Flying Head: A Head-Synchronization Mechanism for Flying Telepresence

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Abstract

Flying Head is a telepresence system that remotely connects humans and unmanned aerial vehicles (UAVs). UAVs are teleoperated robots used in various situations, including disaster area inspection and movie content creation. This study aimed to integrate humans and machines with different abilities (i.e., flying) to virtually augment human abilities. Precise manipulation of UAVs normally involves simultaneous control of motion parameters and requires the skill of a trained operator. This paper proposes a new method that directly connects the user's body and head motion to that of the UAV. The user's natural movement can be synchronized with UAV motions such as rotation and horizontal and vertical movements. Users can control the UAV more intuitively since such manipulations are more in accordance with their kinesthetic imagery; in other words, a user can feel as if he or she became a flying machine.

Index Terms: 5.2 [Information interfaces and presentation]: User Interfaces—User-centered design;

Figure 1: Flying Head is a telepresence system that remotely connects humans and unmanned aerial vehicles (UAVs). The system synchronizes the operator's head motions with the UAV's movement and it enables the operator to experiences augmented abilities as if he or she become a flying robot.

1 Introduction

The underlying idea of telexistence and telepresence comes from "Waldo", which is a science fiction story by Robert Heinlein; he proposed a master-slave manipulator system for big scale robot control[6].This master-slave manipulator system of controlling a robot using the human body has been introduced as the research area of telepresence [26, 2, 3]. Remote-operated robots have many applications, such as telecommunication [16] and disaster site inspection [14, 25]. Technologies involved in remote operation are often called telexistence or telepresence.

An unmanned aerial vehicle (UAV) is a flying robot that can move freely through the air and circumvent poor ground conditions such as uneven roads and non-graded areas. When the Tohoku-Pacific Ocean Earthquake occurred, human-controlled UAVs were used to survey the damage at the Fukushima Dai-1 nuclear plant. In a recent study, UAVs were used to capture 3D reconstructed images of indoor and outdoor environments using mounted cameras [11, 31]. Open-hardware UAVs such as MikroKopter [19] and Quaduino [23] have also contributed to projects.

This paper addresses the challenge of realizing telepresence using a UAV. "Flying Telepresence"is the term we use for the remote operation of a flying surrogate robot. We propose a head-synchronization mechanism called Flying Head. Flying Head synchronizes user head motions with the movements of a flying robot, which can be easily manipulated with motions such as walking, looking around, and crouching. Thus, an operator can feel as if he or she became the flying machine.

We have already reported the prototype of this system configuration [9]. In the previous paper, we conducted the study about the operability of this system. In this paper, we aim to focus on user experience and potential applications using Flying Head. By adding extra values to the moving parameters, the operator can experience augmented abilities when controlling a UAV. In the user test, Flying Head showed better control of a UAV compared to a joystick and hand-synchronization methods. The same result was obtained when twice the values were added to the moving parameters.

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2 Flying Head Mechanism

Flying Head is a head-synchronization mechanism that uses human head motions to control UAV movements. In this method, the operator wears a head-mounted display (HMD) and moves his or her body. With these body motions, the operator can intuitively manipulate a UAV as the movement of the vehicle is mapped to the user's kinesthetic imagery. For example, when an operator walks forward, the UAV flies in the same direction. When the operator crouches, the UAV also lowers itself to the ground. When the operator looks right or left, the UAV rotates to the same direction.

2.1 Superiority of body control

The Flying Head characteristics with regard to UAV control are as follows.

- Operators can intuitively determine the UAV's position and orientation.
- Operators can obtain the movement distance of the UAV based on kinesthetic imagery.

With the Flying Head system, an operator can easily control a UAV's location and orientation using a set of head motions (Figure 2). To control UAV movements, the user should generally set parameters for horizontal and vertical movements and orientations. UAV operation requires simultaneous control of several parameters: pitch, roll, yaw, and altitude. Currently, many UAV systems are controlled by hand-operated devices such as proportional R/Cs,

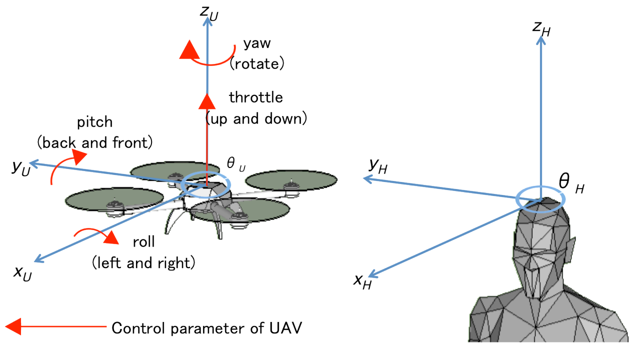

Figure 2: This mechanism synchronizes positions and orientations of humans and UAVs. For parameters (pitch, roll, yaw and throttle) are sent to control the UAV .

joysticks, and keysets. However, such device control methods are difficult and require long training times With Flying Head, human motions such as walking and looking around are used to set the flight parameters, which allows the operator to input parallel control parameters of the UAV simultaneously.

When controlling any vehicle or remote robots for the first time, the operator finds it difficult to send accurate parameters. For instance, when an operator uses a lever to manipulate a UAV, he or she needs training in order to get a sense of the mapping parameters like how strong he or she should press the lever. With Flying Head, where an operator's kinesthetic information is used to control the UAV motion, the operator can intuitively manipulate the UAV. In the Flying Head, in which operator's kinesthetic information is used to control a UAV motion, an operator intuitively can manipulate a UAV.

2.2 Filling in the Gaps

However, a UAV is not supposed to be synchronized to all human motions owing to human physical limitations compared to UAV flight capability. UAVs can fly at higher/lower altitudes than the operator, which makes postural control of flight uncomfortable or even impossible. Thus, we combined Flying Head with other control methods for altitude control. We focused on a small device that does not constrain human body movement. The UAV can move to high altitudes with easy manipulation of the device. The device is also applicable to horizontal movements.

Flying Head enables a user to experience augmented abilities by the addition of extra values to the moving parameters. When the mapping rate is doubled, the UAV moves 2 m when the operator walks 1 m. As the operator's small movement can be extended to a large movement by the UAV, the operator can control the speed of the UAV and feel less fatigue. Though a 10 times mapping rate might result in difficulty with control, we think that a double or triple mapping rate would be effective.

3 Related Work

A telepresence robot can conduct a wide range of tasks including telecommunications and remote operations. In recent years, telepresence robots have been used in office environments [27]. Telepresence robots have even attracted attention for use in military applications [20].

3.1 Body motion input

In research applications, telepresence robots are manipulated by human body motions. Mancini et al. developed Mascot (Manipulatore Servo Controllato Transistorizzato), which has two stereo cameras and two rudimentary slave hands [18]. From 1983 to 1988, Hightower et al. demonstrated the possibility of remote presence by developing Green Man, which is an anthropomorphic manipulator with arthroarms [13]. Heuring et al. developed a visual telepresence system that slaves a static pan-tilt camera to human head motions [7]. Although flying robots must engage in up-and-down spatial movements, these developed robots are static plane robots incapable of generating differing vertical motions.

3.2 UAV operations

Quigley et al. described how devices such as PDAs, joysticks, and voice recognition systems can be used to set UAV control parameters [24]. Giordano et al. developed a situation-aware UAV control system that provides vestibular and visual sensation feedback using a CyberMotion simulator [4]. This system represents UAV motion information within the operator's vestibular system. Naseer et al. developed a person following UAV using gesture recognition technique. [21]. Shan et al. demonstrated a hand gesture-controlled UAV that uses six different gestures to control movements such as takeoffs, landings, climbing, and descending [29]. However, these gestures are essentially just a replacement for the device input, so using them for inputting parallel control parameters of the UAV is difficult. Vries et al. developed a UAV mounted with a head-slave camera [28]. We focus operator's kinesthetic imagery for instinctive controlling the UAV.

3.3 Interactive applications with UAVs

Recently, UAVs are used in many types of field such as entertainment, sports training, and media art. Iwata demonstrated a interactive installation "Floating Eye", which can show out-of-body images from a floating camera [12]. Yoshimoto et al. developed a unmanned blimp system, which has four types of use-case in entertainment computing fields [32]. Okura et al. proposed a augmented reality entertainment system using autopilot airship and omni-directional camera [22]. Previously, our group proposed a autonomous UAV to capture out-body-vision images for entertainment contents and sports training [8, 10]. Graether et al. also presented a jogging support UAV "Joggobot", which accompanies user's jogging to motivate exertion activities [5]. We aim to realize telexistance and telepresence fields with UAVs.

4 Prototype System

The prototype system comprises a positioning measurement system, mini UAV, and HMD. Figure 3 shows the configuration of the system control using point information. An operator wears an HMD to represent the UAV's camera image, which allows the operator to control successive motions of the UAV.

To synchronize the operator's body motion with that of the UAV, the system requires position information. We used OptiTrack as an optical motion capture system for positional measurements. An OptiTrack S250e IR camera with a high frame rate can capture 120 fps, and motion capture allows the marker's position to be calculated to an accuracy of 1 mm. We captured the marker motions by installing eight cameras in a room divided into human and UAV areas: each was 3.0 m long $\times$ 1.5 m wide.

4.1 Micro-Unmanned Aerial Vehicle

We used AR.Drone as the flying telepresence robot: this is a small quadcopter with four blade propellers that can be controlled using Wi-Fi communication. AR.Drone has two cameras: one on the front and the other at the bottom. Flying Head uses the front camera for visual feedback.

AR.Drone has four control parameters: $pitch, roll, yaw$, and $throttle$. The $pitch$ controls the forward and backward movements, and the $roll$ controls the right and left movements. When the yaw parameter is changed, AR.Drone rotates on its site, and when the

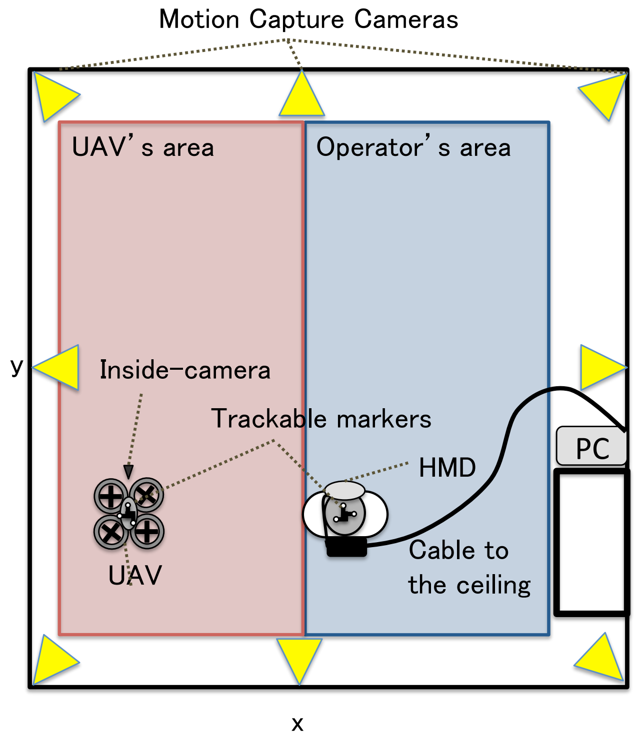

Figure 3: System configuration: The prototype system incorporates a position measurement system using eight motion capture cameras, a mini-UAV, and an HMD. The system is capable of several mapping scales.

throttle parameter is changed, AR.Drone moves up or down. The system sends the control parameters to AR.Drone once every 30 ms.

4.2 Visual Feedback

The operator wears a device with an HMD to represent images captured from the UAV cameras. For the HMD, we adopted a Sony HMZ-T2, which provides high-definition (HD) image quality. The HMD has markers that the system uses to track the operator's body motions. The user determines the next manipulation of the UAV based on visual feedback from the previous manipulation. The wearable device is connected to 12 m long HDMI and power source cables that are extended to the ceiling. The inner camera of the AR.Drone has a QVGA resolution of 320 × 240 pixels with a capture speed of 30 fps. This camera is located at the front side of the AR.Drone.

4.3 Control of horizontal movement

The system uses the position information of the operator and UAV generated from the positioning measurement system. The positioning parameters include the plane point $[x,y,z]$ and its direction $[\theta]$. Horizontal movement control does not use the height direction. Therefore, the system sets the *pitch* (front and back), *roll* (right and left) and *yaw* (rotation) parameters.

The system obtains the location points of the HMD (H_i) and UAV (U_i) at time i ($i = 0...k$). At N times, the mapping scale, the system calculates different D_i in H_i at each time (N=1 means 1:1 mapping scale).

$$\mathbf{H}_i = \{x_i, y_i, \theta_i\} \quad (i = 0..n) \tag{1}$$

$$\mathbf{U}_i = \{x_i, y_i, \theta_i\} \quad (i = 0..n) \tag{2}$$

$$\mathbf{D}_i = N\mathbf{H}_i - \mathbf{U}_i \tag{3}$$

At time i, $pitch_i$, $roll_i$ and yaw_i are calculated based on the following equation.

$$\begin{pmatrix} pitch \\ roll \end{pmatrix} = \begin{pmatrix} cos\ \theta_U & sin\ \theta_U \\ -cos\ \theta_U & sin\ \theta_U \end{pmatrix} \begin{pmatrix} y_D \\ x_D \end{pmatrix} \tag{4}$$

$$yaw = \frac{\theta_D}{\pi} \tag{5}$$

The system also estimates the future position (expression 6) of the UAV based on the position history for a fast-converging UAV movement. The system transforms the control condition (expression 8) so that the future position is greater than the current position (C:constant).

$$\mathbf{F}_{i+1} = \mathbf{U}_i + (\mathbf{U}_i - \mathbf{U}_{i-1})\Delta t \tag{6}$$

$$pitch = -pitch \times C \tag{7}$$

$$roll = -roll \times C \tag{8}$$

4.4 Altitude Control

Flying Head provides two methods for UAV altitude control: equal control and a combination of devices. Equal control is used to move the UAV up and down the same distance moved by the operator's head: for example, if the operator lowers his or her head by 20 cm, the UAV descends by 20 cm. When the mapping rate is 2 times, the horizontal or vertical movement is double that of the operator's movement.

For the combination of devices, the operator uses a combination of body motions for most movements and the control device for altitude control only. Initially, the altitude baseline is the head height of the operator, and the device can switch its baseline height. We adopted a Wii remote controller connected to a PC through Bluetooth. The operator changes the baseline by pressing the remote controller's arrow keys.

5 User Study

To review the operability of the Flying Head mechanism, we conducted two user studies. We conducted this task in order to reveal the potential of remotely operated UAV for searching and inspecting a certain object. In the first study, We compared body movement and joystick controls: the Flying Head (1:1 mapping scale), and the joystick mechanism. In the second study, we compared head-synchronization and hand-synchronization methods when the mapping scale was changed: the Flying Head (1:2 mapping scale), and the hand-synchronization mechanism (1:2.5 mapping scale). We assigned the same task for both of these studies The participants captured four static markers using the inner camera of the UAV with the different control methods.

5.1 Environment

We measured the time to task completion. The participants captured four visible markers using each UAV control mechanism. Figure 4(a) shows the experimental environment, which included a pole extending to the ceiling and four 2D markers. The markers were given the numbers 1-4. The participants captured the markers using the UAV camera in numerical order. We placed the markers on the pole in a counterclockwise fashion at heights of 80-230 cm. When using Flying Head, the participants combined body and device control to set the altitude. Figure 4(b) shows the image from the inner camera of the UAV; the detection area of the markers is framed in the red square. Figure 4(c) shows detection of the marker. The

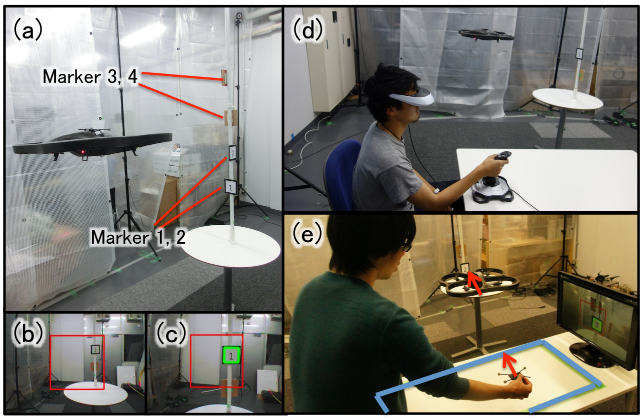

Figure 4: Environment of study 1: The participants captured four visible markers using the each control mechanism. We measured and compared the completion time of task.

marker is framed by the green square when captured by the operator. Each participant performed three experiment sessions. We preliminarily decided markers positions, which were different in each session. However, the participants were not informed in advance.

5.2 Study 1

In the first study, we focused on body movement and joystick controls: Flying Head (1:1 mapping scale), and joystick mechanisms. R/C-style joystick mechanism is traditional small UAVs control style. In this study, we compared our system with traditional control methods. The purpose of this study is to point out which method, controlling with body movement or with the device, is more suitable for searching and capturing tasks.

We adopted joystick mechanisms for comparison with the Flying Head. A joystick has one stick and various buttons; the participants used the joystick to manipulate the UAV's position in the manner described in section 4.3. For the joystick control, the participants wore an HMD for visual feedback (Figure 4(d)). In this study, participants were six people between the ages of 23 and 25 and heights of 161-175 cm. Figure 5 shows to compare the average completion time of every participant for all three sessions. Flying Head (1:1) produced the fastest times for all three sessions. The average completion time for the three sessions was 40.8 s with Flying Head and 80.1 s with the joystick method. We conducted a paired t-test from the average of each participant, which gave us a $p-value < .01$.

Figure 6 shows the UAV trajectory during each session plotted in a 3D-point diagram. For the joystick method, the UAV frequently moved in a rectilinear trajectory. These results suggest that it was difficult to set the parallel control parameters each time with the joystick control. The trajectory of Flying Head suggests that this mechanism can easily control parallel parameters. In particular, the trajectory during the third session showed a smooth movement.

We conducted a questionnaire survey asking the participants about Flying Head and the joystick method (Figure 7). The questionnaire consisted of six questions: each was evaluated on a scale of 1 to 5 with a higher score indicating a better result. Question items are as follows.

Q1 Was control mechanism simple to control?
Q2 Could you control it properly?
Q3 Was Study 1 easy?
Q4 Did the latency interfere with the operation?
Q5 Did you enjoy the experiment?
Q6 Did you become tired with the experiment?

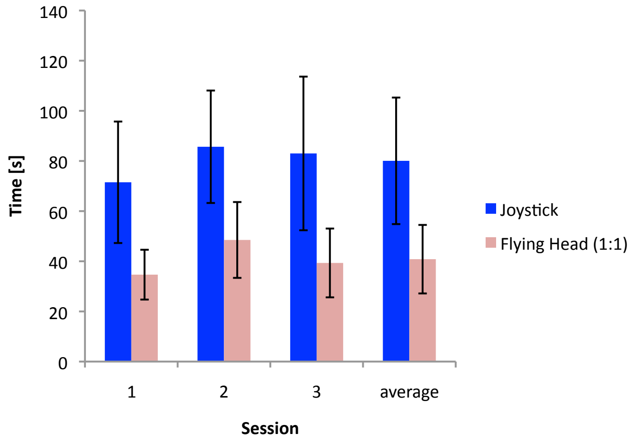

Figure 5: The result of study 1: A comparison of the average time required for each participant during three sessions, where the shorter time is the better. The Flying Head (1:1) was faster than the joystick for every session. The average completion time for the three sessions was 40.8 s with Flying Head (1:1) and 80.1 s with the joystick method. Black lines show standard deviation.

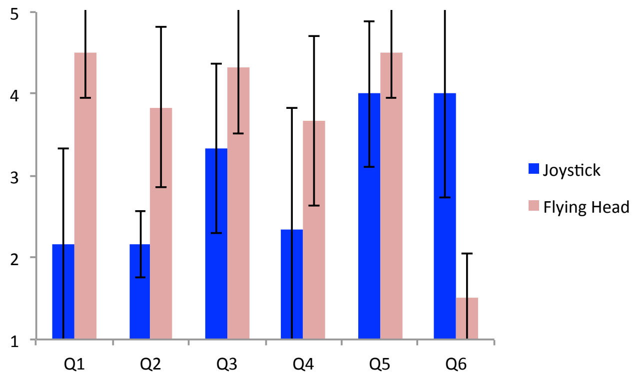

Figure 7: Result of the questionnaire: The questionnaire consists of six items each of which was evaluated on a scale of 1 to 5, with the higher score indicating the better. Black lines show standard deviation.

5.3 Study 2

In the second study, we compared head-synchronization and hand-synchronization methods when the mapping scale was changed: the Flying Head (1:2 mapping scale), and the hand-synchronization mechanism (1:2.5 mapping scale). The purpose of this study is to reveal if the operator's head is better way to map the trajectory of the UAV or if the operator's hand is more suitable when controlling in the master-slave method that synchronizes the UAV's movement with the one of operator. In this method, we set the mapping ration as 1:2.5 so that users didn't have to move their arms too widely. This ratio can be changed depending on areas where UAVs are deployed. In the hand-synchronization, the operator determines the UAV's position and direction by controlling a small dummy of the UAV with his/her hand (Figure 4(e)). In this experiment, the UAV moved 2.5 times more than the movement of the dummy UAV. The user sees the view from the display, not from the HMD. In this study, participants were six people between the ages of 23 and 30 and heights of 154-180 cm. We instructed each method to partic-

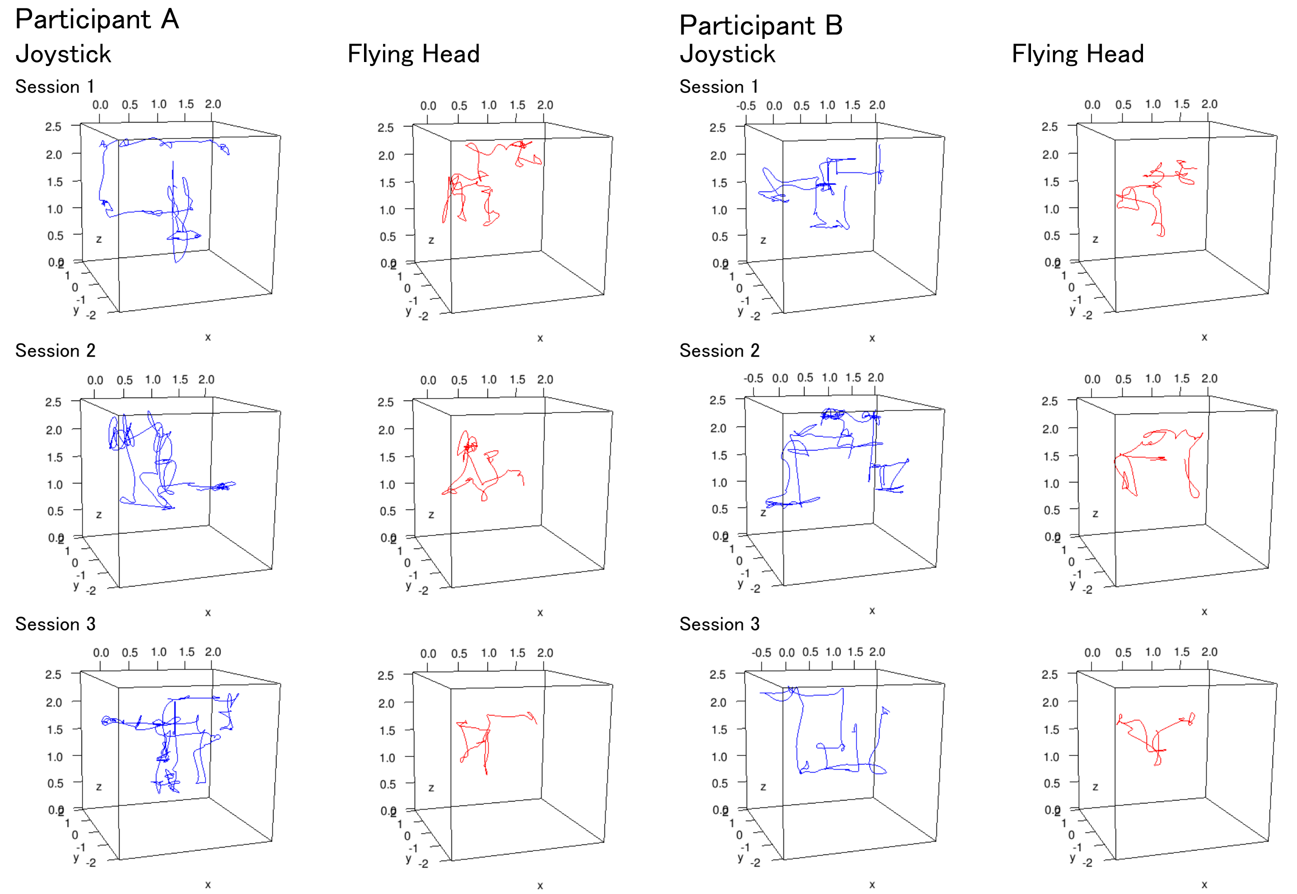

Figure 6: Trajectory of the UAV in study 1: where each line is the migration path of the UAV. The red line is trajectory with the Flying Head, and the blue line is trajectory with the joystick.

ipants for 10 minutes. Figure 8 compares the average completion time of every participant for all three sessions. Flying Head (1:2) produced the fastest times for all three sessions. The average completion time for the three sessions was 53.1 s with Flying Head (1:2) and 99.1 s with the hand-synchronization method. We conducted a paired t-test from the average of each participant, which gave us a $p-value < .01$. No tracking error was found during the study.

Even when the mapping rate was doubled, the same result was produced as at the 1:1 scale. The participants said the control method surprised them the first time, but they managed to get used to it soon after they started. They also said that they could control the UAV without a problem no matter what the mapping ratio was, and they did not feel any sickness when controlling it.

The hand-synchronization mechanism received worse results than Flying Head. The reason of this result would be that it is difficult to recognize the UAV's trajectory with the hand-synchronization mechanism and also hard to understand the position difference between the dummy and the UAV. With the Flying Head, on the other hand, as the UAV synchronizes with the head movement, it would be easier to recognize the position difference between the head and the UAV.

6 Discussion

In this section, we discuss some plans for future research and applications of flying telepresence

6.1 Limitations

In an outdoor environment, Flying Head cannot use optical motion capture to locate the UAV owing to sunlight or disturbances in the air. We intend to develop a new localization system for outdoor use that will possibly involve the use of GPS, Wi-Fi, or ultra wide-band technology. Due to its accuracy, we feel that the use of an Ubisense ultra wide-band system as a real-time locator may be a valid approach. On the other hand, UAVs can estimate position and orientation using sensor devices such as, GPS, gyro, acceleration sensor, and visual odometry. Although this method is low accuracy, operators may able to easily manipulate UAV because they can be aware of self head trajectory.

6.2 Combination with other control methods

In this study, the UAV only flew within ranges commensurate with the distances walked by their operators. However, in some telepresence exercises, the operator and the robot will not move at equal scales, in which case the system should be able to perform distance scaling. For instance, if the operational range of the robot is three times that of the operator, a distance of 1 m walked by the operator would be mapped to a UAV movement of 3 m. We plan to expand the Flying Head system to include such scalability and to measure its usability as well as combine and creatively use additional manipulation methods.

We developed another UAV control mechanism to be matched with the Flying Head mechanism. This mechanism maps the human head inclination with the UAV movement (Figure 9). This method

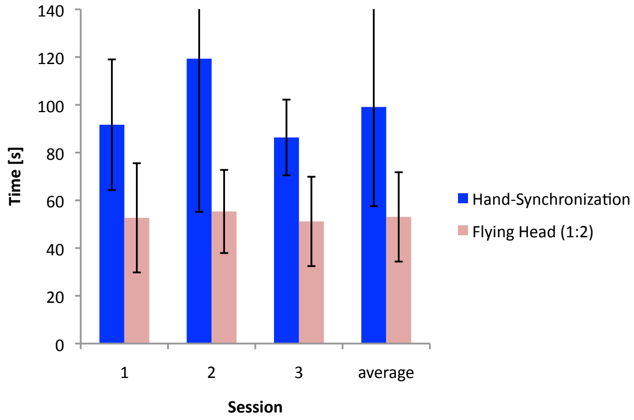

Figure 8: The result of study 2: A comparison of the average time required for each participant during three sessions, where the shorter time the better. The Flying Head (1:2) was faster than the hand-synchronization method for every session. The average completion times for the three sessions were 53.1 s with the Flying Head (1:2) and 99.1 s with the hand-synchronization. Black lines show standard deviation.

is switched on by the A key of the Wii Remote controller, which is similarly used for altitude control. When the operator inclines his or her head forward, the UAV moves forward. When the operator raises his or her head, the UAV also continually rises. Each yaw rotation is synchronized between the operator and UAV like with the Flying Head mechanism. Future work is needed to identify the viability of combining this method with Flying Head.

6.3 Future Flying Telepresence Applications

6.3.1 Inspection

With this mechanism, the operator can control a UAV as if he or she was a flying robot; this is useful for remote operations such as inspections. A UAV is better able to get into areas inaccessible to people than ground robots. By setting a small UAV in certain facilities, we can always connect to it for inspections or in the event of an emergency. Tiny helicopters (around 15 cm wide) can currently be purchased at low prices; we can consider scenarios of putting this kind of helicopter in every room of a facility.

6.3.2 Remote Collaboration

Figure 10 shows an application that provides instructions to a remote operator using a laser pointer mounted to the UAV as an example of flying telepresence. This function is used by a specialist to provide instructions to a non-specialist situated in a remote location. For example, people in a disaster-affected area may receive instructions to manipulate a certain device from a specialist with the assistance of pointing. In many cases, audio instructions are inadequate to provide instructions at the remote location. Therefore, visual instructions such as pointing are required to increase communication efficiency. For tasks in large indoor areas or those involving the manipulation of large devices, UAVs need to move and provide instructions simultaneously. Flying Head can realize these tasks because the UAV has hands-free control, and the operator can thus simultaneously point to provide visual instructions.

6.3.3 Teleoperation

Flying telepresence can also be used to facilitate remote operations. For example, UAVs with manipulation equipment can be employed

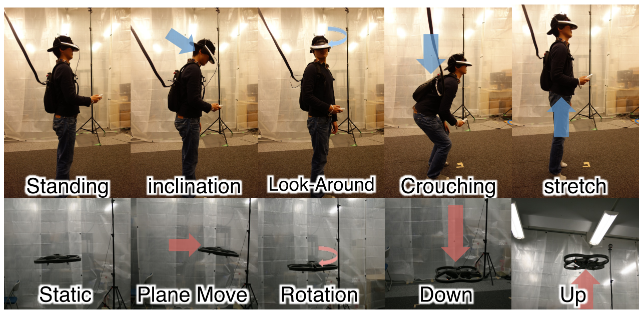

Figure 9: another UAV control mechanism to be matched with the Flying Head mechanism.: This mechanism is mapping human head inclination with the UAV movement. Future work is needed to identify the viability of combining this method with Flying Head.

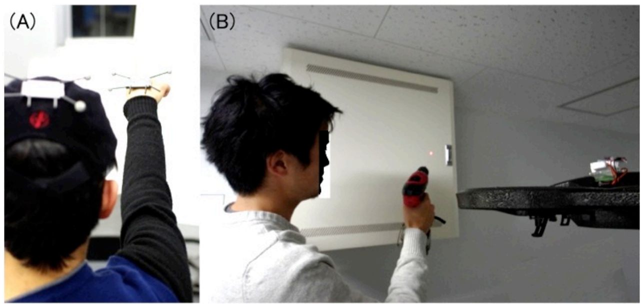

Figure 10: Example: a specialist provides instructions to a non-specialist situated in a remote location. (A) The specialist points with fingers. (B) an remote operator gets assistance via a flying telepresence robot

in tasks such as disaster relief or high-altitude construction. However, current UAVs lack free manipulation equipment comparable to the hands of a human operator. NASA has developed Robonaut, which is a telepresence robot for exterior work in outer space [1]. Robonaut has two arms that are synchronized to the operator's hand motions. Lindsay et al. demonstrated the construction of a cubic structure using mini-UAVs with a crane [17]. Figure 11 shows a potential future two-armed flying telepresence robot that can be used for teleoperation. The operator can manipulate this flying telepresence robot's hands as if they were his or her own by using motion capture.

6.3.4 Capturing platform

The VR system can set the location and orientation as a virtual camera using instinctive devices. Ware et al. proposed the hand manipulation of a virtual camera [30]. We believe that Flying Head can be used to manipulate physical camera systems such as digital movie cameras for motion pictures and game creation for shooting high-realistic movies. Flying Head can be used in future video content creation systems in which a camera operator would capture the action through the highly effective employment of positioning and orientation. Laviola proposed hands-free camera navigation, which introduce user's head movements in virtual reality environments [15]. We plan to introduce this technique to move wide length fields with Flying Head.

6.3.5 Entertainment Platform

Flying telepresence may also provide an out-of-body experience or the sensation of leaving one's own body. When we demonstrated a Flying Head prototype to a large audience (more than 300 people), many participants noted the novelty of the experience of see-

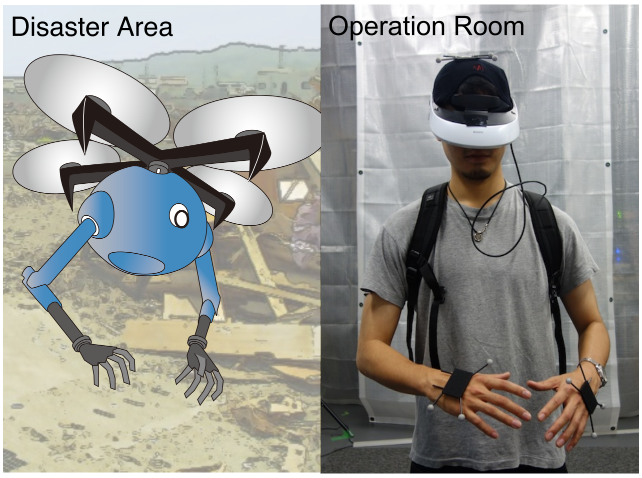

Figure 11: An Example of Future flying telepresence robot: The UAV's two-arms are synchronized with operator's hands

ing themselves from outside their bodies; this reflects the ability of flying telepresence operators to observe themselves through UAV cameras. By changing the mapping ratio of the movement, a user can experience an augmented ability. This can be regarded as a new experience and has potential for an entertainment platform.

7 Conclusion

Flying telepresence is a term used for the remote operation of a flying surrogate robot so that the operator's "self" seemingly takes control. In this paper, we propose a control mechanism termed Flying Head that synchronizes the motions of a human head and a UAV. The operator can manipulate the UAV more intuitively since such manipulations are more in accord with his or her kinesthetic imagery. The results of study indicated that Flying Head provides easy operability that is preferable to that of hand-operation. Second study's result also shows that head-synchronization mechanism is We discussed additional flying telepresence applications such as capturing platforms, teleoperation, and entertainment platform.

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