To the best knowledge of authors, drones can identify the damages of very high-rise buildings and the scanning of hidden areas using thermography [40]. Understanding this requirement, various researchers proposed low-cost approaches, i.e., in [53] where orthoimages of the site are produced using multiview photogrammetry with a resolution of 0.066 of the digital elevation model using UAV. The results provided great help in identifying the faults more accurately.

In addition to this, one may see [54] where UAV is equipped with real-time thermography and some thermal sensors for the assessment of different building structures. As far as the shortcoming of such techniques is concerned, then one can see two major shortcomings as stated below:

> The battery timings of UAVs restrict them to monitor or inspect the large complex building structures.

> While identifying the defect, UAV cannot remember the exact location of fault; hence, the operator must remember the exact location. This is because of the lack of 3D mapping. Hence, for unknown targeted buildings, the defects and flaws are not relocatable.

Summarizing it all, the surveys and inspections based on drones/UAVs are highly time-efficient and productive. However, despite having such perks of drone-based surveillance and inspection, there is a huge lack in the utilization at construction industries. This strategy not only inspects the progress but also monitors for energy audits on large complex construction sites, as shown in [16].

2.5. 3D Modelling via Thermography. The inspection of any construction site, whether any bridge or building, must be performed time efficiently as well as nondestructively. This is the major reason researchers proposed several techniques such that virtual building geometry and thermography based on infrared and orthothermogram [12]. Such thermographic techniques help in identifying water leakages and heat losses in a very accurate manner. In this section, 3D modeling based on thermography and mapping is covered for large-scale construction sites. The framework discussed in [12, 55, 56] shares the mapping of infrared thermal images onto point clouds of the building structure. Some researchers had refined the image processing algorithm for both thermographic and laser-scanned point clouds to acquire better results. Furthermore, some researchers suggest a hybrid strategy such that the merge of thermal modeling with the LiDAR system. Though this hybrid technology provides the best results, due to huge postprocessing concurrency, this can never opt for real-time implementation. To address this issue, one may replace the LiDAR with stereo depth sensors, as discussed previously in this manuscript [57]. This technique has high accuracy, but still, the technique was time-consuming for large complex construction sites.

For mapping the indoor environment, there had been various wheeled mobile robots (WMRs) are proposed that amalgamate both infrared thermography and laser scans to generate the three-dimensional orthothermogram [58]. This approach produces fine radiometric results of an indoor environment as shown in Figure 6. To acquire the qualitative defect recognition and analysis, this review manuscript proposes the integration of such techniques within unmanned aerial vehicles (UAVs).

2.6. Damage Detection through Computer Vision and Machine Learning. Computer vision or image processing is the most emerging field that is opted to render an image for machine perception [59]. This section will review the most trending image processing-related investigations made for the inspection of buildings or any construction site, i.e., indoor or outdoor environments. Since last two decades, there has been a lot of advancement in the domain of computer vision technique design for the inspection of offline and online construction sites [60]. During this epoch, various algorithms had been introduced so far, i.e., convolution neural network (CNN) in [61, 62], used for the identification of cracks in metal surfaces. In the same way, one can see the research contribution of [63] where a nondestructive image processing algorithm is proposed to monitor the defects of historical buildings. The research was mainly focused on erosion on the surface of building structures. Furthermore, this research concluded that it is very difficult to automate the defect identification without considering the physical variables such that environmental factors such as temperature and humidity.
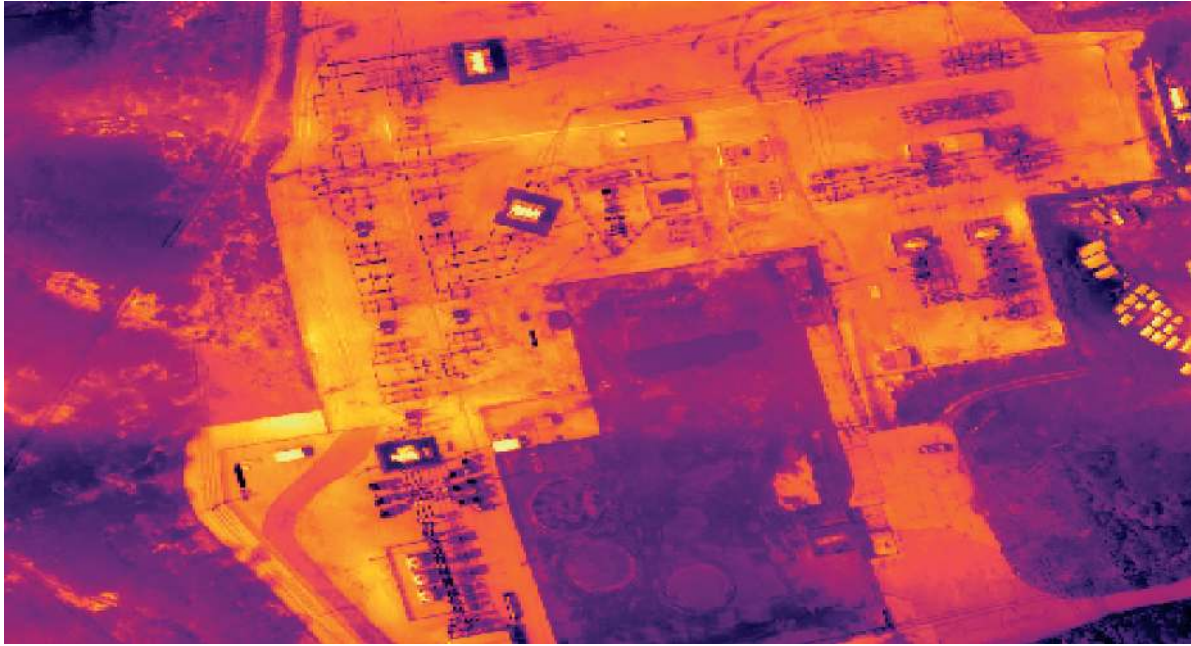
FIGURE 6: A radiometric result.

Thus, there is an immediate need to have an extraordinary approach (machine learning tactics) to automate the defect analysis and identification with these physical parameters. In the literature, one may find mobile-enabled cost-effective and deep learning-oriented damage analysis strategies [64]. In this approach, the CNNs had been trained for more than 30,000 iterations and 3 hours with more than 600 images of various cases. This proposed approach provided high-accuracy outcomes with consistent identification. The unknown fault or irregular defect must be trained first, and this was the only shortcoming for this algorithm. A similar approach had been introduced to identify the earthquake, i.e., spalling and corrosion [65]. It has been seen that the results had more than 86% accuracy rate in real-time. The contributors of this work suggested embedding the same algorithm within unmanned aerial vehicles to reduce both time and cost while covering the entire large-scale inspection. This is not an end yet; the same approach had been seen in visualizing the energy auditing too [66].

If one is looking for fault/defect analysis and identification with high-accuracy and time efficiency, then the only way is to hybridize the machine learning algorithms with the image processing strategies. So far, the algorithms such as artificial neural networks and CNN can produce a meaningful outcome in various fields [67]; hence, they are suggesting being hybridized with image processing algorithms and deployed within the UAVs for better timely response in real-time [68].

From Sections 2.1 to 2.6, there were the several trending techniques that can be useful for the inspection and surveillance of any construction sire with large-scale efficiency. Moreover, Table 1 shows the summary of entire techniques along with their perks and shortcomings.

3. UAVs for Worker's Safety

This section presents the usage of unmanned aerial vehicles at construction sites ensuring the proper mitigation of potential risks. In addition to this, it also highlights the most significant role of UAVs in health and safety assurance at the site so that every professional may perform their tasks at their workplace safely. The utilization of robotics and autonomous systems in every field is common today; thus, this manuscript emphasizes the usage of IoT-enabled UAVs within the construction site too. Before this, the UAVs are commonly used in many areas such as military, recreational activities, fire/emergency units, traffic management aerial photography, and surveillance. Regarding the use of UAVs for worker's or workplace's safety, very rare literature is available. There are several uncertain incidents that have been occurred at various construction sites [65]. The use of UAVs will surely decrease this number by close and continuous monitoring of the site [69, 70]. Amalgamating the same computer vision algorithm within UAVs, one can monitor the dress-up of labours and professionals that whether they have worn safety helmets and shoes or not. These drones can fly with variable altitudes and thus can be used to monitor the person who is doing welding or steel bending. Later, the people who are not following the health and safety rules may be penalized too with photographic proof or evidence [71].

4. Internet of Things and Its Diversity

The Internet of things (IoT) is defined as the intelligent connection of things by using some active sensors to the Internet [72]. The paper suggests the IoT-enabled drone to achieve better inspection method for construction sites. In

TABLE 1: Trending techniques for the inspection of the construction site.

S. no.	Techniques	Constraints
1	Machine learning with image processing algorithms	(i) Greater number of iterations are required to derive a reliable outcome. (ii) Testing data must be updated for high-accuracy results.
2	Thermographic modelling	(i) The proposed approach is heavy due to computational work and time-consuming because of the superimposition of thermal imaging to point clouds.
3	Simultaneous localization and mapping (SLAM)	(i) The existing method is depending on the laser scans or laser communication which is not good for aerial survey. (ii) In the existing approach, the switching of normal mode to direct photogrammetric mode will distort the reliability of the derived outcomes and localization.
4	RGB-D type photogrammetry	(i) The approach consumes computing power a lot. (ii) In addition to this, it has a noise effect due to IR depth sensors. (iii) It consumes time also because of postprocessing.
5	Stereo imaging-based photogrammetry	(i) Encountered with parallax effect that leads to an inaccurate model reconstruction.
6	Laser scan technique	(i) The hardware setup is much expensive and not recommended for aerial mapping.
7	Monocular photogrammetry	(i) The results were of low resolution. (ii) The plain walls were reconstructed inaccurately in this approach and the algorithm was light depended.
8	Unmanned aerial vehicles (UAVs)	(i) The only shortcoming is the less flight time, especially in the presence of inertial measurement unit and other additional sensors, i.e., depth sensor/camera or GPS.

this way, one can also address the constraints of IoT also, i.e., scalability of the network, computing constraints, and diverse provisions for diverse applications. By proposing IoT-enabled UAVs, one may not only address these constraints but also enhance these three critical expectations of Internet of things. In the past few years, there is a boom of IoT, and it is used significantly in various areas. In simple words, the IoT concept is related to connecting the system with varying capabilities of the Internet. Thus, it most frequently opts for a machine-to-machine communication [73]. The paper is therefore suggesting communicating the drone with a base station system where a supervisor of the entire construction site is evaluating the progress of work [74].

Since a decade, it is observed that there is a lot of emphasizes on the amalgamation of IoT with AI and computer vision algorithms to derive the better results [75–78]. One of the reasons to discuss IoT-enabled drones in this manuscript is that the Internet of things has great capability to tackle the extracted information from the image data capture by drone and analyse it for better measurements of entire progress at the site. This capability is usually known as automated intelligence [79]. This concept of automated intelligence has been introduced for many years ago, but at that time, the realization of the construction site, it is still in its early days. The primary focus for using IoT is to process and analyse the massive image data derived by UAV-enabled camera. To achieve reliable results with automated intelligence, one must ensure the three constraints as mentioned below:

One should establish the scalable network architecture with ubiquitous coverage known as scalability of the network.

Ensuring the best computing algorithm that extracts the data and concludes the outcome easily, this is termed as intelligence.

Support of diverse sensors to acquire the data known as diversity.

These three constraints are illustrated in a better way in Figure 7. These three constraints are defined under this section briefly.

If one is establishing the Internet of thing-based system, then scalability is one of the most important things to ensure. Scalability is the working area in which the network can communicate efficiently. In the case of monitoring the large and complex construction sites, it is very much necessary to integrate such communication techniques that may continuously bound the system within the communication; otherwise, the results are not easy to derive. Since the outcome is to identify the faults and defects, hence in this regard, artificial intelligence and computer vision algorithms are required. The IoT feature will gather all data, i.e., images of construction sites from a scalable network over a complex and large site to enable these algorithms so that the defects and progress can easily be identified. The term "diversity" indicates the different applications based on several sensors and geographic visual display techniques [80] that automate any procedure of IoT. If the sensors do not perform well or have time delay in sensing the physical data or capturing images with low-resolution in our case, then the outcome will not be reliable enough. This section concludes that one should need to achieve these expectations and so far, the best solution is to deploy the multiple nodes and design a complete network within the construction site. For such deployment, IoT-enabled nodes that will retrieve the data will be based on power source as well as storage space too.

5. Inspection Using IoT-Enabled UAVs

This section offers the benefits of UAVs along with technical as well as nontechnical issues related to the utilization of UAVs. The technical issues and shortcomings are discussed below in the context of prototyping, algorithm design, and flight operations of UAV systems.
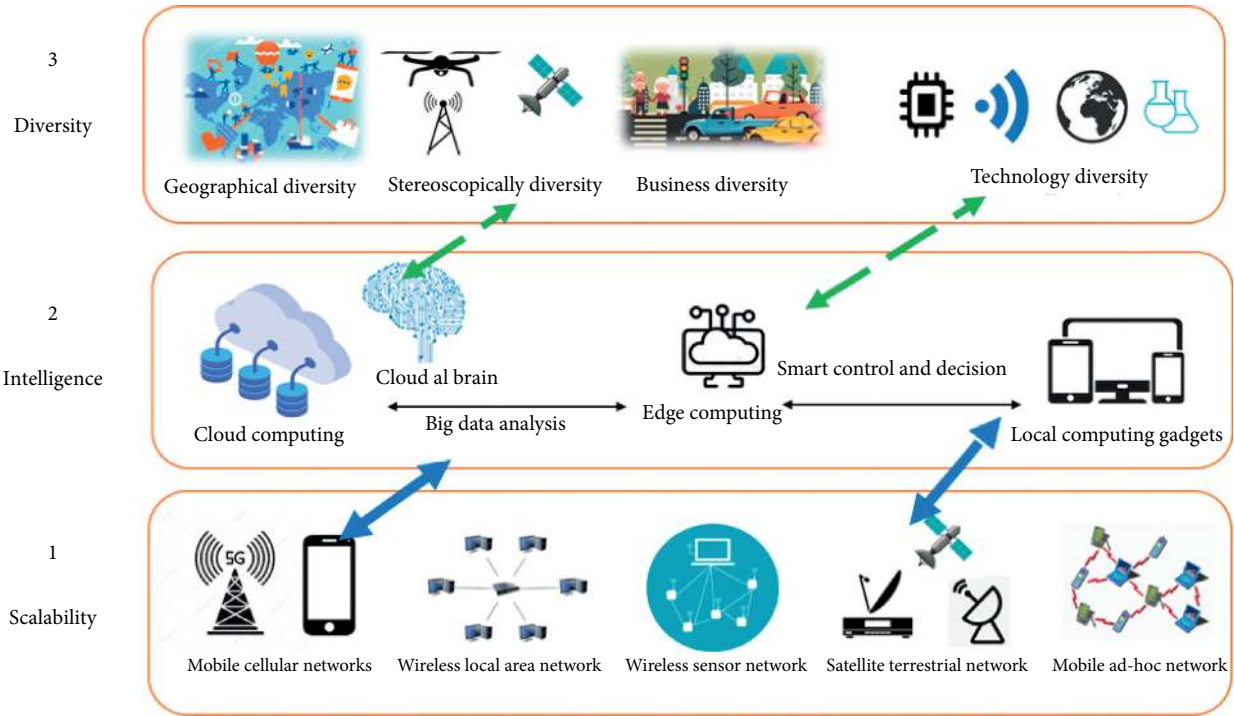
FIGURE 7: Three constraints of Internet of things (IoT).

5.1. Technical and Nontechnical Issues in Utilization of IoT-Enabled UAVs. One of the concerning issues for utilizing the IoT-enabled UAVs is security. The first issue is the privacy issue. During the flight of an unmanned aerial vehicle, especially with an embedded camera, this may infringe on the privacy of people around [81]. In many countries, there are some of the regions which are restricted areas; hence, the UAVs must not fly over them, and in this regard, the communication between UAV and ground control room (GCR) must be enough protected and secured. If these drones are utilized in smart cities, then one must consider the type of all security attacks [82]. These issues are of various types, i.e., malicious-prototype attacks, where the design of drone assembly is done to harm others. The second type of attack is concerned with the mission configuration parameters where one may access the communication system and amend it to change the mission settings, i.e., wrong path planning. It is also suggested that one should secure the computers that are involved in communicating these unmanned IoT-enabled systems [83]. While studying the literature, one may come across many security and privacy strategies recommended for such scenarios, i.e., vehicular ad hoc networks (VANETs), wireless LAN (WLAN), voice over IP (VoIP), radio RFID, wireless sensor networks (WSN), and Internet of things (IoT) [84, 85]. The second most trending issue related to IoT-enabled UAVs is the safety issues as they are executing various missions and flights from one point to the second point. This is because, during flight and aggressive maneuvers, this drone will pass by buildings and even nearby people too. Thus, safety is among the best issues in this domain. Looking over these issues, researchers have proposed the hybrid algorithms and integration of advanced sensors within UAVs. Researchers

proposed certain regulations, i.e., speed, height at which these drones must be operated, and last but not least is the proximity [86–90].

Reliability is also one of the technical issues where one may look for fewer chances for hardware failure or the loss of the rotor's effectiveness loss. This happens because of any malfunctions within the mechatronic components. Researchers have studied this point and have proposed various approaches. In one of the most frequent approaches, one may find the adaptive-robust fault-tolerant control designs to detect the system faults and balance it accordingly [91]. These hardware or prototype faults can be compensated, but the failure in communication between the ground control room and UAVs is the most major issue. This failure can be in the form of time delay also, and thus, it cannot deliver for the mission properly. Researchers have proposed multi-channel-oriented communication. However, most of these failures can also be detected using systematic verification, as indicated in research [91].

The communication failure issue has been studied in detail, as this is the only bridge between UAVs and GCR. Researchers proposed multiple channels and nodes to establish a stable communication [92]. In establishing such techniques, many of the parameters have been dictated such that quality of service for bandwidth, time delay in communication, and data transfer rate. In order to ensure security, safety, and reliability, one should first think up for this issue. Many manuscripts already initiated solutions such that by recommending the direct link, and cellular and mesh topologies [93]. It has been observed that various topologies have different constraints such that direct link is one of the smart techniques, but the signal strength can be weakened in case of obstruction, and it does not support longer distance-

based communication. For having long-distance communication, it needs high-powered transmitters and modified antennas. This is not yet simple because if there are multiple drones in an area, this may lead to high communication delays. The cellular topology though has several advantages, but it can never be recommended for UAVs as this will degrade the cellular networks within the region. The possible and a bit expensive solution for this is to propose a separate cellular infrastructure within an area. Moreover, the last technique is mesh topology used to synchronize the GCR with the UAVs, which is still an attractive topology, but this requires high security as mentioned in the research [94].

In designing such smart and IoT-enabled UAVs, one must concern about the factor of cost. One must design the UAVs in a manner that it can be cost-effective, but simultaneously it can execute major functions too. For such a cost-effective hardware design, the majority of the researchers go for the underactuated systems [95]. Some of the research contributions have suggested the modular type of prototyping too, along with various but suitable and flexible software architectures that can be changed from application to application [96, 97]. It has been seen that there had been a rapid growth in the field of designing autonomous controls for the stability of such underactuated systems [98, 99] that can surely reduce the cost either on the hardware or software algorithm.

Integrating or amalgamating the UAVs with other subsystems is one of the major steps, and there are many constraints too as highlighted in the above section of the literature. This type of integration is essential and may lead to exploring various dimensions of the drone in several other fields but challenging at the same point. To tackle such things such that manipulating some payload from one place to another, researchers have proposed some middle software framework; this integrates two applications such that flight mode of UAV, and it can also accommodate the global position of UAV [100]. In addition to this, when any design is implemented first, it is tested too, which means it requires a specific testing environment for validating the software simulation results. In most of the cases, it has been observed that the prototypes developed for the first time are tested in the limited development environment and help in providing close results as well. So far, there is not any comprehensive environment that helps in producing many effective results. One of the nontechnical issues one may find is ethics. Flying drones and UAVs in the sky may infringe privacy, and this is not as per the ethical norms because of the multiple public and private areas. There is a great chance of spying the spots using UAVs. This can be one of the constraints in utilizing an IoT-enabled drone [101]. Thus, the manuscript suggests a code of ethics for implementing the drones within any territory. This code of ethics will define the boundary and procedures for proper uses of UAVs.

In addition to this, one may set a focus on proposing an appropriate transportation system for smart cities with network scalability to enforce such drones to monitor the construction sites such that proposed in [102]. There are several solutions that are based on blockchain which addresses the limitations such that high transaction storage, latency in response, communication with ground control room (GCR), and lastly the bandwidth. Keeping this in mind, researchers have proposed unmanned aerial vehicles (UAVs) with secure communication protocol in compliance with the recent architecture of 5G communication and the power of artificial intelligence [103]. The techniques such as InterPlanetary File System (IPFS) facilitate nowadays the storage limitation and provide better network performance and security. These techniques already proved their robustness and flexibility on decision taking measures via amalgamating the 5G and artificial intelligence (AI)-based strategies.

6. Research Findings, Vision, and Future Directions

After discussing the techniques for inspecting the site, technical and nontechnical issues related to the UAVs, one may see the integration of such strategies into one another may provide the time and cost-effective solution to inspect the online or offline construction site. After studying several research contributions, one may come across with some of the challenges that are associated only with the methodology by which one is going to implement the work. Discussing these research findings, one may see the on-board controller deployed on UAV such that underactuated quadrotor will be performing so many things such that the efficient inspecting algorithm with high-quality visual feed and thermal facility, real-time data monitoring that maps up the data from a number of sensors embedded with this board, visual-based odometry, and live transmission and may also tackle the glitch-free communication in between the UAV and ground control room (GCR). Thus, a powerful board is therefore required that surely consume more power sources, i.e., battery. This will surely reduce the flight duration and one may not inspect the large area of the site easily with these IoT-enabled UAVs [104].

Furthermore, one may see the complex and hybrid machine learning algorithm for fault identification at either real-time or offline consumes huge processing time and in addition to this, they require multiple data set with several training iterations and experimentations. Till now, there is an efficient algorithm produced because of qualitative analysis and one should work on quantitative analysis too for better fault identification [105]. It has been noticed that the average flight duration for the UAVs proposed is in between 20 and 35 minutes. Hence, this will be one of the major limitations in inspecting the large area of the construction site. However, researchers have proposed some of the advanced mobility options [7, 39, 58, 106]. One of the most suitable options is to propose the scheduling for UAVs to land at one of the nearby jurisdictions and get themselves self-charged to improve the time and speed, but in this approach, one may see the discontinuity in the mapping results and ultimately in the reconstruction of a superimposed 3D thermographic model. This section offers the main research findings of IoT-enabled UAVs as summarized in Table 2.

Table 2: Summary of all research findings.

Sr.	Research findings	References
1	On-board controller for IoT-enabled UAVs requires high power consumption because of several tasks.	[104]
2	One should come up with hybrid predictive learning algorithms based on quantitative and qualitative analysis for fault identification.	[105]
3	UAVs with usually have 20–30 minutes to fly in the sky which is very less time for monitoring any construction site. Thus, we need some smart mobility strategies.	[7, 106, 107]
4	For LiDAR-based reconstruction techniques, there is always huge time requirement, and thus, this is not recommended for large construction sites.	[108, 109]
5	There is also an immediate need to improve the communication between ground control room and UAVs.	[110]

Table 2 defines the main findings that are retrieved by the author after evaluating the literature review. The techniques used before for the same purpose using drones and some computing algorithms have some limitations. These limitations include the high-power controller or general-purpose processor [104], the necessity of efficient computer algorithm that assesses the quantitative faults such that the progress of one building or storey, and qualitative fault analysis too such that the cracks in the bridge pillars or wall. This table also states that there is an immediate need to establish a good communication network between ground control room (GCR) and the IoT-enabled drones.

The idea behind this manuscript is to provide vision and future directives to improve the construction industry by introducing the IoT-enabled unmanned aerial vehicles that are equipped with advanced computer vision and artificial intelligence-based algorithms as discussed in this manuscript. Not only does this type of amalgamated system accelerate the construction of megaprojects with an easy update, but also, in addition to this, one may visualize and predict the way the construction progresses. There had been more than 50 plus megacities in the year 2017 in Asia where it is reported that more than 1.5 billion people have been moved to these cities and yet to travel by the next 20 years. In these cities, there are various mega projects going on. Thus, the government of each state has invested a lot of their resources and budget. To monitor the right progress, the idea presented in this paper is so far the best suitable fit for it. This is an admitted fact that the potential of IoT, computer vision, and AI-enabled applications is limitless and there are various advantages, i.e., network agility, easy to deploy, orchestrate, and secure at hyper-scale. Many mega construction projects in metropolitan cities can be completed on time by utilizing this approach:

Integration of mapping techniques and AI algorithms needs a powerful controller board and proper battery resources [111].

The LiDAR-based approach is much reliable, but for the small-scale construction site, whereas it is not recommended for a huge area of construction because of its time consumption while scanning [107, 108, 109]. It has been noted that while performing high definition thermal imaging, it requires real-time data processing, and this is still a potential restriction that can be unrestrained using 5G-based data communication [112].

While studying the LiDAR-based SLAM algorithm, it has been observed that in real-time, it does not reconstruct the dense map that results in a less accurate outcome. To cope up, one may opt for an artificial algorithm and its utilization to improve the mapping outcomes as proposed in [110, 113].

7. Conclusion

The main aim of this manuscript is to present the major opportunities for inspecting any online or offline construction sites using the application of autonomous UAVs enabled dully with the feature of the Internet of things (IoT).

In this comprehensive survey paper, a variety of inspection techniques and applications of UAVs with technical and nontechnical issues have been discussed. Furthermore, one may also explore the limitations and constraints of amalgamating these techniques together, which is the most trending thing nowadays. This is because of reducing the inspecting construction sites mainly where one is mainly concerned to monitor the progress and reduce the emission of carbon and improve the execution of any mega construction project.

The discussion regarding the inspection, i.e., LiDAR-based approach, SLAM, and thermographic methods, with an amalgamation of artificial intelligence and IoT plays a very vital role in deriving the quality results. The key findings of this entire study are mentioned in the below postulates: there is an immediate need to explore and develop the hybrid solution to amalgamate the inspecting techniques with artificial intelligence and IoT features for such smart UAVs.

One must go for both types of analysis such that quantitative as well as qualitative when it comes to thermographic 3D model reconstruction. The advent of artificial intelligence so far improved the methodology for fault detection, and they can be incorporate with IoT-enabled drones for qualitative and quantitative inspection for online and offline construction sites over a large scale.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

For the paper, Ghulam E Mustafa Abro, Muhammad Farhan, and Amber Israr were responsible for idea and conceptualization; literature review was performed equally by all the authors; data analysis was done by Saif ul Azrin Bin Mohd Zulkifli and Sadiq Ali Khan; and the manuscript was drafted by Ghulam E Mustafa Abro and critically revised by Saif ul Azrin Bin Mohd Zulkifli and Muhammad Farhan.

Acknowledgments

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