Flying Head: A Head Motion Synchronization Mechanism for Unmanned Aerial Vehicle Control

Keita Higuchi
Interdisciplinary Information Studies, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku
Tokyo 113-0033 Japan

Japan Society for the Promotion of Science
6 Ichiban-cho, Chiyoda-ku
Tokyo 102-8471 Japan
khiguchi@acm.org

Jun Rekimoto
Interfaculty Initiative in Information Studies,
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku Tokyo
113-0033 Japan

Sony Computer Science Laboratories, Inc.
3-14-13 Higashigotanda,
Shinagawa-ku Tokyo
141-0022 Japan
rekimoto@acm.org

CHI 2013 Extended Abstracts, April 27–May 2, 2013, Paris, France.

Abstract
We propose an unmanned aerial vehicle (UAV) control mechanism, called a "Flying Head" which synchronizes a human head and the UAV motions. The accurate manipulation of UAVs is difficult as their control typically involves hand-operated devices. We can incorporate the UAV control using human motions such as walking, looking around and crouching. The system synchronizes the operator and UAV positions in terms of the horizontal and vertical positions and the yaw orientation. The operator can use the UAV more intuitively as such manipulations are more in accord with kinesthetic. Finally, we discuss flying telepresence applications.

Author Keywords
Unmanned Aerial Vehicle, Control Mechanism, Flying Telepresence.

ACM Classification Keywords
H .5.1 Multimedia Information Systems

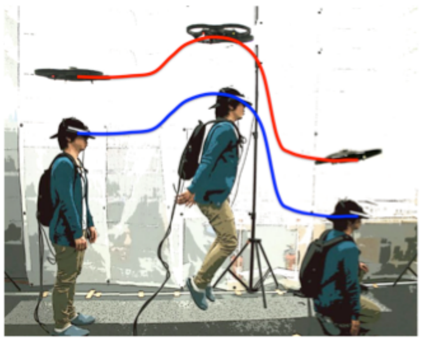

Figure 1. The Flying Head: The system synchronizes human head motions with those of an unmanned aerial vehicle (UAV).

Introduction

Remotely operated robots can be used in such applications as telecommunications [1] and disaster relief [2]. The technologies involved in remote operation are collectively called telepresence, a field for which there is a growing body of research and development. An unmanned aerial vehicle (UAV) is a flying robot that can move freely through the air and can circumvent poor ground conditions such as uneven roads and non-graded areas. Following the Tohoku-Pacific Ocean Earthquake, human-controlled UAVs were used to survey the damage at the Fukushima Dai-1 nuclear plant. In recent research, the UAV can capture a 3D-reconstruction image in indoor and outdoor environments using mounted cameras [3]. Open-hardware UAVs have also enhanced projects such as MikroKopter and Quaduino.

Currently, many UAV systems are controlled by hand-operated devices such as proportional R/Cs, joysticks, and keysets. Such devices are not instinctively easy to manipulate, and long training times are needed for precision flying. Precision control on the part of the operators necessary to suitably control the flight parameters such as the altitude, pitch, roll, and yaw in real time. Proportional R/C, which s a typical UAV control system, involves the use of several sticks and switches for setting the flight parameters and performing other tasks.

This paper addresses the challenge of revealing the possibility of telepresence to a UAV. We propose the UAV control mechanism, called the “Flying Head”. The Flying Head synchronizes user head motions to the movements of a flying robot, which can be easily manipulated through such motions as walking, looking around and crouching (Figure1). “Flying Telepresence” is the term we use for the remote operation of a flying surrogate robot in such a way that the operator's “self” seemingly takes control. Flying telepresence can be implemented under a variety of conditions: indoors or outdoors, and in tight or open spaces.

Flying Head

The Flying Head is a UAV control mechanism that uses human head motions to generate similar UAV movements. Using this method, the operator wears a head-mounted display (HMD) and moves their body. Through such body motions, the operator can intuitively manipulate the UAV as the movement of the vehicle is mapped to the user's kinesthetic imagery. For example, the operator can control the horizontal movement. In addition, when the operator crouches, it causes the UAV to lower itself to the ground. When the operator rotates their head, the system rotates the body of the UAV.

Superiority of body control

The characteristics of the Flying Head for introducing human body motions for UAV control are as follows.

- Operators can concurrently determine the UAV's position and camera orientation.
- Operators can recognize the movement distance of the UAV based on the kinesthetic imagery.

A Flying Head operator can easily manipulate a UAV using a set of head motions to control its location and orientation. The operator should manipulate parallel

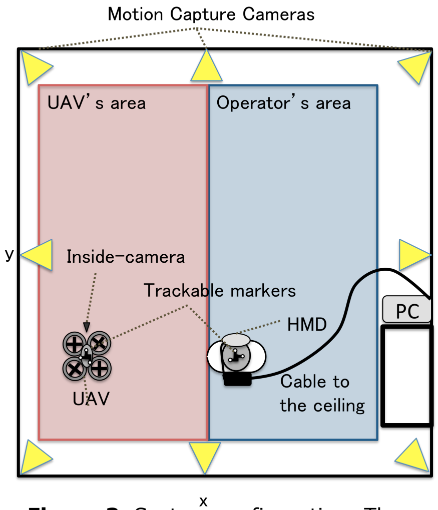

Figure 3. System configuration: The prototype system incorporates a position measurement system using eight motion capture cameras, a mini-UAV, and an HMD.

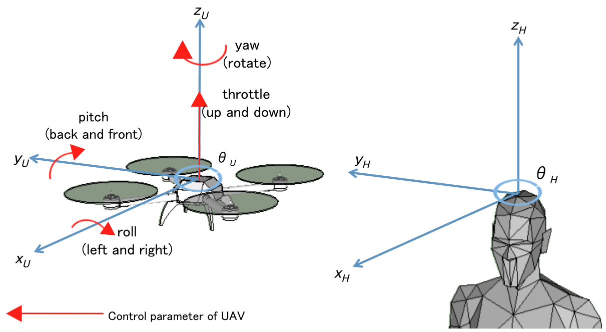

Figure 2. System mechanism: A quadcopter has four control parameters such as *pitch, roll, yaw* and *throttle*.

parameters such as the horizontal and vertical movements and orientation of the UAV. UAV operation involves the simultaneous control of several parameters, including the pitch, roll, yaw, and altitude. The method used to input the representative movements into the manipulated device are limited by the ability of the system to accept input in parallel with the mapped behaviors. With the Flying Head, we have adapted human motions such as walking and looking around for setting the flight parameters, allowing the operator to input parallel control parameters of the UAV simultaneously.

The operator understands the UAV movement distance as the UAV is synchronized to the operator's body motions. The Flying Head uses the operator's kinesthetic information to control the UAV motion, mitigating the need for vestibular system feedback.

Filling in the Gaps

However, a UAV does not fully synchronize to all human motions, owing to human physical limitations with respect to UAV flight capability. UAVs can soar to high altitudes or fly at altitudes lower than human stature, making postural control of flight uncomfortable or even impossible. We combine Flying Head with other control method for altitude control. We focus a small device that does not constrain human body movement. The UAV can move high altitude as easy manipulation of the device.

Latency indicates an unpreventable difference between the position of the UAV and the operator's head. Latency complicates an instinctive manipulation as the operator cannot properly recognize the current position of the UAV. However, latency cannot be fully smoothed out cause of transmission speed and difference in motion performance.

The Flying Head provides a latency representation to the operator using an image processing method for a better understanding of the UAV position. The system applies a transformation of the feedback image when latency occurs.

Prototype System

We developed a prototype system of the Flying Head, which synchronizes an operator and a UAV motions that include x, y and z position and yaw orientation (Figure 2). The prototype system incorporates a positioning measurement system, a mini-UAV, and an HMD. For control, the system requires accurate point information for both the human operator and the UAV; therefore, we adopted a point-recognition system that measures the location information of the operator's head and the UAV. Figure 3 shows the configuration of the system control using this point information. As the figure indicates, an operator wears an HMD for a representation of the UAV's camera image, allowing the operator to control successive motions of the UAV.

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

We adopted an AR.Drone, which is a small quadcopter with four blade propellers that can be controlled using wireless communication, as a flying telepresence robot. We set trackable markers with motion capture capability on the AR.Drone to provide spatial (x-, y-, and z-coordinate) and angle-of-rotation (pitch, roll, and yaw) information. AR.Drone has a front camera and underside cameras; The Flying Head uses the front camera for visual feedback.

The AR. Drone has four control parameters; *pitch, roll, yaw* and *throttle* (Figure 2). The *pitch* is the front and back movement parameter, and the *roll* is right and left movement parameter. When changing the *yaw* parameter, the AR. Drone rotates on site, when changing the *throttle* parameter, the AR. Drone moves up or down. The system sends the control parameter to the AR. Drone once every 30 milliseconds.

An operator wears a device with an HMD to represent images captured from the UAV cameras. For the HMD, we used a Sony HMZ-T1, which provides high-definition (HD) image quality. The HMD is attachable to markers that can track the operator's body motions as the system can recognize body motions only through time-line point information provided by trackable markers. The user locates the next manipulation of the UAV based on visual feedback from the previous manipulation. The wearable device is connected using 12 m long HDMI and power source cables that extend to the ceiling to remain out of the way of the body motions of the human operators. The inner camera of the AR.Drone has a QVGA resolution of 320 x 240 pixels, with a capture speed of 30 frames per second. This camera is oriented for the viewpoint from the front side of the AR.Drone.

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 one direction [θ]. Horizontal movement control does not use the height direction. Therefore, the system sets up the *pitch* (front and back), *roll* (right and left) and *yaw* (rotation).

The system obtains the location points of the HMD (H_i) and UAV (U_i) at time i (i = 0 … k). The system calculates the different D_i in H_i at each time.

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

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

$$D_i = H_i - U_i \tag{3}$$

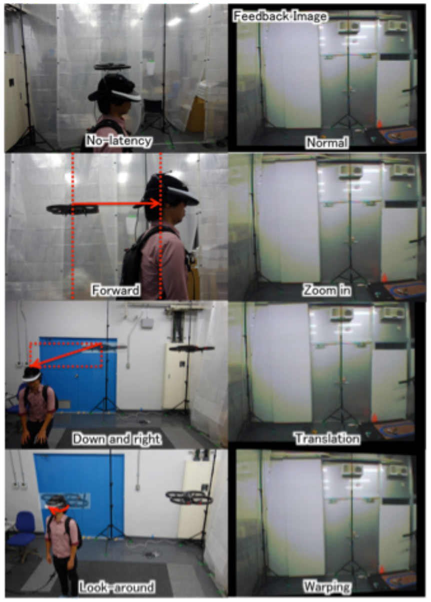

Figure 4. Latency representation method: The system provides a latency representation to the operator for understanding the UAV position using an image processing.

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

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

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

Additionally, the system estimates the future position (expression 6) of the UAV based on its position history for a fast-convergent UAV movement. The system has led to a transformation of the control condition (expression 7,8) in which the future position is greater than the current position (*C*: constant).

$$F_{i+1} = U_i + (U_i - U_{i-1})\Delta t \tag{6}$$

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

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

Altitude control

The Flying Head provides two methods for UAV altitude control that are equal control and a combination of a device. Equal control is used to move the UAV up and down the same distance as the operator's head moves; for example, if the operator lowers their head by 20 cm, the UAV descends by 20 cm. This provides what many operators consider a highly sensitive degree of control; however, it means that the UAV cannot exceed the vertical height of the operator.

For a combination of the device, the operator can use a combination of body motions and the control device but only for altitude control. 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. We map the altitude of the UAV to the remote controller's arrow keys.

Latency representation method

Figure 4 (no-latency) shows a no-latency visual feedback image from the inner camera of the UAV. The system zooms in on the image when the operator is in front of the UAV's position, and the system zooms out from the image under a reverse situation. During a period of latency, the system translates the image in an effort to represent its left, right, top, and bottom areas more properly.

User Study

To review the operability of the Flying Head mechanism, we performed a user study of its capturing ability. We made a comparison between the Flying Head and a device control method using two studies. For study 1, the participants captured four static markers using the inner camera of the UAV through both control methods. For study 2, the participants captured a moving vehicle, i.e. a Plarail toy train using each method.

For a comparison of the control mechanisms, we adopted a joystick control with one stick and various buttons. The participants manipulated the UAV's position using the joystick in the manner described in the Control Horizontal Movement section. For the joystick control, the participants wore an HMD for visual feedback, which used a latency representation method.

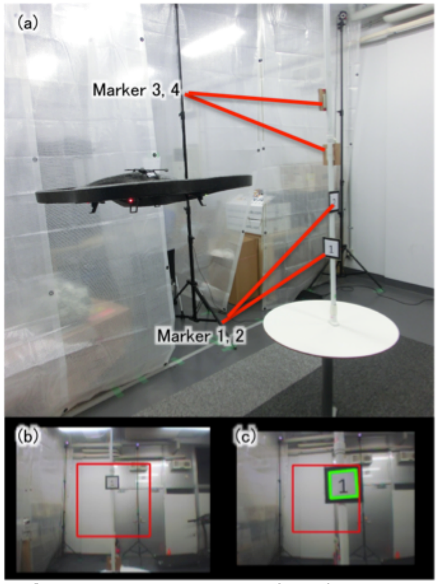

Figure 5. Environment of study 1: The participants captured four visible markers using the Flying Head and joystick control mechanism. We measured and compared the completion time of each method.

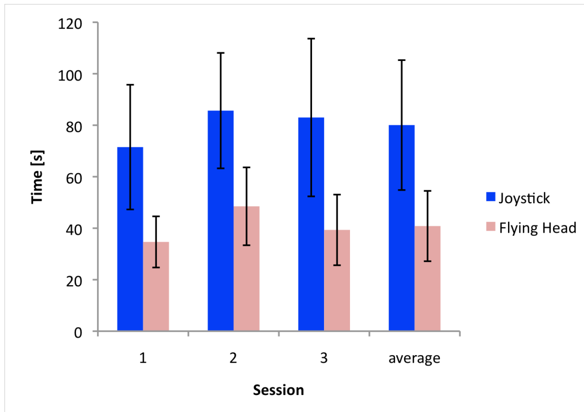

Figure 6. Result of Study 1: A comparison of the average time required for each participant during three sessions, where a shorter time is better. The Flying Head was faster than the joystick for every session. The average completion times for the three sessions were 40.8 s for the Flying Head and 80.1 s for the joystick. Error bars show the standard deviation.

The joystick control differs from the Flying Head in that only input method parameters such as the x, y, and z positions and yaw orientation. Six people between the ages of 23 and 25 with heights of 161 to 175cm participated in this study. Three of the participants tried using the Flying Head mechanism first, and the joystick mechanism thereafter. The other participants tried the joystick mechanism first, and the Flying Head mechanism second.

User study 1

In this study, we measured the time of task completion. The participants capture four visible markers using each UAV control mechanism. Figure 5 (a) shows the experimental environment, which includes a pole extending to the ceiling and four 2D markers. We configured the markers using numbers 1 through 4. The participants captured the markers using the UAV camera in numbered order. We placed the markers on the pole in a counterclockwise fashion ranging in height from 80 to 230 cm. When using the Flying Head, the participants had to use equal control and combination of the device for altitude control. Figure 5 (b) shows the image from the inner camera of the UAV, with the detection area of the markers framed in the red square. Figure 5 (c) shows detection of the marker. The marker had to be framed by a green square. We performed three sessions of experiments for each participant. We also used different marker positions for each session, which the participants did not know in advance.

Figure 6 shows a comparison of the average value of every participant for all three sessions. The Flying Head showed the highest time for all three sessions. The average completion time for the three sessions was 40.8 s for the Flying Head and 80.1 s for the joystick method. We conducted a paired t-test from the average of each participant, which gave us a p-value of 0.007.

User Study 2

In study 2, we compared the accuracy of shooting a moving vehicle when controlled by the Flying Head or a joystick. The moving vehicle is a Plarail toy train. We compared the time during which the UAV followed the 2D marker located on the back of the train. The Plarail toy train drove on an elliptical course as shown Figure 7 (a). The marker was set upside down and toward the direction of the Plarail toy train. The participants tracked the marker by controlling the UAV while the Plarail toy train ran five laps around the course. We

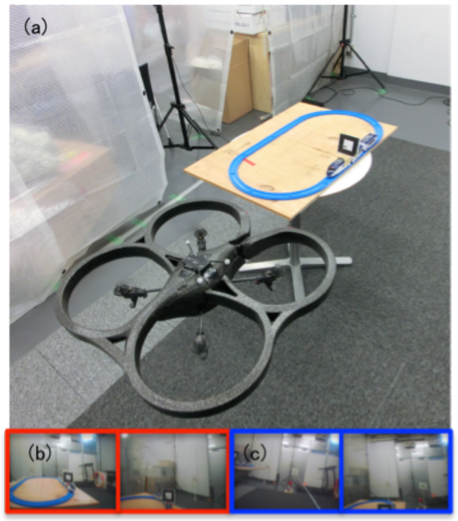

Figure 7. Environment of study 2: The participants captured a moving vehicle using the two UAV control mechanisms. We compared how long the participants took to track the train using both methods.

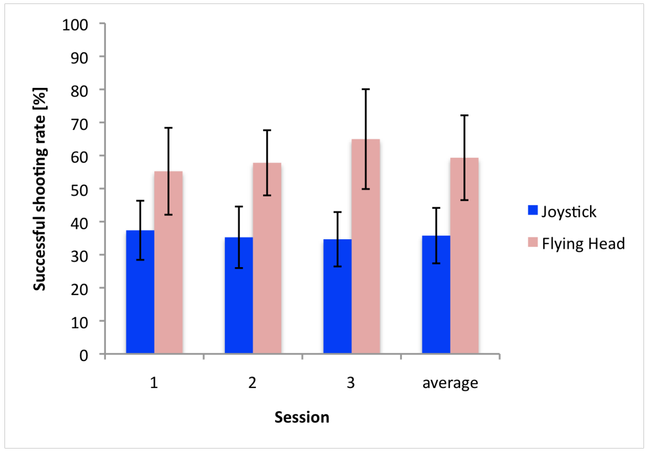

Figure 8. Result of Study 2: The result of study 2: This is a comparison of the average value for all three sessions, which every session was 59.3%for the Flying Head and 35.8 % for the joystick method. Error bars show the standard deviation.

measured how long the participants took to track the train.Therefore, the percentage of successful shooting time (Ps) can be formulated based on the entire shooting time (Tall) and the amount of successful shooting time (Ts) as shown in expression 9.

$$P_s = \frac{T_s}{T_{all}} \quad (9)$$

The entire course was 221 cm long, and the velocity of the Plarail train was 13.8 cm/s; each session lasted about 80 s. In each session, the Plarail toy train was driven five laps around the course. Once again, we conducted three sets of experiments for each participant. Before the experiment began, the participants were allowed to set the starting position of the UAV while the Plarail was driven three laps before the experiment started. The marker was 8.5 cm by 8.5 cm. We performed a visual check of the successful shooting time for user study 2. Figure 7 (b) shows the successful shooting, capturing four vertices of the marker. Figure 7 (c) shows a failure in shooting, in which the marker could not captured.

Figure 8 shows a comparison of the average value for all three sessions. The Flying Head showed the highest rate of successful shooting for each session. The average successful shooting rate was 59.3 % for the Flying Head and 35.8 % for joystick. We again conducted a paired t-test on the results of these sessions, which gave us a p-value of 0.012.

Questionnaire

We conducted a questionnaire survey the participants regarding both the Flying Head and joystick method. The questionnaire consisted of 8 questions, each of which was evaluated on a scale of 1 to 5, with a higher score indicating a better result. Table 1 shows question items. As a result, the Flying Head received positive answers to questions Q1 through Q7 (Figure 9).

Q1	Was control mechanism simple to control?
Q2	Could you control it properly?
Q3	Was Study 1 easy?
Q4	Was Study 2 easy?
Q5	Did it understand latency representation?
Q6	Did the latency interfere with the operation?
Q7	Did you enjoy the experiment?
Q8	Did you become tired with the experiment?

Table 1. Questionnaire item.

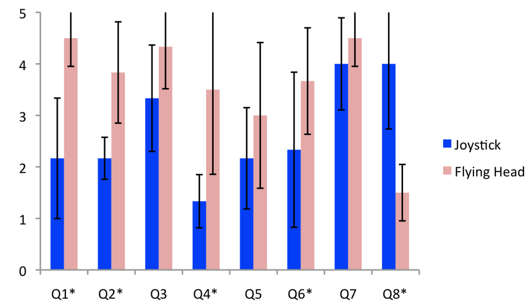

Figure 9. Result of the questionnaire: The questionnaire consists of 8 items each of which was evaluated on a scale of 1 to 5, with a higher score is a better. Items with * are significantly different between groups. Error bars show the standard deviation.

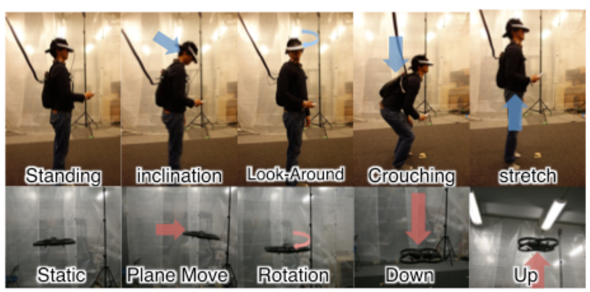

Figure 10. Other control method for match-up Flying Head: This mechanism is mapping human head inclination and the UAV movement. Future work is needed to identify the availability of this method with a combination of the Flying Head.

Discussion

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

Limitation

In an outdoor environment, the Flying Head cannot use optical motion capturing for locating the UAV, owing to sunlight or disturbances in the air. We intend to develop a new localization system for outdoor use, possibly involving the use of GPS, Wi-Fi, or ultra-wideband technology. In light of its accuracy, we feel that the use of an Ubisense ultra-wideband system as a real-time locator may be a valid approach to this issue.

Combine other control method

In the study described herein, the UAV flights were implemented only 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, 1 m walked by the operator would be mapped to 3 m of UAV movement. We plan to expand the Flying Head system to include such scalability and to measure its usability, as well as to combine and creatively use additional manipulation methods.

Thus, we developed other a UAV control mechanism for match-up Flying Head mechanism. This mechanism is mapping human head inclination and the UAV movement (Figure 10). This method is switched by A-key of Wii-Remote controller, which similarly uses “Altitude control”. When the operator is an inclination of the body in front from switching head position, the UAV moves forward. When the operator raises head position, the UAV also continually raises. Each yaw rotation synchronizes the operator and the UAV as with the Flying Head mechanism. This method does not have limitation of moving range because it does not need the UAV position information. Future work is needed to identify the availability of this method with a combination of the Flying Head.

Other feedback

We have considered other feedback methods, such as sound or haptics, to map the UAV modes to the operator's senses. One participant in the experiment said that they "did not sense a clash of the UAV with the object." The operator determines their next body motion based on sentient sensations provided by kinesthetic information or visual feedback. Lam et al. designed the UAV collision avoidance method using haptic interface in a virtual environment [4]. We plan to use a feedback system to provide sentient environmental information from the UAV's periphery by means of a combination of depth cameras, nearby sensors, and sensor types.

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 [5]. We believe that the Flying Head can be used to manipulate a physical camera system, such as digital movie cameras used in motion pictures and game creation for shooting stereoscopic 3D images. The Flying Head has the possibility to be used in future video content creation systems, in which a cameraman would capture the action through the highly effective employment of positioning and orientation

Teleoperation

Flying telepresence can also be used to facilitate remote operations. For example, UAVs with manipulation equipment can be employed 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, a telepresence robot to be used for exterior work in outer space [6]. Robonaut has two arms that synchronize to the operator's hand motions. In their current research, Lindsay et al. demonstrated the construction of a cubic structure using mini-UAVs with a crane [7]. As Flying Head operators would not be constrained to the use of their a hand, they would be able to use a hand free body motions to control the UAVs.

Sport training and healthcare

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 100 people), several participants noted the novelty of the experience of seeing themselves from outside their bodies, reflecting the ability of flying telepresence operators to observe themselves through UAV cameras. The Flying Head may be applicable to the use of out-of-body vision to promote correct postures for standing, walking, and running for use in sports training, health promotion, and rehabilitation. Additionally, the system can be used as a remote learning platform with professionals such as sports coaches, mentors, and teachers.

Related Work

Recent research of UAVs focuses controlling methods. Quigley et al. described how devices for establishing UAV control parameters, including PDAs, joysticks, and voice-recognition systems, can be used [8]. Giordano et al. developed a situational-aware UAV control system that provides vestibular and visual-sensation feedback using a CyberMotion simulator [9]. This system represents UAV motion information within the operator's vestibular system. However, these gestures are essentially just a replacement for a device input, and it is difficult to use them for inputting parallel control parameters of the UAV. Vries et al. developed a UAV with a toting head-slave camera [10]. However, these operation methods require long training times as parallel parameters need to be set.

Conclusion

Flying telepresence is a term used for the remote operation of a flying surrogate robot in such a way that the operator's "self" seemingly takes control. In this paper, we propose a control mechanism, termed the Flying Head, which synchronizes the motion of a human head with the motion of the UAV. The operator can manipulate the UAV more intuitively as such manipulations are more in accord with kinesthetic imagery. The results of this user study indicate that the Flying Head provides an easy operation preferable to that of a joystick. Finally, we discuss additional flying telepresence applications, such as capturing platforms, teleoperation, sports training, and healthcare.

Acknowledgements

This research was partially supported by Grant-in-Aid for JSPS Fellows Number 24-10424.

References

[1] Lee, S. Automatic gesture recognition for intelligent human-robot interaction. In Automatic Face and Gesture Recognition, 2006. FGR 2006. 7th International Conference on, IEEE (2006), 645–650.

[2] Kamegawa, T., Yamasaki, T., Igarashi, H., and Matsuno, F. Development of the snake-like rescue robot. In Robotics and Automation, 2004. Proceedings. ICRA'04. 2004 IEEE International Conference on, vol. 5, 5081–5086, (2004).

[3] Wendel, A., Maurer, M., Graber, G., Pock, T., and Bischof, H. Dense reconstruction on-the-fly. In Computer Vision and Pattern Recognition (CVPR) 2012, 1450 –1457, (2012).

[4] Lam, T. Mung, Max Mulder, and Paassen M. M. van. Haptic Interface For UAV Collision Avoidance, he International Journal of Aviation Psychology Volume 17, Issue 2, (2007).

[5] Ware, C., and Osborne, S. Exploration and virtual camera control in virtual three dimensional environments. In ACM SIGGRAPH Computer Graphics, vol. 24, ACM (1990), 175–183.

[6] Bluethmann, W., Ambrose, R., Diftler, M., Askew, S., Huber, E., Goza, M., Rehnmark, F., Lovchik, C., and Magruder, D. Robonaut: A robot designed to work with humans in space. Autonomous Robots 14, 2 (2003), 179–197.

[7] Lindsey, Q., Mellinger, D., and Kumar, V. Construction of cubic structures with quadrotor teams. Proc. Robotics: Science & Systems VII (2011).

[8] Quigley, M., Goodrich, M., and Beard, R. Semi-autonomous human-uav interfaces for fixed-wing mini-uavs. In Intelligent Robots and Systems, 2004.(IROS 2004). Proceedings. 2004 IEEE/RSJ International Conference on, vol. 3, 2457–2462, (2004).

[9] Giordano, P., Deusch, H., L̀achele, J., and B̀ulthoff, H. Visual-vestibular feedback for enhanced situational awareness in teleoperation of uavs. In Proc. of the AHS 66th Annual Forum and Technology Display (2010).

[10] Vries, Sjoerd C.; Padmos, P. Steering a simulated unmanned aerial vehicle using a head-slaved camera and hmd: effects of hmd quality, visible vehicle references, and extended stereo cueing. In Proc. SPIE, 80–91.