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Development of Drone System Embedded with Multiple Distance Sensors for Inspection Task of Social Infrastructure

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Abstract—**A new drone system embedded with multiple distance sensors was developed in this paper. Recently, drone has been considered as an appropriate device for inspecting building or social infra structure because it shows high mobility and quick approachability by moving through free space in the air. In general, it uses GPS as a fundamental tool to obtain position of itself in the air because it provides sufficient performance required for autonomous flight. However, in most inspection applications a drone should move or keep hovering near walls or artificial structures. Then, during such inspection tasks, GPS is useless because of no or multi-paths problem of radio signals from satellites. Moreover, a drone is required to move and perform task according to commands given from tele-operation by a user who exists far from objective point.**

Therefore, a special function to detect walls as well as prevent collision is essential to the drone for inspection works. This research proposes a method to use multiple tiny distance sensors embedded in a drone for detecting walls near itself. Besides, a drone system installed with four distance sensors was developed, and the usability of the proposed method was confirmed through experiments.

Index Terms—**Drone, Distance Sensor, Inspection Task**

I. Introduction

In recent years, technologies related to drone are showing rapid advances in wide application areas. Especially drone is recognized as a good device for inspection tasks because it has capability of not only moving directly to objective point through free space in the air, but also keeping hovering motion for taking pictures near region of interest.

Meanwhile, maintenance of deteriorated old infrastructures such as bridge and tunnel has been considered as an important issue in many countries. Even in the case of Japan, about 700,000 bridges are being used in Japan, 50 years had elapsed in 2010 since about 8% of them had been constructed. Besides, it is expected that about 26 % in 2020, and 53% of them in 2030, respectively, will become old bridges with ages of more than 50 years [1]. Likewise, rapid deterioration of physical social infrastructure, such as bridges typically, has recognized as a big problem in Japan because huge cost is also required for maintenance of old infrastructures. For example, all bridges should be checked through regular inspection one time per five years under the law of Japanese government. Most maintenance works are carried out by manual processes accompanying direct access of field workers. Thus safety of workers and their accessibility to the inspection area are the main difficulties in inspection tasks. In addition, if the public road is temporarily prohibited for inspection or maintenance task, it also causes additional economic damage in the industries or businesses related to that facilities.

Therefore, these problems naturally cause demands of improving efficiency of inspection task and advanced devices. Accordingly drone and robot technologies have been attracting attention from researchers because they are recognized as appropriate solutions for these problems. Some robotic systems having special functions of wall climbing or robotic mechanism to access high places have been investigated in these days. Robots having the capability of adhering to the ceiling or wall have been also proposed [2-6]. However, although they can move on the surface of the wall, they cannot move to target point in some conditions where the surfaces are uneven or not connected continually owing to corner and edge. Several types of multi-rotor crafts, generally called as drone, have been also developed for effective inspection tasks because of their high performance in mobility to approach target position [7-9]. Recently, experimental tests with unmanned aerial vehicles (UAVs) for bridge inspection have been carried out in field situations [10].

The essential functions of a drone for inspection task are safe moving to and stable hovering near a target position. However, GPS providing position information cannot be used near building, and it is known that general drones are weak to collision with structures, which cause accidents of crash or fall. So they cannot access or contact directly to the surface of structure or building. As a solution for the problems, a new drone system was proposed in our previous research [11]. In addition to the basic flying functions of general drones, it has special guard plate for adhering to the ceiling and wheels for moving on there. A control method with distance sensor for hovering motion of the proposed drone is investigated in this paper. For safe and efficient flight of the drone near the target

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position of building where correct position information is not provided because GPS cannot be used, a method to support tele-operation by using multiple tiny distance sensors is proposed.

This paper is organized as follows. In Section II, the configuration of a drone system developed in this research is explained. In Section III, a control algorithm using distance sensors for a drone moving near buildings is addressed. In Section IV, experimental works to confirm usability of the proposed algorithm are explained. Finally, conclusions and future works are addressed in Section V.

II. Development of Drone System

A. Configuration of Drone System

Fig. 1 shows the developed drone system installed with special guard plate for adhering function. The width and the length of the guard plate made of Styrofoam material are 300 [mm] and 350 [mm], and the height is 70 [mm], respectively. It plays a role of suction plate when the drone adheres to the ceiling surface. By using it, the power consumption for

Fig. 1. Top view of the developed drone system installed with guard plate for adhering function

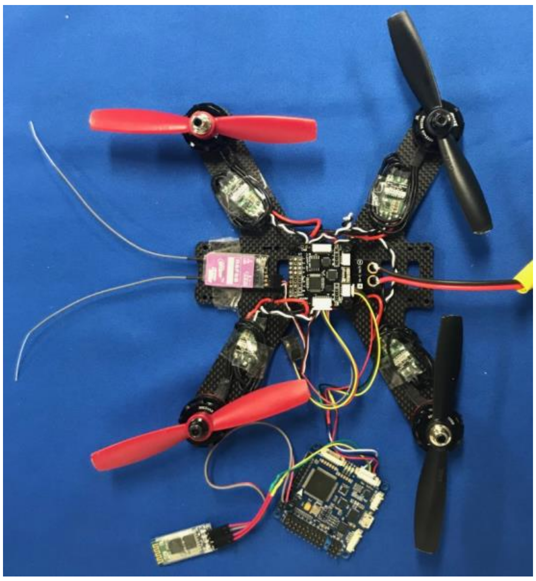

Fig. 2. Control hardware of the drone system

adhering can be reduced drastically than usual hovering. Four distance sensors for detecting walls and height of itself were attached on the guard plate, and their detailed explanation is given in the last part of this section. Four propellers of 5 inches in diameter were used in the system. A lithium-polymer battery having large charge capacity of 1300 [mAh] was employed as main power embedded in the system. The total weight of the system including battery is about 510 [gf].

B. Control Hardware

Fig. 2 shows control hardware of the developed system and its schematic is displayed in Fig. 3. It consists of four motors and drivers, flight controller, microcontroller connected with distance sensor and Bluetooth module, and battery as power source. It has two controllers, namely flight controller and microcomputer. As flight controller, 'SPRacing F3 Deluxe' was employed in this research. It includes accelerometer and gyroscopes which are used for computing body posture angles in real time. Besides, it performs motion control to keep posture angle and throttle of the drone according to command from microcomputer or joystick in general. The control output of the flight controller is transferred to motor drivers as reference speed of four brushless motors resultantly. Another controller which is denoted as 'Microcomputer' in Fig. 3 takes roles of managing sensors and computing motion plan based on measurement and user instruction.

Microcomputer's status is transferred to monitor computer

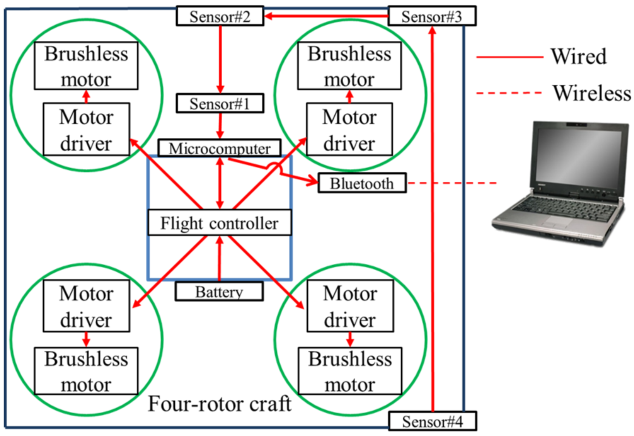

Fig. 3. Configuration of control hardware

TABLE I
Fundamental MSP Commands Used in This Research [12]

Command	Description	Variables and Ranges
MSP_RC	Receive the channel data from FC	ROLL/PITCH/YAW /THROTTLE/AUX1 /AUX2/AUX3/AUX4; Range [1000;2000]
MSP_SET_RAW _RC	Send the channel data to FC	ROLL/PITCH/YAW /THROTTLE/AUX1 /AUX2/AUX3/AUX4; Range [1000;2000]
MSP_ATTITUDE	Receive the Attitude data from FC	Angle-x; Range [-1800;1800] Angle-y; Range [-900;900] Heading; Range [-180;180]

through Bluetooth wireless communication, and user instruction from the monitor computer also can be given to Microcomputer reversely. Where, 'MultiWii' board was employed as Microcomputer. Both controllers are connected through wired serial communication channel and MSP (Multiwii Serial Protocol) was employed for communicating between them. The representative MSP commands used in this research are given in Table I [12].

C. Distance Sensor

Small sized RGB camera is well known sensor for general drone, also used in many applications to obtain pictures or movie of target area. However, as a sensor for autonomous flight, camera requires complex algorithm and computation burden for image processing. Moreover, it is not easy to obtain accurate distance to objects, thus special sensors such as depth sensor are used in case when the vehicle has power to deliver the sensor and computing hardware [13].

To cope with the problems, multiple tiny distance sensors were employed for measurement of distance to objects around the drone. As displayed in Fig 4, four distance sensors were attached to the suction guard plate of the developed drone system. The sensor has characteristics of tiny size and light weight as shown in Fig. 5. Its measurement range from 0.03 [m] to 200 [m] is appropriate for supporting motion control. It provides serial communication interface of I2C and multiple sensors can be used via the same communication channels by setting address of each sensor module and controlling its 'XSHOT' input port. The example circuit for the case of four sensors is given in Fig. 6.

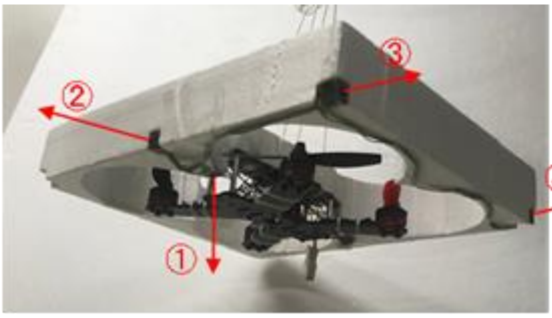

Fig. 4. Bottom view of the drone system equipped with four distance sensors (Number of distance sensors; ①: Bottom, ②: Front, ③: Side front, ④: Side rear)

Fig. 5. Distance sensor (VL53L0X, ST Microelectronics Co., size: 13.3mm * 10.5mm *2.4mm, weight: 0.5g)

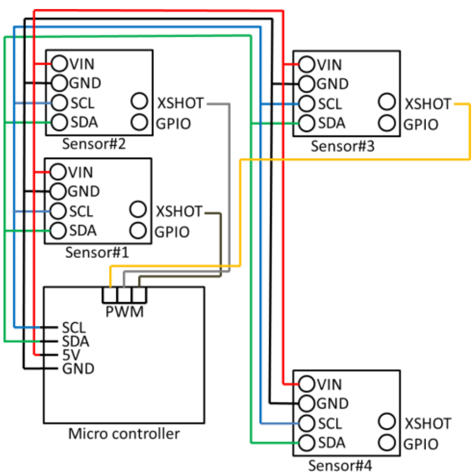

Fig. 6. Connection circuit of distance sensors equipped in the developed drone system

III. Flight Control Using Distance Sensors

This paper proposes three methods of flight control using distance sensors as follows. Firstly, it can be used for hovering motion to keep distance and angle from walls, and height from the ground or distance from the ceiling. Secondly, in case when the drone is moved by tele-operation, sensors can provide distance information to the objects around itself in real time. Then virtual walls can be made based on the measurement. Namely, if the value of any distance sensor is smaller than threshold, then the motion to the direction of the sensor should be restricted. Finally, automatic adhering motion to the ceiling can be realized by using a sensor measuring vertical distance. The common operation for above three methods are realized with four control commands that are generated by the microcomputer based on behavior plan and the relationship between the drone and walls near itself. Namely, angular rates of three pose parameters of vehicle body, i.e., roll, pitch, and yaw, and throttle for regulating lifting force are computed based on behavior plan with sensor data and transferred to flight controller.

IV. Experimental Works

In order to confirm the capability of the developed system and distance measurement by using multiple sensors, two experimental works were conducted.

A. Measurement during Manual Movement

After testing basic flight function of the developed drone, experiment to check the measurement of multiple sensors was carried out. As shown in Fig. 7 (a) and (b), four sensor values were obtained during manual motion from 'A' point to 'B' point by operator's hand. The change of sensor values during the motion are depicted in Fig. 7 (c), where all values were reduced because the drone was moved nearer to both walls and to the ground from the start position. Besides, the body posture and sensor values when the drone system is near the start and the end position are depicted with wire frame in 3D graphics of monitor computer, as shown in Fig. 7 (d) and (e). All status of flight controller and microcomputer can be transferred to the monitor computer in real time, thus the 3D animation is also provided simultaneously.

B. Measurement during Flight

Experiment to measure distance to walls and the ground was carried out also in the case of manual flight. As shown in

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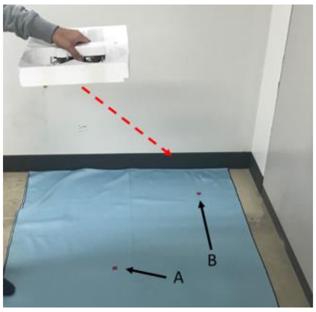
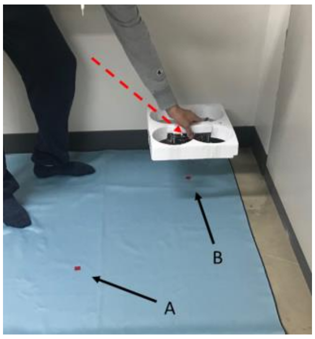
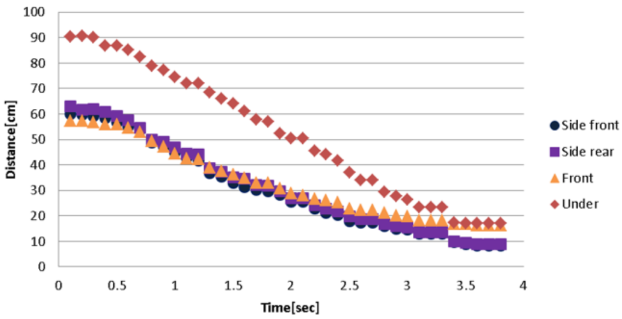


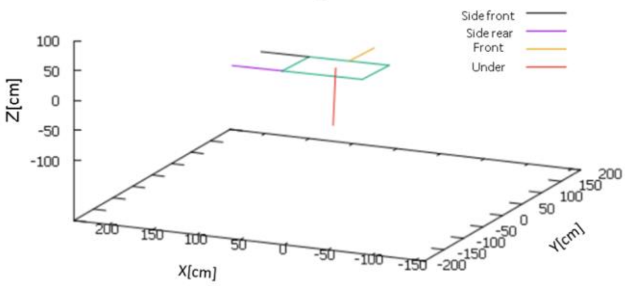
(a) When the drone is at the start point whose horizontal position is marked as 'A' on the ground.



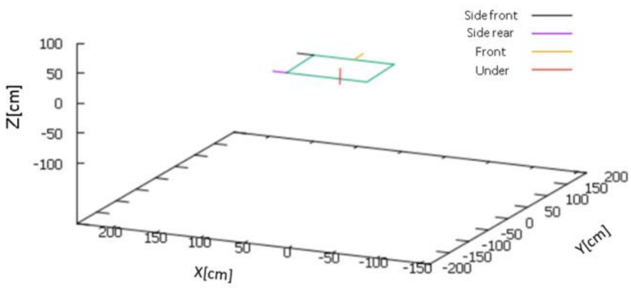
(b) When the drone is at the end point whose horizontal position is marked as 'B' on the ground.



(c) Change of measured values of distance sensors during experiment

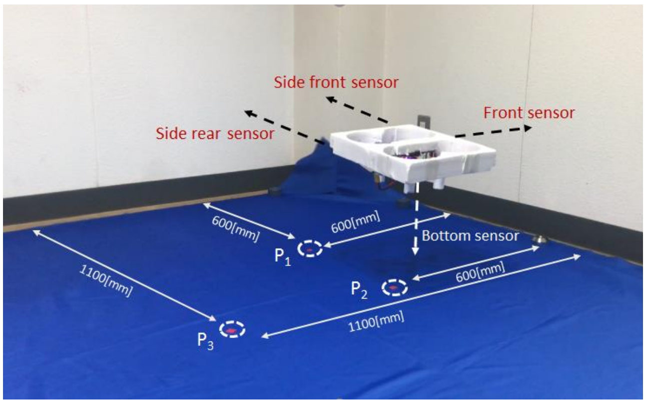


(d) Posture and distance values of the drone when it is at the start point marked as 'A' on the ground

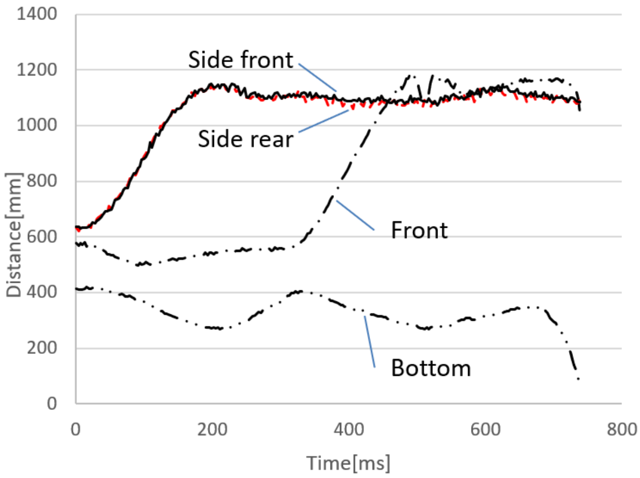


(e) Posture and distance values of the drone when it is at the end point marked as 'B' on the ground

Fig. 7. Experiment of detecting walls of the developed system during manual movement with hands



(a) Hovering motion over 'P_2' position



(b) Change of measured values of distance sensors

Fig. 8. Experiment of detecting walls of the developed system by manual flight

Fig. 8 (a), the drone took off at 'P_1' point, then flew to the above of 'P_2' point, and the above of 'P_3' point, finally landed. The values of distance sensors measured during the flight are depicted in Fig. 8 (b). Where, the data is saved from hovering motion over 'P_1' point. First of all, it is observed that all measured data could be obtained robustly and their shape are not noisy. And according to the flight motion from 'P_1' to 'P_2' point in the experiment, values of side front and side rear sensors increased. The value of front sensor also increased according to the flight motion from 'P_2' to 'P_3' point. Then the value of bottom sensor shows the change during flight, finally it was decreased to around zero owing to landing motion. The results confirm that the developed system with the sensors can provide sufficient distance information for automatic flight.

V. Conclusion and Future Work

A novel drone system embedded with multiple tiny distance sensors was developed in this research. Besides, control methods how to utilize distance sensors for supporting drone's flights near buildings was proposed. Through experimental works, it was confirmed that the proposed system can be exploited effectively in inspection applications needs to fly near building or automatically adhere to ceiling surface.

As future work, automatic control of adhering motion with multiple distance sensors is planned for the drone system developed in previous research.

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