HAPTIC HOVERING TEACHING SYSTEM FOR HELICOPTERS

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Abstract

This research is targeting the development of a helicopter hovering teaching and assistance interface utilizing haptic directional feedback on the cyclic pitch handle. In the teaching system configuration, it is aiming to speed up the hovering training process of prospective helicopter pilots in a simulator. This shall be achieved by enhancing situational awareness and simplifying the understanding of the complex flight dynamics of the merely stable state of hovering. As an assistance interface in the cockpit, it shall help pilots to increase hovering accuracy and stability in environments and situations with distant or limited visual cues requiring high accuracy and stability of hovering, like power line inspection and rescue missions.

The present paper is composed of three parts. The first part describes the design of the haptic interface. Pre-liminary results of experiments for both applications, the educational and the assistive feedback are being presented and discussed in the second part. The third part discusses conclusions and future works.

1 Introduction

The most challenging aspect for a helicopter pilot is the balancing of this merely stable system when hovering. The initial crucial step for beginners towards successful hover control, is a psychomotor learning process mentally linking the locomotor system of the pilot (his hands) on the controller interface to the corresponding dynamic reactions of the flying object.

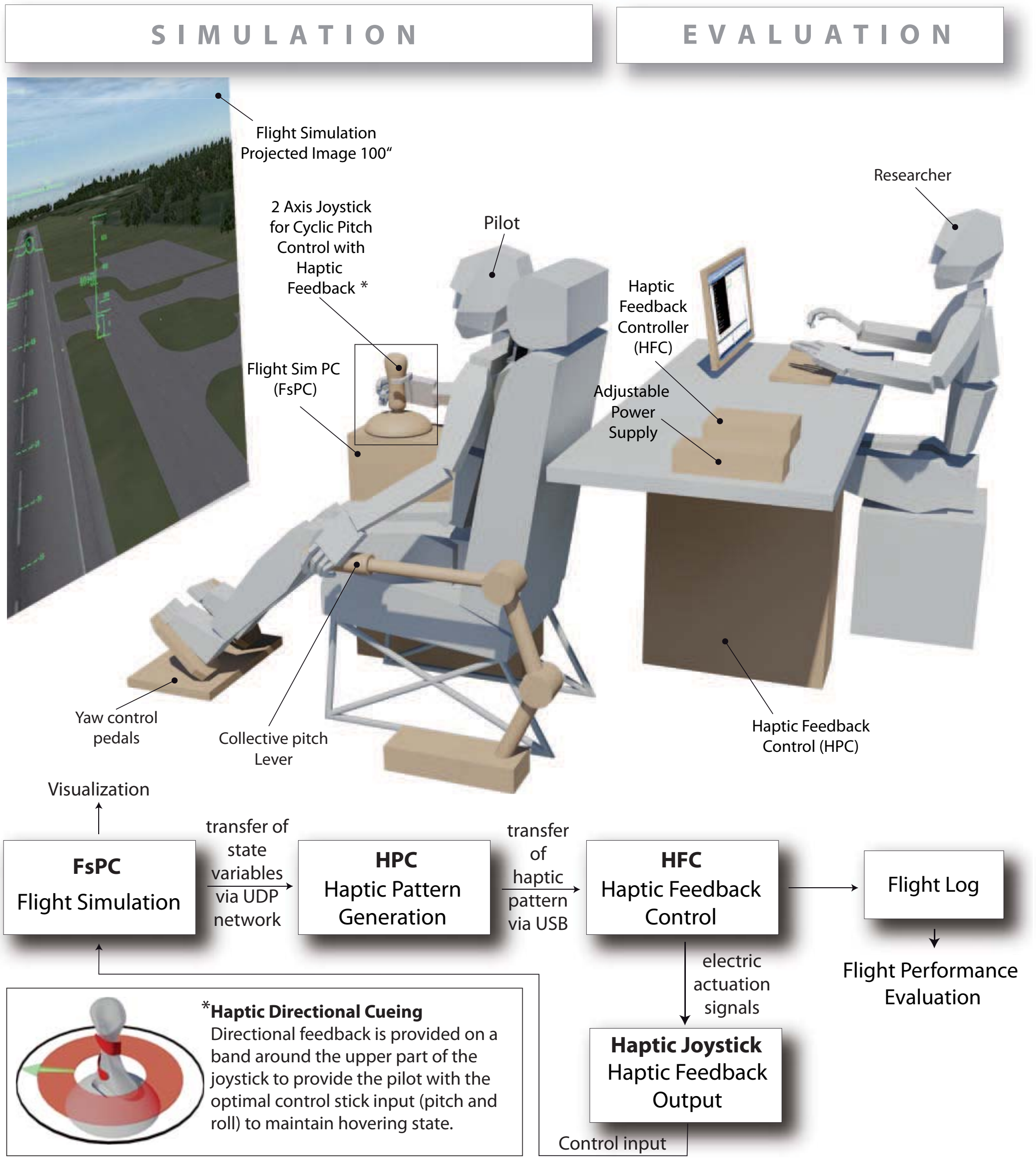
Up until today, helicopter pilots are mainly provided with visual and auditive feedback. However, due to the compexity of tasks like hovering, visual hovering assistance can lead to an overload of the visual channel. Moreover, time lags within the perception and action loop of the human operator can drastically reduce the effectiveness of such a time critical assistance system.

Previous research by our group [1] utilizing a visual hovering assistance interface for RC helicopters providing the pilot with optimal control stick input based on a custom LQR algorithm has demonstrated effectiveness of this concept by hovering performance increase. Among other results it has also shown limitations such as pilot induced oscillations as a result of the human processing time lag between visual perception and locomotor actuation in a time crtical task as hovering.

The haptic approach in this research shall demonstrate the reduction of this effect by the identitiy of the perception and actuation channel and their identity in the device.

1.1 Haptic Feedback

Haptic and tactile feedback are concerned with information aquisition through touch. They can code information in form of surface texture, roughness, temperature and shape of an object or provide feedback through force, respectively. Both methods can complement or substitute visual feedback, resulting in a multi-modal interface which allows pilots to enhance their situational awareness. The temporal acuity of a fingertip is about 5ms and therefore 5 times higher that



***Haptic Directional Cueing**
Directional feedback is provided on a band around the upper part of the joystick to provide the pilot with the optimal control stick input (pitch and roll) to maintain hovering state.

Fig. 1 Experimental Set Up for Haptic Joystick Hovering Teaching and Assistance

Fig. 2 Haptic Joystick Hardware

that of the human eye with 25ms. The information capacity though lies within 10^6 to 10^9bits/sec for the human eye while being at 10^2bits/sec for the fingertip [2]. Research e.g.[3] or [4] has been concentrating on haptic force feedback, e.g. in [5] where the pilot is limited in his controls when reaching the structural flight envelope. Instead of control limitations or counterforces, this research is focussing on directional vibro-haptic feedback for hovering teaching and assistance. The system provides haptic cues on the inner skin surfaces of the hand. The goal is to teach the psychomotor system of the pilot without affecting his freedom of movement and control.

2 Experimental Set Up

Figure 1 illustrates the experimental set up. Pilot subjects were seated in a pilot seat in front of a 100" 4:3 aspect screen displaying the flight simulation with a fixed viewpoint from inside the cockpit through the front window. The control hardware was based on thgat of a real helicopter. The collective pitch was controlled by a side lever to the left of the pilot. Pedals were utilized to control yaw. A 2 axis joystick with a custom made head capable of directional haptic cueing was utilized to control the cyclic pitch of the simulation and to display haptic feedback on lateral and longitudinal velocity of the helicopter. An Intel Core i7 CPU at 3.2GHz with 6GB RAM (FsPC) was running the flight simulation "X Plane" of "Laminar Research". Lateral and longitudinal velocity within the global coordinate system were transferred via UDP data protocol to an Intel Core2Duo at 2.66GHz with 2 GB RAM (HPC) generating the haptic feedback patterns. These were sent through USB to a custom made Haptic Feedback Controller (HFC) which was controlling 12 vibration motors on the haptic joystick. A flight log with the main state variables was recorded throughout all experimental sessions. The helicopter dynamics model was based on a Seaking 61.

Figure 2 shows photographs of the haptic joystick and the HFC hardware. It consisted of a microcontroller board, the Ardunio MEGA with a ATmega 1280 microcontroller and a custom made motor controller board using 6 Ti SN754410NE ICs of which each controlled 2 DC vibration motors. The 12 PWM and 24 digital IOs of the Arduino MEGA board were connected to the motor controller board. A 24 pin cable connected the haptic joystick with its 12 vibration motors with the HFC. The motors were positioned in a circle around the upper part of the joystick to be in contact with the inner skin surface of the right hand of the pilot. There alignment would create a contact area with the inner skin surface from the tip of the forefinger to the tip of the thumb and naturally fit the form of the right hand. Power was supplied externally to be able to carefully adjust voltage and current to tune intensity of vibration. The ATmega 1280 board was powered through USB power supply from the HPC.

2.1 The Flying Task

As shown in figure 3, subjects had to take off from (1) at runway 21 of Ohshima Airport (Japan), reduce velocity from about the second third of the runway (2) and finally manage to hover at the opposite end of the runway (3). The lower part of this figure illustrates an ideal flight log as reference for experimental results. Before participation in this experiment, subjcets had to successfully complete at least two of three experimental test cycles. For the altitude experiments, the initial position was set to different altitudes which were supposed to be kept during the flight round.

2.2 The Haptic Feedback Concept

Directional haptic cues were provided in real time based on the normalized velocity vector, rectangular to the gravity field. The current amount and direction of velocity, if, exceeding a defined threshold value, was indicated as an attractive cue urging the pilot to take measures to reduce velocity below the threshold value, and therefore maintain hovering or slow forward flight respectively. It would not show the pilot the optimal control input or reaction to the situation, but teach or assist by providing a velocity indicator to enchance the pilot's decision making process. For example, in case of a forward velocity above the minimum threshold value, the rear vibration motor, facing the pilot, would start to vibrate. This would indicate the amount of velocity and which direction it would have to be reduced to. The decision on proper countermeasures had to be made by the pilot. This would ensure a learning process for prospective pilots in the teaching system set up.

2.2.1 Haptic Feedback Patterns

Figure 4 illustrates haptic feedback patterns which were applied. The greyscale values represent different vibration intensities, numbered from I to IV with increasing frequency and amplitude. They would be triggered by exceeding defined threshold values in specific directions. White areas had no feedback. There were two types of patterns. The slow forward flight pattern on the right of figure 4 would pursuade the pilot to keep a slight positive pitch to slowly fly forward. The centered hovering pattern on the left would assist the actual hovering on the spot. The positive pitch pattern was introduced to gradually lead pilots to the centered hovering in the assistance system set up. As for the teaching system, some pilots were not able to achieve the centered hovering in the beginning of a training session so that they were gradually introduced to centered hovering by firstly achieving a stabilized slow forward flight with the positive pitch feedback pattern.

There were three positive pitch feedback patterns differing in their threshold values and one centered hovering pattern which would be triggered as shown in figure 5 depending on the flying status and velocity. At a transition between two different feedback patterns, all vibration motors would be shortly actuated simultaneously to inform the pilot.

2.3 Educational Feedback Experiment

To investigate the influence of the system on the learning behaviour of individuals in simulated flight, the following experiment was conducted. Four student subjects, male, aged 25 - 27, particpated. All subjects had a similar limited experience level with helicopter flight simulation. The above mentioned flying task of taking off, increasing and decreasing velocity and finally hover would have to be completed 12 times

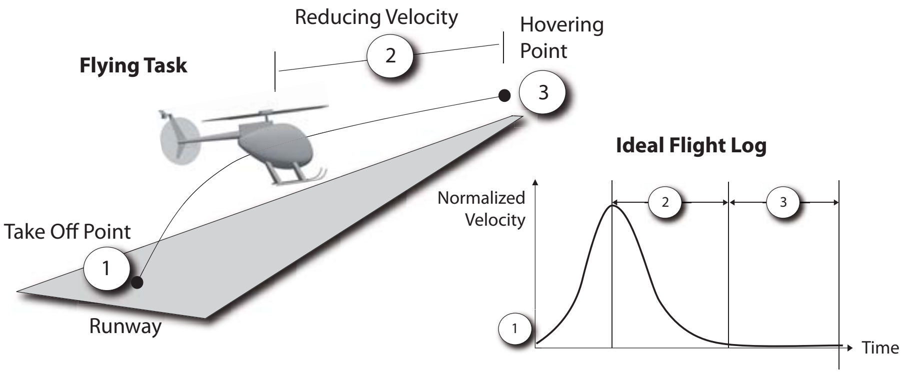


Fig. 3 The Flying Task

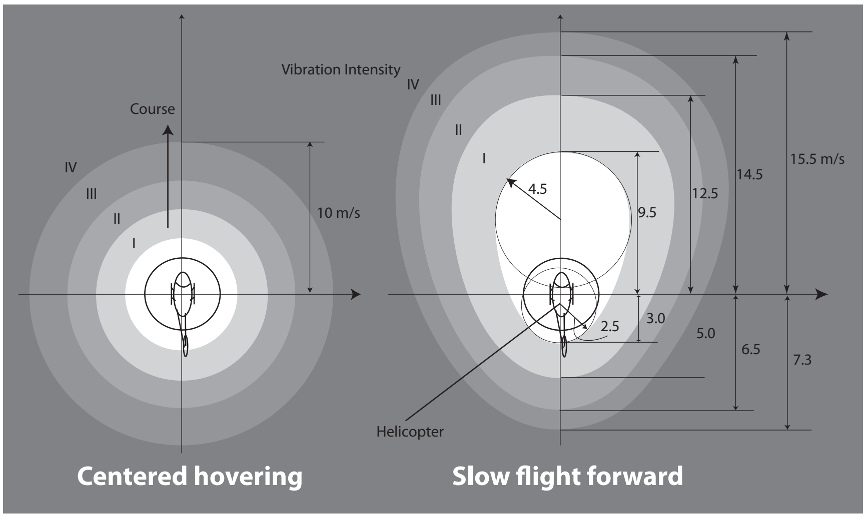


Fig. 4 Haptic Hovering Patterns

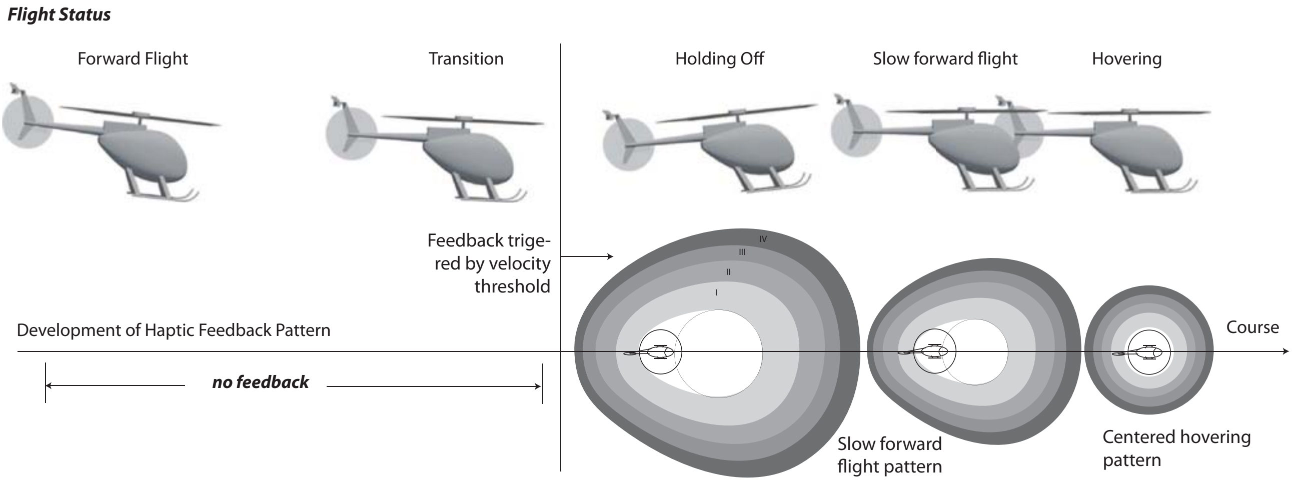


Fig. 5 Haptic feedback dependency on flying status

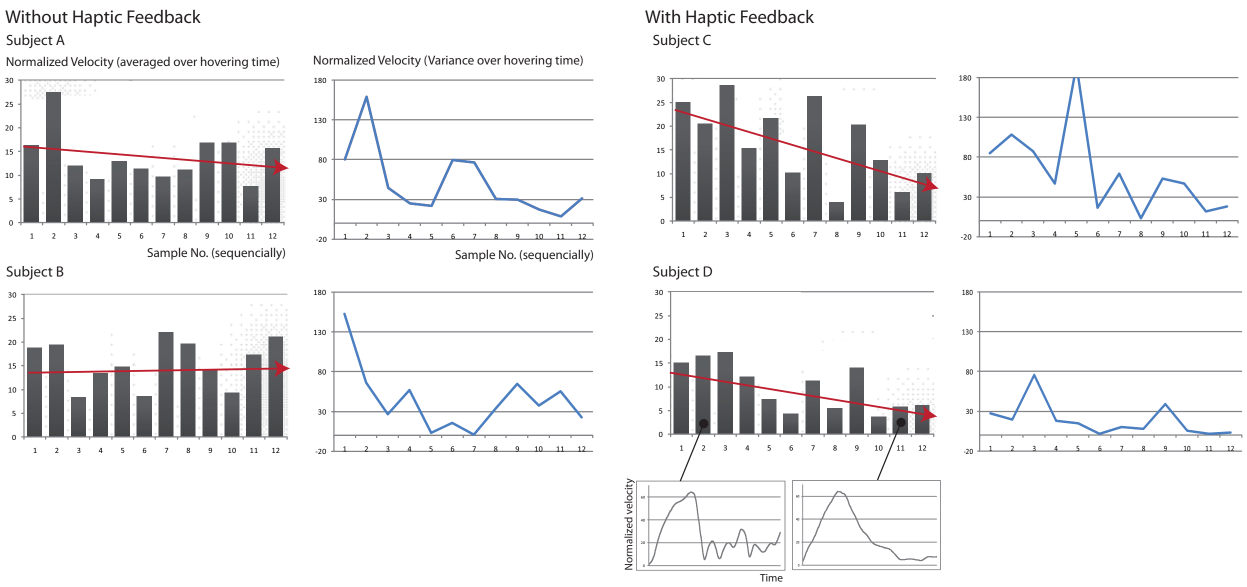


Fig. 6 Influence of haptic feedback on the aquisition of hovering skills

while increasing hovering performance as much as possible during the course of this traning. Two of the fours subjects had to utilize the feedback interface throughout the whole experiment while the other two were training without haptic feedback. Altitude and airspeed indicator were provided visually.

2.3.1 Pre-liminary Results

Due to the low number of subjects, the experimental results illustrated in figure 6 should be regarded as pre-liminary. For each of the four subjects, results consists of a graph of the average normalized velocity during hovering and the variance of the data for all 12 cycles. Subjects C and D were provided with haptic feedback. The variance of velocity during hovering, indicating the stability of hovering, was gradually reduced during the course of the 12 training cycles for all four subjects. Therefore all subjects improved their hovering stability. Considering the averaged normalized velocity, indicating hovering precision, there is a significant difference in the linear gradient (red arrow) of the development of this parameter over the 12 cycles between subject group A,B and C,D respectively. Data for subjects C and D indicates a sharper decline of these values. So it can be concluded that the subjects utilizing the haptic feedback had a higher increase of hovering precision. Summing up, subjects C and D were mainly concentrating on increasing the stability of hovering by reducing the rate of change of velocities whereas subjects A and B with haptic feedback, showing the same behaviour, additionally significantly increased hovering precision.

2.4 Assistive Feedback Experiment

This experiment was carried out to investigate the feasibility and effectiveness of haptic feedback as an assistance system during flight. Three of the four subjects were students, male, aged from 26-29, had helicopter simulator experience and a comparatively high hovering performance towards the subjects from the educational feedback experiment. The forth subject was a private R22 pilot.

Subjects had to complete the task shown in figure 3 by starting at the beginning of the runway, flying to the end of the runway and hover above it. Altitude after take off was to be kept stable. To investige possible changes of utilization of haptic feedback at a change of the visual environment, each experimental session was carried

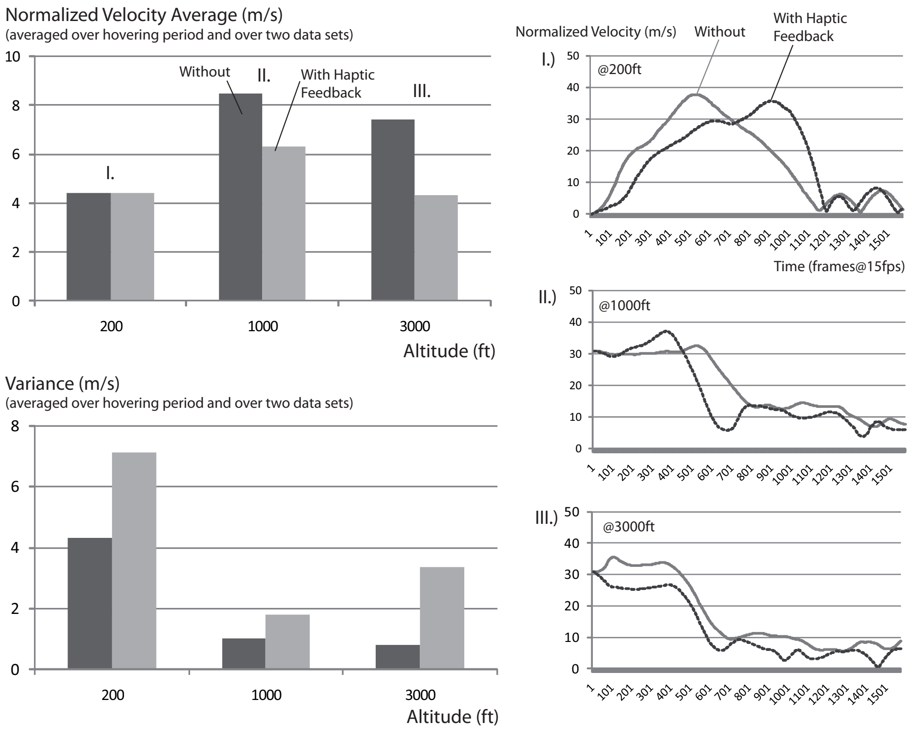


Fig. 7 Haptic Feedback in dependency on Altitude

out at three altitudes, 200, 1000 and 3000 feet. At higher altitudes (1000 and 3000ft), the number of visual cues would be reduced or more they would be more distant, reducing the accuracy of vision based hovering. Altitude and airspeed indicator were provided visually.

2.4.1 Pre-liminary Experimental Results

Similar subject's comments suggested that the haptic feedback was very helpful as a stable measure at the two higher altitudes, 1000 and 3000 feet. At the lowest altitude of 200 feet, the feedback would not increase their hovering precision. The haptic interface would be a helpful indicator for the backward motion of the helicopter since that could not be inferred from the instruments. Evaltuaing flight log data, all subjects, except for the privat pilot, increased hovering precision, indicated by averaged normalized velocity during hover, at all altitudes, including the lowest 200 feet. The R22 pilot had no significant difference in hovering precision at that altitude. However, he and one other subject had a significantly higher precision increase at altitudes of 1000 and 3000ft compared to 200ft which confirmed their comments.

The other two subjects commented similarly that they felt a hovering precision increase utilizing feedback at altitudes 1000 and 3000ft, but not at 200ft. Despite this, objective data indicates about the same quantity of precision increase through feedback utilization for all altitudes. The reason might be lying at a higher confidence in control due to the haptic velocity indicator at higher altitudes and therefore in situations with decreased and or distand visual cues. Comments also suggest a potentially bigger precision increase with an even tighter haptic pattern for the two subjects with the best hovering performance. Figure 7 shows the experimental result of the R22 pilot. He increased hovering precision (normalized velocity average) at altitudes 1000 and 3000ft with haptic feedback. The variance of normalized velocity utilizing haptic feedback increased for all altitudes compared to without. This leads to the conclusion that this subject's hovering precision increased at the cost of a slight decrease in hovering stability resulting from adapting to the haptic interface. A similar behavior was observed with one other subject. The other two subjects exhibited increase of both precision and stability, meaning a decrease of averaged velocity and variance, for all altitudes when utilizing haptic feedback. Summing up, the haptic feedback lead to an overall increase in hovering precision for all subjects. Two subjects decreased in hovering stability utilizing the feedback. But comments suggest that this circumstance could be avoided by more individual threshold settings of the haptic feedback patterns.

3 Conclusions and Future Works

Research utilizing a haptic directional cue joystick using 12 vibration motors as a hovering teaching and assistance interface lead, in preliminary experimental results, to an overall increase of hovering performance in precision and stability and increased the speed of aquiring hovering skills in an educational set up. It has shown its potential to teach the psychomotor system of the pilot to increase understanding of helicopter dynamics. Furthermore, this interface has shown its applicability to assist hovering in environments with insufficient visual cues. This could help to increase hovering precision in missions requiring high hovering precision in situations with limited visual cues, like rescue missions or power line inspections in special situations. However, this research has also identified the issue of a necessary individualization of threshold values for different pilots. Further experiments should be carried out to investigate the feasibility of learning algorithms for the system to adopt to individual pilot's control patterns. As a dynamic model for the helicopter, the Seaking S 61 was used. Further experimental series should be carried out with different dynamic models.

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