Preliminary System Design for Teleoperating Construction in Extreme Environments

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Abstract -

Automation of construction is urgent needs for improving efficiency of works, reducing the number of personnel, and working in extreme environments such as other planet or moon or disaster-stricken area. However, the current situation is still insufficient due to reasons of such complexity of work and high risk especially at building sites. In terms of heavy machinery in building construction, it is indispensable to measure its own position and attitude because their precision directly relates to construction accuracy. If lifting and delivering works can be unmanned or teleoperated, it is expected to drastically reduce the number of personnel and improve efficiency. In this research, we have found that a mating connection mechanism can aid teleoperating construction. This mechanism works without any fastener, that is utilized in the construction of the temporary cover of Fukushima Daiichi nuclear power plant unit 1, with RTK/GNSS (Real Time Kinematic, Global Navigation Satellite System) positioning systems is possible to realize the teleoperating construction. By conducting confirmatory experiment of positioning system using a tower crane, we have confirmed the normal operation of all systems. In terms of position and azimuth angle, the accuracy is sufficient to meet requirements for building construction with the mating connection mechanism. Regarding ICP matching by LIDAR (Laser Imaging Detection and Ranging), it was confirmed to be possible to compute the altitude angle with extremely high accuracy utilizing point cloud information from the LIDAR and CAD data using the ICP (Iterative Closest Point) matching library. Detailed preliminary unmanned building construction concept and some results are shown in this paper.

Keywords -

Building Construction; Lunar Base; System Design

1 Introduction

In recent years, automation of construction is urgently required with aims of improving efficiency of works, reducing the number of personnel, and working in extreme environments such as other planet/moon[1, 2] (Fig. 1) or disaster-stricken area. However, the current situation has not progressed rapidly due to reasons of such complexity of work and high risk especially in building sites. Automation of construction works by an unmanned system requires precise positioning method of the self and the target, object recognition and shape recognition system, precise and high speed control, etc. Among them, obtaining detailed position information of the moving object is the most important technique. In terms of heavy machinery such as a crane lifter in particular, it is indispensable to measure its own position and attitude, and their precision directly relates to construction accuracy. If lifting and delivering works can be unmanned or teleoperated, it is expected to dramatically reduce the number of personnel, positioning work of structures, changing work of materials, scheduling lifting plan of cranes, etc. Furthermore, smooth collaboration of information with design, construction control and building management will be achieved. A certain degree of positioning error can be tolerated with our mating connection mechanism (Fig.2).

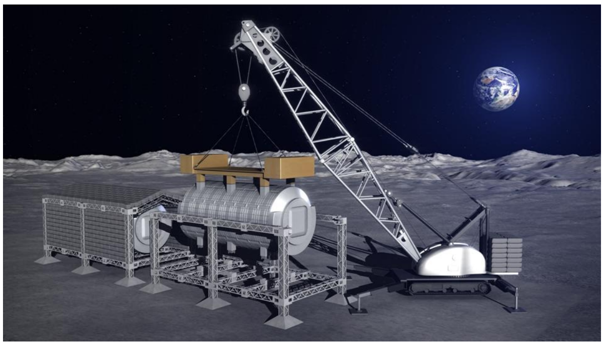

Figure 1. Concept of Lunar Base Construction (Shimizu Corporation)

Several applications of GNSS/RTK in the field of civil engineering have been reported, however, in the building field, there has been little effort so far due to the high accuracies of the position and attitude are required. In this research, we have investigated whether GNSS/RTK receiver can satisfy the requirement by using single frequency receivers, although "fix"(high-accuracy) solution of a single frequency receiver is difficult to always maintain, a problem in which an attitude angle can not be detected, and two or more frequencies receivers are expensive relatively, and so on. At the same time, redundancy performances of IMU and LIDAR have been investigated as alternate methods.

2 Method

2.1 Unmanned Construction in Extreme Environments

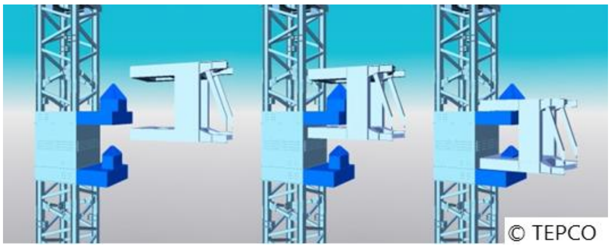

Figure 2. Mating Connection Mechanism

Concerning unmanned construction method, we have experienced and accumulated the engineering techniques in building the temporary cover over the damaged reactor building unit 1 of Fukushima Daiichi nuclear power plant by the teleoperating construction system in high radioactive environment (Fig. 3). All works are conducted with remote control using multiple sensors, cameras, and a crane. It is inevitable that the crane and a lifted object have positional errors, then a tolerate technique is required for safe and reliable jointing. We adopted a mating connection mechanism without any fastener or welding work shown in Fig. 2 that is composed of square holes and quadrangular pyramids. The mechanism is able to tolerate the position and attitude errors of their determination and control by passive adjustment, therefore, fundamentally we adopt the mating connection mechanism positively in this research for building at extreme environments.

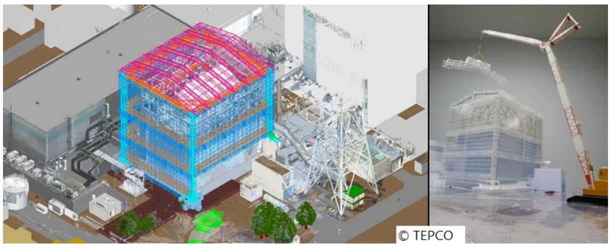

Figure 3. Temporary Cover over the Damaged Reactor Building of Unit 1

Concerning the navigation, in these days, low-cost GNSS receiver, single frequency RTK and IMU (Inertial Measurement Unit) are available with ease, and the performance of LIDAR is further improved. Especially global navigation satellites can be seen at least 10 (maximum about 40) in real-time (GPS (United States), GLONASS (Russia), Galileo (Europe), Beidou (China), and QZSS (Japan)). Comparing to other navigation method (single, differential, static, etc.), RTK has advantages of instantaneity and accuracy, although two receivers (base and rover) are required. Thus, lots of GNSS receivers are introduced, distributed, and integrated in our system that can manage highly accurate position and velocity (3-axis) / attitude angle and angular velocity (3-axis) of heavy machinery and lifted objects. Although GNSS is not available on other planets or on the moon, a relative navigation system can be established by another method (e.g. radio navigation, indoor messaging system, pseudolite, total station), and their accuracies are equivalent performances to GNSS. The positioning system is designed as dual-use for uncertain/extreme environments and general building construction site on the earth (Fig. 4) for the reasons stated above, it can also contribute to productivity enhancement.

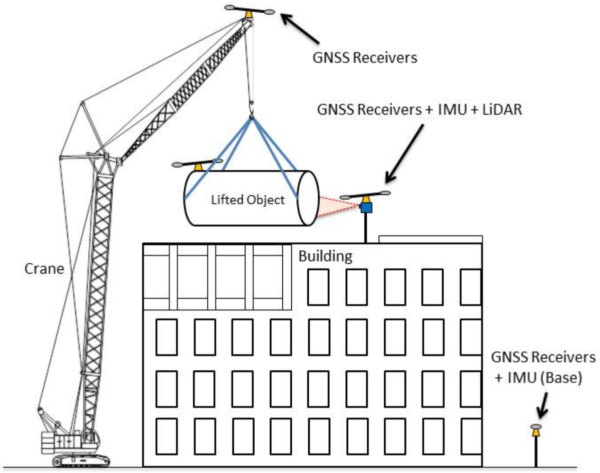

Figure 4. Concept of Unmanned Building Construction

Moreover, we conduct experiments with actual machines with the aim of realizing a production site that can operate construction robots, heavy machinery and general machinery all at once by collaborating with BIM (Building Information Modeling).

2.2 RTK-GNSS Navigation System

2.2.1 Concept

In order to acquire the position and orientation of a crane and a lifted object, the system shown in Fig. 5 was developed. For the purpose of obtaining yaw angle at each position, one pair of GNSS receivers (u-blox NEO-M8T) and antennas (Tallysman TW2710) are located. Since the error of the altitude information is relatively large compared to horizontal position, it also has a barometer (MS5611), which is integrated with a signal from the IMU (AU7554) and transmitted via wired/wireless Ethernet to a microcomputer. Accurate position data is output by analyzing the GNSS signal by the library "RTKLIB" which

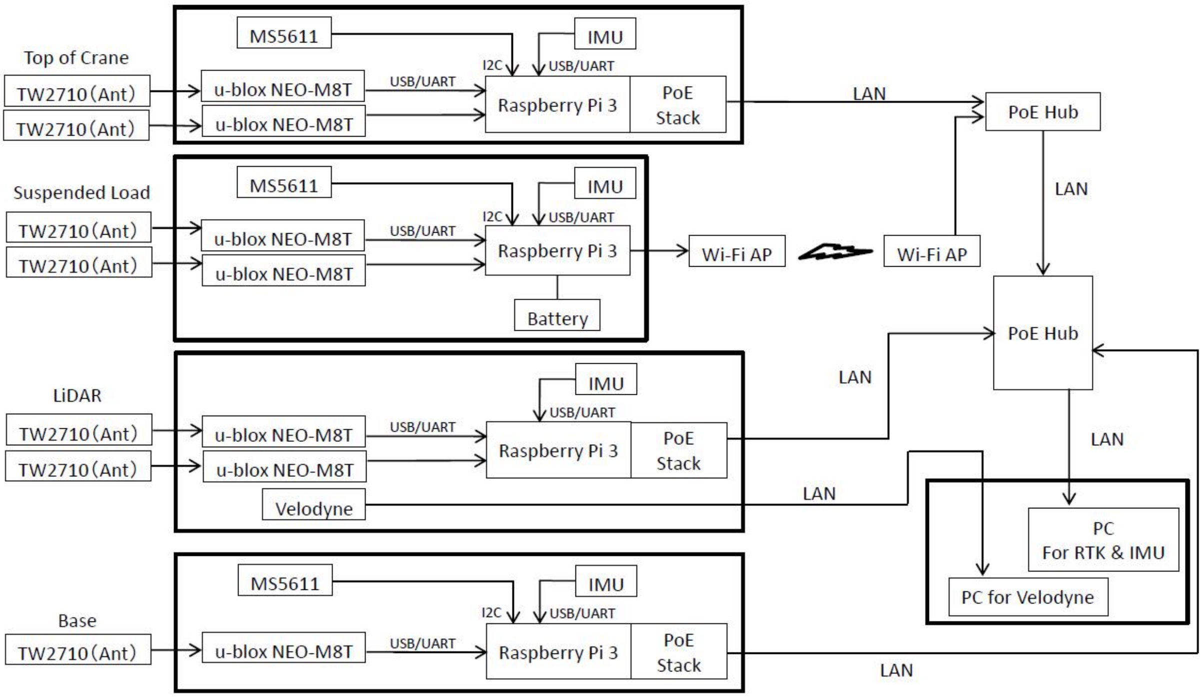

Figure 5. System Diagram

is developed by Takasu[3, 4]. By conducting Loosely-Coupled integration[5, 6, 7] using IMU and barometer signals, appropriate extrapolation is tried to be performed even when RTK solution falls into "float" (low-accuracy solution) using extended Kalman filtering[8, 9, 10] with white noise assumption, or smoothing technique. Internal clocks of microcomputers (Raspberry Pi 3) are synchronized by each time acquired from GNSS, then it can be compensated using the time in integrating multiple sensors.

2.3 System Setup

We developed a measurement system module shown in Fig. 6-7 that is composed of instruments listed up in table 1. PoE (Power on Ethernet) is introduced for power supply of the almost all systems because of the difficulty in accessing the top of the crane for battery charging frequently. However, lifted object is accessible with ease and has the risk of disconnection of wired instrument, batteries and WiFi access point are also attached to it. All electrical systems are in a waterproof-dustproof box, and external antennas are also waterproof. GNSS antennas are attached on wide aluminum plates, and located at 1.5 m height due to prevent the effects of multipath signal on the ground.

In addition, point cloud information from LIDAR is matched by ICP algorithm[11] using the CAD shape data that is stored in the database, thus the attitude angle of the

Table 1. System Instruments

Instrument	Model	Supplier
GNSS Receiver	UBLOX NEO-M8T	CSG Shop
GNSS Antenna	TW2710	Tallysman
IMU	AU7554	Tamagawa Seiki
Barometer	MS5611	TE Connectivity
μC	Raspberry Pi 3	RPF
Storage	MicroSD 16GB	Toshiba
PoE Ejector	PoE-ZR30ATG	Techno Broad
PoE Hub	EHB-UG2B08	Elecom
WiFi Router	WAPS-AG300H	Buffalo
Battery	PowerCore Speed 20000QC	Anker

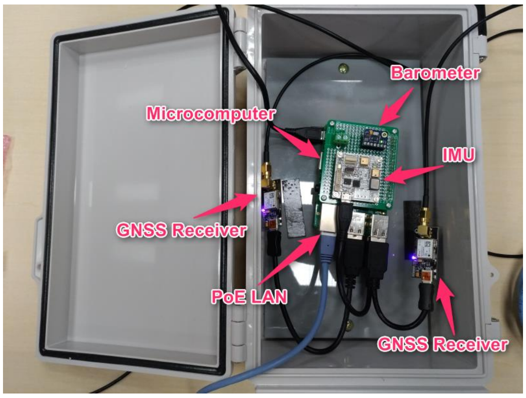

Figure 6. System Box

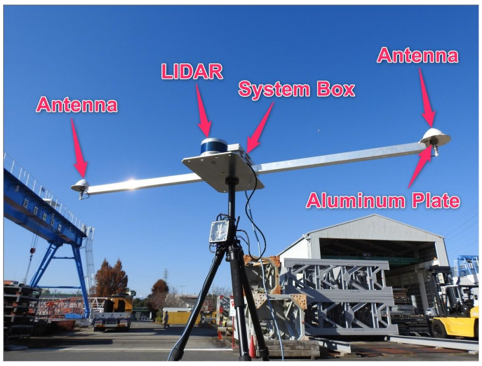

Figure 7. Integrated System

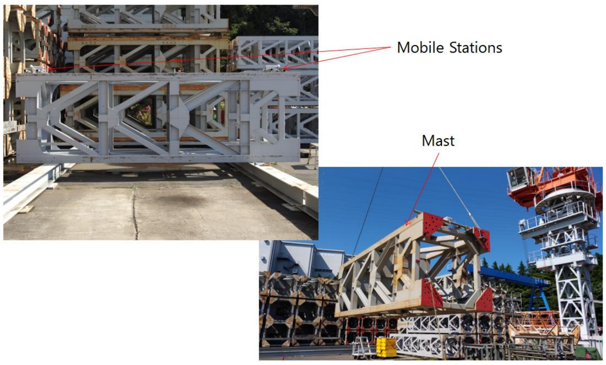

Figure 8. Experimental Site

lifted object is calculated. By adopting the above method, it becomes possible to have redundancy without relying on RTK-only information only.

3 Results

In order to confirm the accuracy of RTK at the building construction site, IMU integration, and the possibility of position and attitude detection by LIDAR, demonstration experiments by lifting was carried out at a facility where a tower crane is permanently installed. The GNSS receiver was installed on several fixed points and lifted object on the ground, and the LIDAR was installed so as to be fixed to the GNSS module and face the direction of the lifted object. Four GNSS antennas are placed at the four corners of lifted object to calculate the azimuth or attitude (Fig. 8). LIDAR is placed in a position where the approach and separation are repeated to see how the difference in point cloud density affects. For the purpose of confirming calculation accuracy of state, a series of operations of lifting the object were repeated 5 round trips by hoisting motion (about 1 m in height), horizontal motion (about 15 m) by slewing, and grounding by hoisting motion. Furthermore, in order to confirm the influence of multipath of RTK/GNSS, it was repeated to move from the place where the stock is accumulated to the open place.

Figure 9 shows the solutions of antenna positions on the lifted object. "1L" or "2R" in the legend means left and right antenna of each measurement system 1 and 2. The average number of satellites used for calculation was about 17. According to preliminary experiments, it is known that the "fix" (high-accuracy solution) rate is highest when 30 deg of masking elevation angle of satellite and 30 dB of masking SN ratio of GNSS signal was applied. In figure 10, the blue line and the green line represent the fix solution and the float solution respectively. Occasionally the position sometimes deviated greatly, then Kalman filter was applied to correct it, however, it did not work well because the slewing speed at the time of the experiment was too slow. Nonetheless, some degree of accuracy is maintained even with a "float" solution, and overall it was within 5.0 cm, which is a general RTK/GNSS error.

Regarding ICP matching by LIDAR, we adopted a method to compare the point cloud obtained by Velocyne LIDAR[12] and the 3D CAD model of the lifted object as shown in figure 11. Although it has symmetry in the rotation in the long axis direction, it seems that there is no problem because the introduced method has high initial value dependency and that the lifted object basically performs only yaw rotation. The CAD model is transformed into point clouds, and the result of executing matching using the ICP library[11] is shown in figure12.

The coordinate system is the LIDAR-referenced, and relative positions and orientations are calculated by fitting a point cloud model in the database to the measured point cloud. Differences of position and attitude estimation by GNSS-RTK were within 0.1 deg and 1.0 cm under optimal condition. However, there were some cases of matching failure, for instance, when the point cloud was not sufficiently obtained. In addition, since one calculation

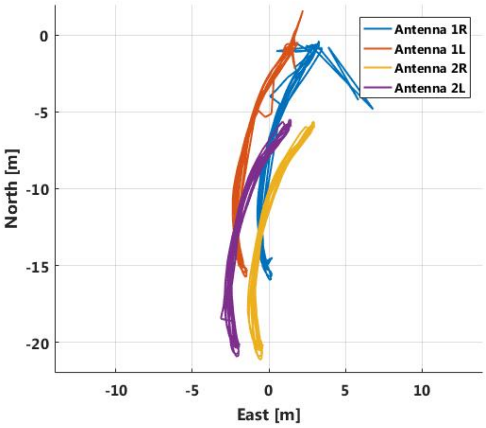

Figure 9. Position Results

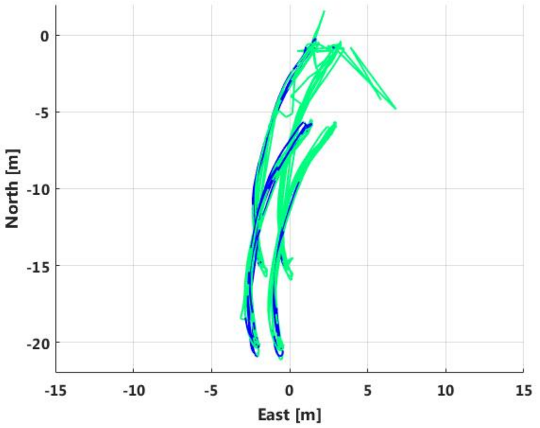

Figure 10. Position Accuracy

time was about 1 second on a typical personal computer, it seems that real-time processing at 1 Hz is also possible. Since there is a problem that LIDAR also detects surrounding objects, recognition and extraction functions will become necessary in the future. Figure 13 shows the distance between the antennas installed on the lifted object calculated from the result of RTK/GNSS position. The correct distance is 1.5 m, and although a slight deviation is observed in "float" solution, the error is kept within 3.0 cm. Based on the above results, we calculated the azimuth angle (Fig. 14). The longer the distance between the antennas, the more stable the azimuth can be calculated. It can be calculated with an accuracy of about 1.0 deg even if the distance is 1.5 m, so it was found that it can be used as an alternative way to a magnetometer.

4 Conclusion

We designed and fabricated a position and attitude determination system for lifted objects for the sake of unmanned construction, and confirmed its usefulness by carrying out the experiments in situations that is similar to

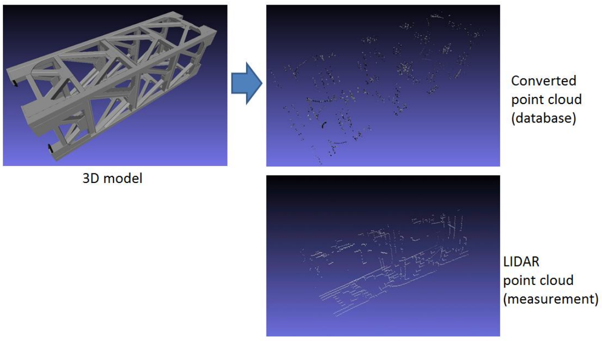

Figure 11. Pointcloud Comparison

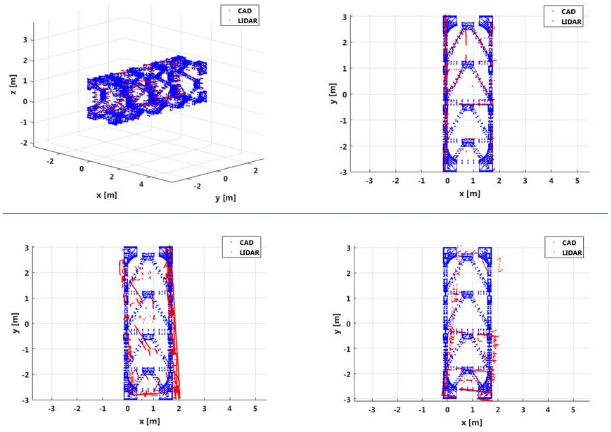

Figure 12. ICP Results

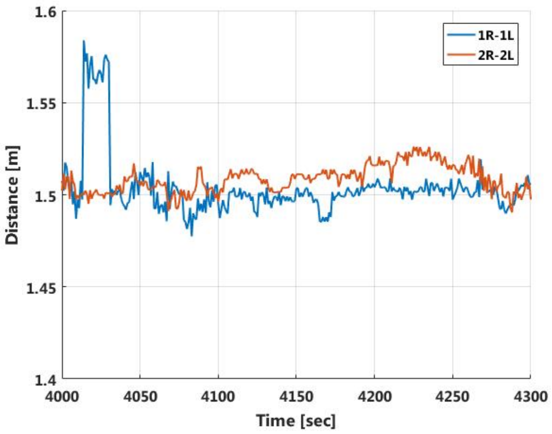

Figure 13. Distance between Antennas

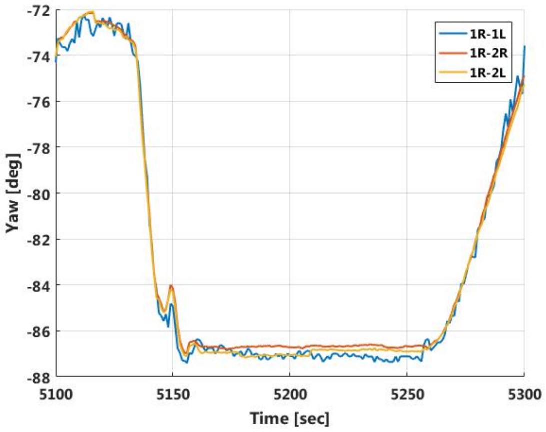

Figure 14. Azimuth Results

actual building construction sites. There was concern that the satellite radio wave environment deteriorated due to surrounding cranes and metal structures, nevertheless the calculation of the position was within the general accuracy of RTK/GNSS without using any optimal filtering. Therefore, it was confirmed that the system would be able to perform remote control using our mating connection mechanism.

ICP matching using point cloud information also succeeded and it was found that there was a possibility that it could be used as a redundant means, however issues such as accurate point cloud extraction of objects remained.

In the future, we plan to develop a system that is able to visualize the position and azimuth of the lifted object in real-time.

Acknowledgment

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