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Opportunities for construction site monitoring by adopting first personal view (FPV) of a drone

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Abstract. Understanding the current status of a construction project is necessary to achieve successful on-site management. Real-time information delivery is a major concern for construction industry practitioners in order to expedite decisions and discussions. We propose the use of a first personal view (FPV) system of a quadcopter drone as a tool for monitoring on-site status and communicating between construction participants. The most important function of the drone FPV system is its ability to visually monitor construction site situations in real time. An on-site management system process is developed, verified, and applied to several construction work tasks after determining factors that affect efficient construction management. The proposed system is expected to assist the construction manager in achieving high efficiency.

Keywords: unmanned aerial vehicle (UAV); first personal view (FPV); on-site management; reinforced concrete work; construction management

1. Introduction

Project performance in the construction industry needs to be efficiently controlled to achieve better visibility and traceability because a variety of unexpected problems will always occur. Problems frequently occur in large construction projects such as buildings, bridges, highways, and plants because these projects usually require the coordination of hundreds of workers and pieces of construction machinery (Kang *et al*. 2014). Moreover, construction activities involve numerous practitioners such as owners, contractors, subcontractors, and tradesmen (Yang *et al*. 2015). Therefore, managing construction activities to achieve maximum operational efficiency is an important issue. According to some research reports, up to 12.4% of construction cost is wasted due to rework of defective components detected late in the construction phase (Burati *et al*. 1992, Josephson and Hammarlund 1999). Also, most construction defects are related to human factors such as unskilled workers, insufficient supervision, lack of cooperation and communication between designers and contractors, and lack of prompt expert decisions during on-site engineering (Aksoy *et al*. 1996, Atkinson 1999, Opfer 1999). To minimize these human errors, an immediate awareness of project-specific issues is the most crucial factor.

Real-time information delivery is one of the major concerns for practitioners in the construction industry. Therefore, many researchers have tried to apply real-time technologies for obtaining site information in a timely manner. A representative example of delivering real-time information is the monitoring system. The success of a project is often determined by the level of awareness of the project status or work task performance (Teizer *et al*. 2007). Site monitoring provides information for the project manager, and aids in developing contingency plans to prevent structural disaster (Leung *et al*. 2008). In addition, it provides information to practitioners to help them easily and quickly make project control decisions (Bohn and Teizer 2009, Bosche *et al*. 2014). Over the past few years, radio frequency identification (RFID) technology has been applied to construction sites in information delivery systems. Kim *et al*. (2013) used RFID technology to manage worker attendance and ready-mixed concrete (RMC) trucks at construction sites. Moreover, RFID technology has been used to track tool inventories, supply chains, safety systems, and materials management (Navon and Berkovich 2005, Goodrum *et al*. 2006, Rittenberry 2006, Wang *et al*. 2007). Researchers have tried several other technologies such as the global positioning system (GPS) and ultra wide-band (UWB). These tracking systems have been applied to location tracking in order to provide better documentation, analysis, and tunnel construction using WiFi (Shen *et al*. 2008, Giretti *et al*. 2009, Cheng *et al*. 2011, Woo *et al*. 2011). However, it was found that the system accuracy was within 3.5 to 5 m, and such accuracy decreased when the RFID tag is moving or obstacles are interposed between the routers and the blind tag (Li *et al*. 2008, Saidi *et al*. 2011).

Recently, many researchers have been showing growing interest in unmanned aerial vehicles (UAVs). A UAV is an aircraft without a human pilot, and is also known as a drone (Kang *et al*. 2014). This system is remotely controlled, and is equipped with precision sensors such as internal motion

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units (IMU) and gyroscopes for recognizing the position of the aircraft (Siebert and Teizer 2014). Therefore, it is anticipated that the adoption of drones at construction sites will affect the real-time acquisition of information such as the behavior of workers, project progress, and events. In this study, we examined the opportunities and benefits of drone use at a construction site. Through the integration of construction site information, the proposed system would allow construction participants to easily understand the site conditions. This paper is organized as follows. First, we review the latest technologies that are related to real-time information and drone applications. Then, we describe the architecture of the system, its components, and the rationale for hardware selection. In addition, we discuss the implementation at construction sites. Finally, we provide conclusions and future research directions.

2. Review of previous drone application studies

Drones were invented in Britain in 1914 (Gao *et al*. 2011). Their first application was for reconnaissance on military missions. Drones are now used for autonomous surveillance, mapping applications, environmental change monitoring, disaster prevention response, resource exploration, and broadcasting (Kontitsis *et al*. 2004, Semsch *et al*. 2009, Cho *et al*. 2014, Kang *et al*. 2014). Recently, unmanned aerial photogrammetry applications have increased significantly due to the development of precision and high resolution digital cameras, the GPS, and small IMUs. Therefore, the monitoring capability of drones has improved significantly, especially in disasters and infrastructure inspections. One example of the using drones in a disaster occurred when a tsunami struck the Fukushima nuclear power plant in Japan due to very unsafe conditions (Irizarry *et al*. 2012). Additionally, Nagai *et al*. (2008) and Cho *et al*. (2014) obtained three-dimensional (3-D) terrain information for disaster and environmental management using drones equipped with an IMU, charge-coupled device camera, compact laser scanner, and GPS. Hwang *et al*. (2015) and Kim *et al*. (2015) researched monitoring systems that can notify the authorities of forest fires and car accidents using drones. Choi *et al*. (2011) developed a close-range real-time aerial monitoring system based on a low altitude drone.

Researchers have applied drones to the mapping and modeling of areas using high resolution remote sensing images. Wang *et al*. (2004) designed a 3-D reconstruction method for city buildings using drone images, and built accurate models to test the feasibility and practicality of this method. They proved that a drone can provide geometry and texture information from drone images. Lin (2008) suggested a method of manufacturing a large-scale numerical map by obtaining images. Remondino *et al*. (2011) used a drone for the mapping and 3-D modeling of an area to acquire terrain information. Also, drone photogrammetry has been used to derive digital surface models and the visualization of geomorphological features (Anders *et al*. 2013). Additionally, a drone has been used to capture images of buildings in order to describe an approach for a fully automatic image-based 3-D reconstruction of buildings (Wefelscheid *et al*. 2011). Wefelscheid *et al*. showed that the accuracy of the obtained model was high, and comparable to the light detection and ranging (LIDAR) method.

Recently, studies have focused on drone use in the construction industry. One research area is the observation and protection of infrastructures. Metni and Hamel (2007) investigated the dynamics of the drone for the monitoring of structures and maintenance of bridges. They presented a novel control law based on computer vision for quasi-stationary flights above a planar target. Murphy *et al*. (2011) investigated a post-disaster bridge inspection using three types of drones. In addition, researchers have considered the use of drones in geologic hazard investigation for oil and gas pipelines, and evaluated rural road surface distresses (Gao *et al*. 2011, Zhang and Elaksher 2012). Drones have been considered for monitoring linear structures such as pipelines, roads, bridges, and canals (Rathinam *et al*. 2008). In their study, Rathinam *et al*. developed a closed-loop control algorithm for detecting linear structures using visual recognition techniques in real time.

Through our literature review, we confirmed that drones have significant benefits such as low cost, high mobility, and high safety when used to collect images. The preparation time for drone image acquisition is relatively short, and real time monitoring is possible. However, most studies that are related to construction focused on linear structure inspections. Finding studies that have applied drones during the construction work was difficult.

3. Definition of a drone system

3.1 Drone types

Drone applications can be classified into two categories: the military domain and the civil domain. In this study, military drones were excluded because of their inefficiency. Normally, military drones are quite expensive to build and operate, and thus do not offer a cost-effective alternative for many users (Siebert and Teizer 2014). In contrast, there are many drones that offer competitive alternatives in the civil domain.

As shown in Fig. 1, there are various drone structures based on shapes, mechanisms, and characteristics because drones are usually developed for specific purposes. Therefore, their hardware and software designs are developed depending on task requirements. The frame structure of a drone can be divided into two types: fixed wing and rotary wing. A fixed wing drone is able to fly using wings that generate lift via forward airspeed and the wing's shape. A rotary wing drone is able to fly using spinning rotors with airfoil section blades to provide lift (Kang *et al*. 2014).

In this study, we focused on the rotary wing drone due to its suitability to construction site usage. The rotary wing drone can be categorized by its structure: no-sensor form or sensor form. The no-sensor drone can be classified as a

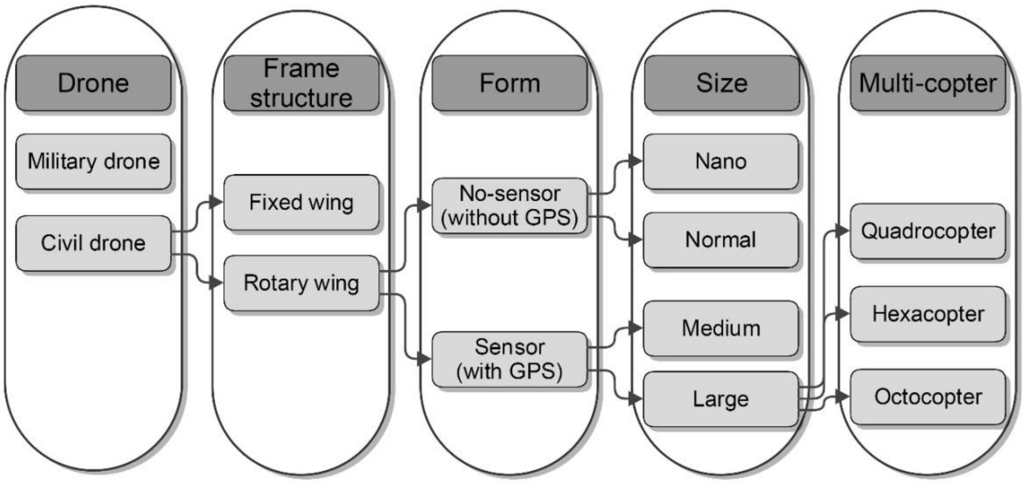


Fig. 1 Main drone types

Table 1 Summary of advantages and limitations of the main drone types

Drone type	No-sensor drone (Without GPS)	Sensor drone (With GPS)	Multi-copter (With GPS)
Cost	low	Average	High
Control method	Manual	Manual, Waypoint	Manual, Waypoint
Payload	Impossible	Average	Good
Weather dependency	Poor	Good	Very good
Flexibility	Good	Average	Average
Image photographing	Impossible	Possible	Possible
Flight range	Poor	Average	Average
Motor output	Poor	Good	Very good
Safety	Poor	Average	Average

nano drone and a normal drone. The sensor drone can be classified as medium and large, depending on its size. Drones that do not have a GPS sensor are usually referred to as no-sensor drones. A no-sensor drone has a manual control that is solely operated through a controller by a person. Thus, it is relatively inexpensive in comparison to the sensor drone, around 90 to 95%. Also, because it has incomparable durability compared to sensor drones, failure in the drone system does not occur easily, even in a crash or impact, and easy replacement or self-repair is an advantage. Among the non-sensor drones, a compact size drone that has less than 5 cm of a center distance (between the wing and the wing) is called a nano-micro-drone, or nano-drone. Nano drones are relatively safe because of their light weight and low motor output.

In contrast, drones that have GPS sensors are usually referred to as sensor drones. Sensor drones are divided into medium size (a center distance of less than 30 cm) and large size (a center distance of more than 30 cm). Sensor drones can be used for a variety of functions such as flying, stop, and back home because it can be self-aware of its location by the transmitter and the position of the GPS satellite. Due to these advantages, sensor drones are stable and precise adjustment than non-sensor drones. Moreover, sensor drones can take high quality photos or videos with less vibration because the camera is connected to the drone through a gimbal.

There are other kinds of drones with center distances of more than 50 cm. These drones are multi- copters and are categorized as quadrocopter, hexacopters, and octocopters depending on the number of wings. These drones are a type of a rotary wing aircraft, and are thus equipped with motors at every wing. Their main advantage is stability and flexibility. In addition, multi-copters are relatively strong in the wind because they have a high power output. Table 1 explains the advantages and limitations of three of the main rotary wing drone types.

3.2 Design and components

A drone can be equipped with cameras, sensors, and communications systems in a variety of sizes and weights from 25 g to 1,200 kg (Kim *et al*. 2015). Technologies to configure drones include mechanics technology based on aerodynamics; software computing technology to control the machine and controller technology for the

Table 2 Components of a drone

Category	Components list
Drone assembly	Remote control, Motor, Frame, Transmission, Flight controller, Power board, Propeller, Battery cable, Battery terminal, LED, Battery, Transmitter, Receiver, Speed controller, GPS, Gyroscope, Barometer, Accelerometer
FPV assembly	Monitor, Image receiver, Image transmitter, RC camera, Camera mount, Gimbal, Antenna, Cable receiver, Battery

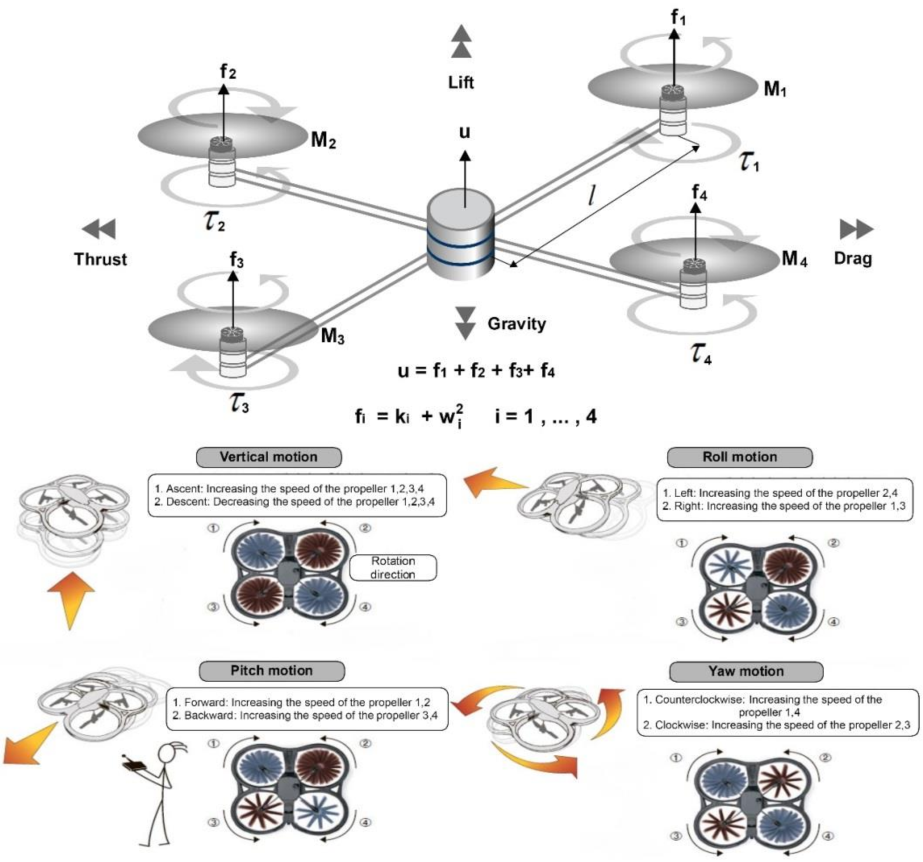


Fig. 2 Four-rotor rotorcraft scheme and motion of the quadcopter

communication technology. The process to implement a drone can be divided into steps including frame assembly, electronics assembly, flight controller tuning, and the addition of optional equipment. The typical components of a drone system include a flight controller (FC) with multiple sensors (such as a GPS, a gyroscope, a barometer, and accelerometers), motors, batteries, propellers, speed controllers, and the camera mount, as shown in Table 2.

For real-time monitoring by drones at a construction site, an appropriate frame structure should be considered in accordance with site characteristic such as operational requirements, maintenance costs, availability, the environment, and initial purchasing cost. Especially, the ability to withstand strong winds and durability are essential issues. For real-time site monitoring, a drone should be equipped with sensors and a single-lens reflex (SLR) camera on drone frame.

3.3 Assembly and operation of a quadcopter

In this study, the quadcopter was selected due to its distinct advantages in addressing many conditions at construction sites. The quadcopter is assembled with four electrical motors, and each propeller is directly coupled to the motor. Also, it is a vertical take-off and landing drone that can fly by remote control (RC) or autonomously using a GPS waypoint navigation system. The flight time is approximately 15 to 30 minutes depending on factors such as payload weight and wind speed (Pérez *et al*. 2013). The central portion of the quadcopter is filled with various sensors and computers. A gyroscope and an accelerometer are used to maintain a posture in the horizontal, vertical, and directions. The basic principle to control the airframe is to change the number of revolutions of the motors. For example, to raise the airframe to the right, the system

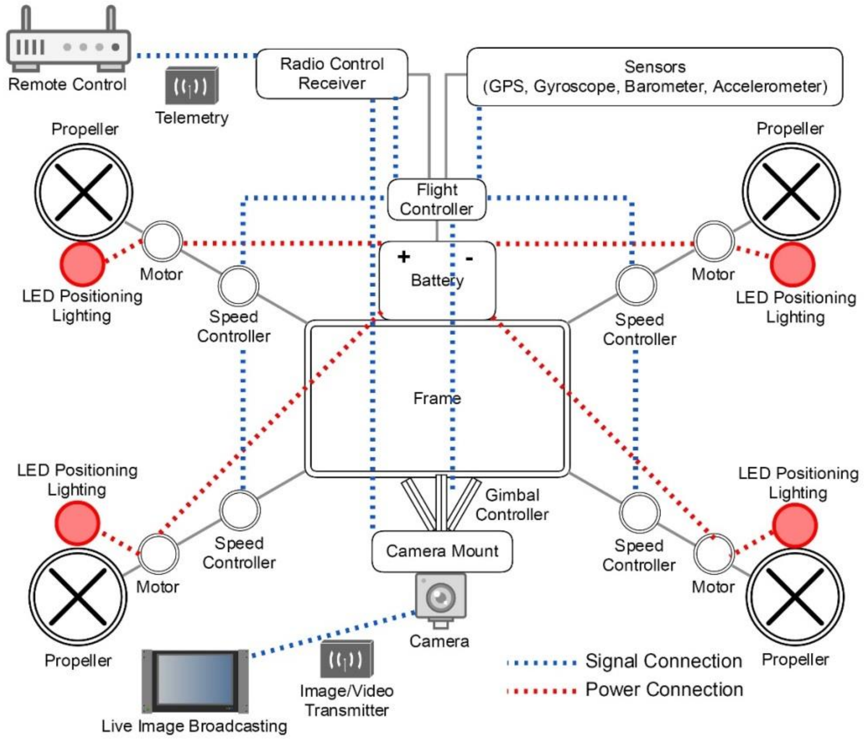


Fig. 3 Hardware assembly of the quadcopter

lowers the output of the right motors and raises the rotation speed of the left motors. To improve the stability of direction of the airframe, equipment of the self-compass is also helpful. Furthermore, in order to maintain the flying altitude, it is an important point that the reaction force of the airframe is minimized. In the case of a multi-copter, it flies through a rotational force of the propeller but, if all the propellers rotate in the same direction, the airframe moves in reverse rotation because of the reaction force. Therefore, in the case of the quadcopter, there is one pair of clockwise propellers and one pair of counter-clockwise propellers, thereby preventing rotation by reducing the reaction force as shown in Fig. 2.

Fig. 2 also shows the motion of the quadcopter. As shown in this figure, a change in the direction of the quadcopter is achieved via the rotational speed of the propellers. Vertical motion is controlled by the collective throttle input, i.e. the sum of the thrusts of each propeller. Forward/backward motion is achieved by controlling the differential speed of the front and rear propellers. To change the direction of the airframe to the left, the number of revolutions of two propellers turning to the right should be increased, and the number of revolutions of the two side propellers turning to the left should be decreased. Finally, yaw movement is obtained by taking advantage of having two sets of propellers rotating in opposite direction. Thus, a yaw angular displacement is obtained by increasing or decreasing the speed of the front and rear propellers while decreasing or increasing the speed of the lateral propellers and every operation of the drone is controlled via RC (Lozano 2013). Common telemetry control systems use radio frequencies in various bands such as FM, WiFi, and four-channel and six-channel microwave (Kang *et al*. 2014). If the camera is mounted to a gimbal, another signal to adjust the angle of the camera is added. Fig. 3 shows the hardware assembly of the quadcopter.

Another reason that a quadcopter can be used for real-time monitoring is because of its first personal view (FPV) ability. Through the FPV, images shown on the drone camera can be transmitted and watched on a monitor screen. At this time, the on screen display (OSD), verifications of drone states such as altitude, battery status, and signal strength are also possible. Therefore, practitioners can observe objects from high viewpoints and explore unreachable or dangerous areas (Kang *et al*. 2014). In addition, multi-copters such as the quadcopter can use a waypoint system. This system is input to the fixed flight trajectory by using a built-in GPS or navigation system. Thus, drone can measure latitude, height and longitude. Also, it is possible to come back to a specified location. The flight trajectory data for a waypoint route is typically stored in a digital file that is submitted to the UAV with a wireless data upload link from a ground control station, mobile computer, or smartphone (Siebert and Teizer 2014).

4. On-site management system

4.1 Feasible applications of the proposed system

Understanding the current status of a construction project is quite important in order to accomplish successful on-site management. In the past, information and image data were usually acquired through visiting the field office

Table 3 Feasible factors

Category	Possible factors
Work task	Crew size, Coordination between trades, Managerial and administrative support, Project progress
Material	Material storage area, Vehicle traffic routes, Tracking material
Unexpected events	Jobsite congestion, Safety management

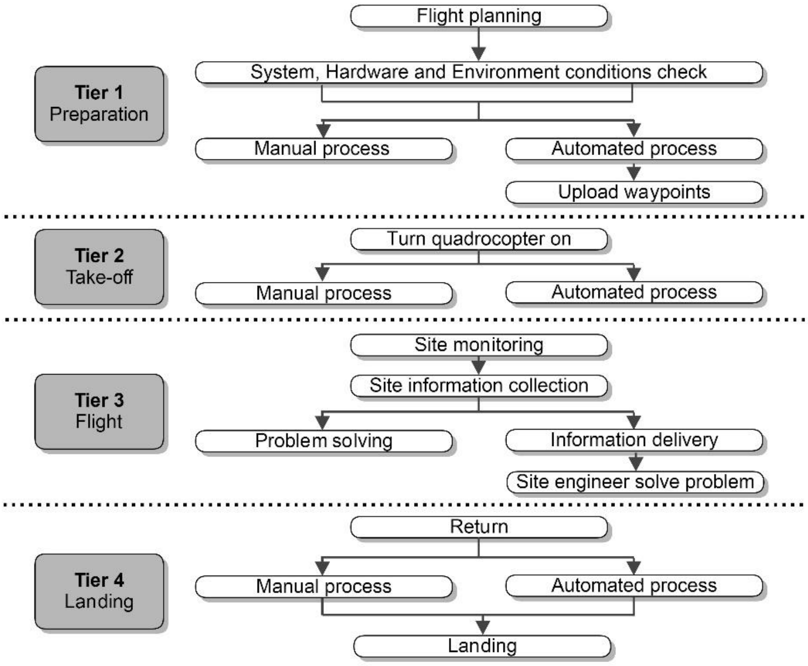


Fig. 4 On-site management system process using the quadcopter

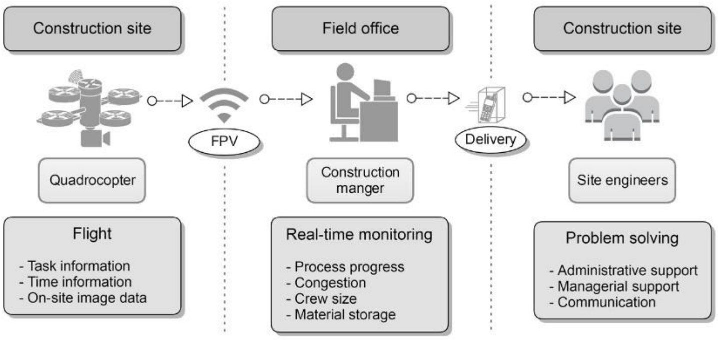
and construction site, respectively (Kim *et al*. 2013). The proposed drone monitoring system provides improved transmission of project information by the FPV ability of the drone. Therefore, this system can play an important role in real-time task management for construction participants.

Prior to developing a drone-based on-site management system, various conditions and factors that affect efficient construction management should be determined. The main advantage of the proposed system is to derive current information in real time for visualization at the field office. Therefore, factors that should be conducted directly in the field by face-to-face communication were excluded, such as communication between workers and managers, related tool and consumable issues, drawing errors, and construction equipment. Feasible drone monitoring factors can be categorized as work task information, material storage area information, and unexpected event information, as shown in Table 3.

The factors in Table 3 are strongly related to roles of the site engineers. At the construction site, site engineers normally carry out tasks under the direction of the field office. However, several limitations occur in terms of time and quick decisions because of the distances involved, especially at large construction sites or in tall buildings. To determine the specific issues, sensors, CCTV cameras and mobile computing technology have been used at some construction sites for capturing image data (Leung *et al*. 2008, Kim *et al*. 2013, Wu *et al*. 2010). However, it was found some limitations to operate in the construction site. In the case of CCTVs, the range of monitoring viewpoint is limited and interferences exist when several viewpoints operate simultaneously resulting in degradation in system throughput (Leung *et al*. 2008). The method of mobile computing technology also has supplement point that should be performed walkthroughs of the site by site engineers to check site conditions. The range of the proposed system is very wide, and it can be used anywhere on the site. Therefore, construction managers can choose a specific construction site location and monitor any issues, and the site managers can easily examine the project information in accordance with the directives of construction managers.

4.2 System architecture

Fig. 4 shows the proposed site monitoring system. This on-site management system is divided four steps: (1) preparing the quadcopter, (2) take-off, (3) flight for site



(a) Real-time construction site data flow

(b) Reinforcement work (c) Form work (d) Slab form work (e) On-site monitoring

Fig. 5 Data flow in site monitoring

monitoring, and (4) landing the quadcopter. The first step is to prepare the quadcopter for flight. In this step, the user checks hardware such as the frame, motors, propellers, battery, sensors, and camera. Then, the user should determine if the waypoint control system will be used.

To use the waypoint system, the flight path should be uploaded. Otherwise, RC is used to control the drone. Before take-off, environmental conditions are checked such as the surrounding airspace, wind, and human hazards.

The second step is the launch of the quadcopter. The user lifts the quadcopter off the ground manually, and switch to autonomous flight mode. After take-off, the quadcopter follows its preset tasks autonomously. If RC is used, specific locations can be observed manually.

The third step of the process is site monitoring. During the flight, construction managers in a field office can verify and collect the site information by the FPV ability of the quadcopter. During this time, construction managers can make site management decisions. If problems are detected, the site engineers can be consulted. The last step is landing the quadcopter. When the last waypoint is reached, the quadcopter returns automatically to the initial point. The landing can be performed manually or automatically. The user can decide to re-launch the quadcopter when more information is needed, or when the size of the area is too large for a single flight.

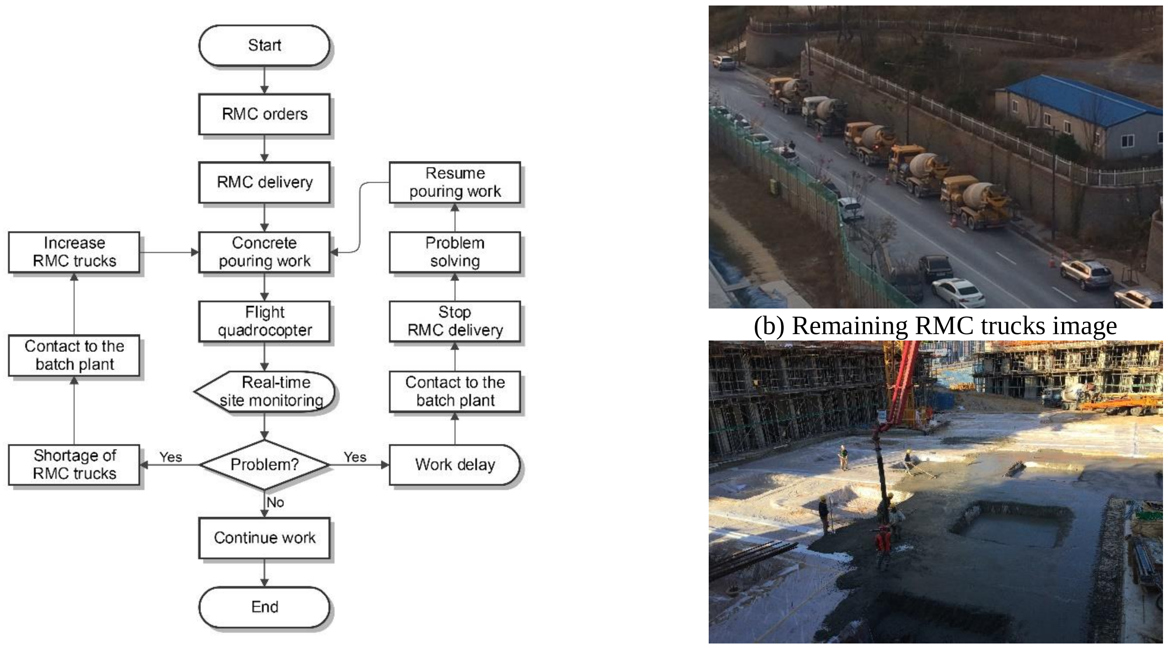
5. System implementation

5.1 Work task information delivery

The most important function of the proposed system is its visualization ability to monitor the construction site in real-time. The system is optimized to use external processes of construction work rather than internal processes such as finishing work. Among the external processes, reinforced concrete work is occupied for the largest portion. This process includes reinforcement work, form work, and concrete work. Thus, many workers are deployed and considerable time and money is normally spent. Furthermore, since each task leads to subsequent tasks such as electrical and equipment work, considerable information management is required. The current method of acquiring work task information from the site involves visiting the site. This method limits the ability to make immediate decisions and respond quickly.

The proposed system can be applied to the reinforcement work and form work processes. These tasks are sequential, and are followed by electrical work and equipment work. Fig. 5 shows the system implementation process. As shown in the figure, the current status of the process can be monitored by the FPV system of the quadcopter, and the construction manager can be aware of all on-site activities, process progress, job site congestion, and the correct crew size. Through this information, a construction manager can carry out the proper managerial and administrative support immediately, without connection delay to the subsequent process step. Also, when problems are found or should be handled by face-to-face communication, an immediate solution is possible through a connection with site engineers.

After finishing the reinforcement and form work process, concrete pouring work begins. At large construction sites, dozens or hundreds of ready-mixed concrete (RMC) trucks are driven per day for the concrete pouring work. The most important aspect of this work is the quality of the concrete. Prior to the concrete pouring work, site engineers or the construction manager contacts the concrete batch plant and RMC trucks drive to the



(a) Concrete pouring process flow

(b) Remaining RMC trucks image

(c) Concrete pouring work image

Fig. 6 Concrete pouring process

construction site. At this time, if the concrete pouring operation is delayed because of a worker's mistake or a breakdown of a pump car, the waiting time of the RMC trucks increases, which affects the concrete quality. To prevent this situation, construction managers order concrete by dividing the amount. However, this method sometimes leads to delays. The proposed system can improve the conventional work process as shown in Fig. 6.

Through real-time drone monitoring, it is possible to check the progress of concrete pouring work and the remaining RMC trucks in the field. Acquiring concrete pouring speed information offers a considerable advantage because the construction manager can easily control the Delivery of RMC trucks. Thus, it is possible to manage RMC trucks with no delay. Using this information, if the concrete pouring speed is decreased, the construction manager can delay the shipments of RMC trucks by contacting the batch plant. If there are not enough RMC trucks in the construction field, the construction manager can increase delivery. It is also possible that this system can reduce the waiting time by modifying the route of the RMC truck because the drone can check the traffic situation. The proposed system can be used to improve the concrete quality and work time because the waiting time of RMC trucks is decreased, and the order for RMC trucks takes place quickly.

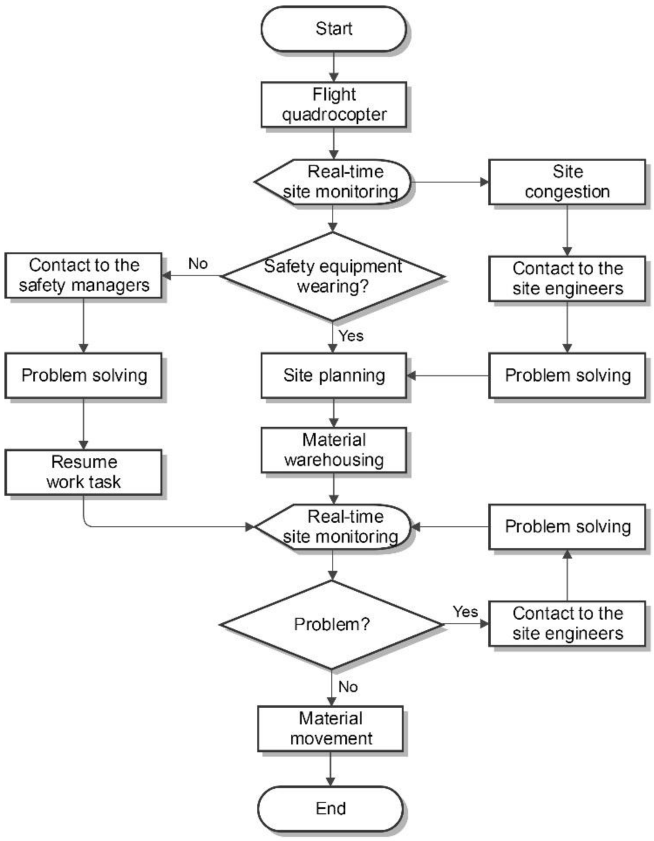
5.2 Material storage area and unexpected event information delivery

Large construction sites always require the coordination of hundreds of workers and pieces of construction machinery. Many types of materials are delivered and shipped every day. This situation leads to jobsite congestion, and sometimes it is very difficult to find a place for material storage. To improve these situations, the construction manager and site engineer should manage a sufficient material storage area not too far from the workplace. However, due to field situation is not expected, no alternative way without confirmation directly by walk. There are other cases that are related to jobsite congestion. If the site plan is insufficient, sometimes a traffic route between vehicles and machines overlaps, which can increase the working time and disrupt the work process. When materials that must move to the workplace immediately are delivered, this situation delays the current working process and subsequent processes.

The proposed system can improve the conventional work process through current information regarding the construction site as shown in Fig. 7. The construction manager can detect any situations that are occurring in the field. Thus, the work plan can be managed before unexpected events occur. Moreover, a construction manager can inform site managers of the site plan beforehand, and they can prescreen unexpected events by coordination between the trades or the priority of work. The proposed system can also improve the monitoring of safety information related to construction participants. For example, during site monitoring, the construction manager can determine if workers are wearing safety equipment. (e.g., wearing a safety belt during high work). Construction participants can take action without visiting the site through contact with the safety managers.

6. Conclusions

We present a novel approach for managing a construction site. In this study, the FPV system of a quadcopter was used as a management tool, and we



(a) Site management process flow

(b) Material warehousing image

(c) Site congestion image

(d) High work image

Fig. 7 Site management process

confirmed that the proposed system allows construction participants to make use of project information irrespective of time and space. The conventional method for managing a construction site is that site engineers and construction managers perform walkthroughs of the site and check the status of labor, materials, and vehicle routes. However, the proposed system allows work task visualization anywhere; ts, it can assist site engineers in easily identifying the locations of work tasks and resources on the construction site in real-time. This benefit provides participants with better project planning, organization, and control by using the acquired information. Also, the proposed approach leads to a decrease in the cost of the construction project. The system can minimize possibilities of rework through the appropriate work order and effective information sharing thus, it helps managers to effectively manage the material and personnel expenses of the project and they can prevent a waste of the project cost. In addition, the quality of a project can be improved. To reduce incidents of defects during construction process, the proposed system provides site information for site engineers to learn about accurate site information. Lastly, it is possible to make decisions immediately, and construction managers can choose a specific construction site to monitor any issues. Overall, the proposed approach ensures improved construction operations, and leads to a decrease in the time and cost of the construction project. However, some limitations of the proposed system need resolution. The flight time of a drone is not enough for long-term monitoring because of battery limitations. Also, this system is not sufficient to satisfy all needs of construction managers because it can be utilized only for external processes. To improve the management process of construction project, in depth scheduling and resource planning should be integrated with the system. Therefore, integration with strong sensing capability based on artificial programs that can be obtained detail of project is encouraged for further study. Future work should address these limitations by using improved technologies for sensors or programs. Also, improved system will possible to use various sectors such as land survey or urban maintenance.

Acknowledgments

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