Identification of Pilot Control Behavior in a Roll-Lateral Helicopter Hover Task

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This paper focuses on the influence of different forms of motion feedback on the perception and control behavior of pilots in a roll-lateral helicopter hover task. To identify this influence, a combined target-following and disturbance-rejection task is carried out where the motion feedback is varied. The participants perform the control task with roll motion only, lateral motion only, combined roll-lateral motion, or with no motion. A cybernetic approach is taken to identify multi-loop pilot describing functions and estimate the parameters of a pilot model. Results show that participants perform significantly better at the control task with feedback of combined roll-lateral motion, and decrease their control activity. For the condition with feedback of roll motion a similar trend is observed. This is explained through the increased amount of information present in the inner roll stabilization loop.

I. Introduction

In 1999, Schroeder performed a series of helicopter flight simulation experiments on the Vertical Motion Simulator at NASA Ames Research Center. These experiments served to uncover the effects of cockpit motion on pilot-vehicle performance, workload and motion perception. Objective measures, such as positioning performance and the root mean square (RMS) value of the stick position and rate, were used to evaluate task performance and showed that performance increased when transitioning from no motion to full motion through several intermediate motion conditions. Motion fidelity ratings and handling qualities ratings were used as subjective measures, which showed results comparable to the objective measures.

Similar results were obtained in an earlier experiment. It was shown that only the one-to-one motion configuration for a roll-lateral task consistently reflected the predicted handling qualities based on an existing handling qualities specification. For the motion with reduced fidelity, i.e. attenuated with a wash-out filter, the ratings were, surprisingly, quite similar. However, in this case it was noted that reductions in motion fidelity can falsely improve handling qualities ratings. A third experiment again found similar results and showed that overall motion fidelity is dependent on the combined effect of roll and lateral motion cues.

In all these previous experiments, subjective measures were used to describe the effect of different motion feedback on pilot ratings. Especially in the experiment by Chung, difficulties were encountered with these

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ratings in the sense that the reductions in motion fidelity falsely improved the handling qualities ratings. Therefore, a cybernetic approach is taken here in which the pilot control behavior is identified from a target-following and disturbance-rejection task using two forcing functions. In this way, the effects of different motion conditions on the parameters of the pilot dynamics can be determined in an objective rather than subjective manner.

For this purpose, a roll-lateral helicopter hover task is performed where different sources of motion are used in order to uncover the effect of each: no motion, roll motion only, lateral motion only and combined roll-lateral motion. The motion platform used during the task is a mid-size Stewart type motion system, located at the Max Planck Institute for Biological Cybernetics in Tübingen, Germany.

The structure of the paper is as follows: first the experimental setup is discussed. Second, the cybernetic approach and the parameters of the pilot model are elaborated. Third, the results are given and discussed and finally, conclusions are drawn and recommendations are given.

II. Experiment

The goal of this experiment is to investigate the effect of different motion conditions on the perception and control of pilots in the loop. For this purpose, a cybernetic approach is taken to identify the pilot control behavior during a roll-lateral helicopter hover task.

II.A. Control task

In order to be able to separate the visual and motion responses of the participants, two forcing functions, \( f_d \) (disturbance) and \( f_t \) (target), see Figure 1, are required in the control task. Each forcing function is a multi-sine signal, and consists of a sum of 10 sinusoids, see Table 1 and for more information Section III. The amplitudes of the individual sinusoids are determined with a squared first order filter with a break frequency of 1.25 rad/s. This attenuates the high-frequency sinusoids such that the control task is not too hard, but keeps the low-frequency sinusoids intact such that the forcing functions are not too predictable.

Table 1: Definition of the forcing functions, where \( k_i \) is the number of periods of sinusoid \( i \) that fits within the measurement time, and \( \omega_i, A_i \) and \( \phi_i \) are the frequency, amplitude and phase of sinusoid \( i \), respectively.

<table>
<thead>
<tr>
<th></th>
<th>Disturbance</th>
<th>Target</th>
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<tbody>
<tr>
<td>( i )</td>
<td>( k_i )</td>
<td>( \omega_i, \text{rad/s} )</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>0.3835</td>
</tr>
<tr>
<td>2</td>
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<td>0.8437</td>
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<tr>
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<td>13.576</td>
</tr>
<tr>
<td>10</td>
<td>226</td>
<td>17.334</td>
</tr>
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</table>

This setup leads to a combined disturbance-rejection and target-following task as can be seen in Figure 1. The target forcing function \( f_t \) mainly affects the visual cues, whereas the disturbance forcing function \( f_d \) has an influence on both the visual and motion cues. The RMS value of the disturbance forcing function is 4.51° and for the target forcing function the value is 2.84°. Therefore, the disturbance-rejection task is dominant.

The disturbance forcing function is prefiltered with the inverse dynamics to counteract the attenuation caused by the system dynamics. This is already accounted for in Table 1. The target forcing function is presented to the participants by moving a target in the visual scene. This target has the same dynamics as the helicopter to be controlled, see Equations 1 and 2. The forcing function acts on the roll angle of the target and the lateral position is calculated based on the dynamics.
II.B. Participants and instructions

Six participants took part in the experiment. One participant had experience as a helicopter pilot, all had previously performed a helicopter hover task on the same motion platform used here. The participants were informed about the existence of the different forcing functions and instructed to counteract the disturbance on their control signal. They were also told to follow the target as precisely as possible by aligning the vertical of the helicopter with that of the moving target. For this purpose, the participant’s vertical was shown on the screen as a cross. If this is done perfectly, the lateral position of the helicopter would be similar to that of the target. Of course, this was never attainable due to the influence of the disturbance forcing function and therefore participants were instructed to also attend to the difference in lateral position between the helicopter and the target and to try to minimize this distance.

II.C. Apparatus

The experiment is performed on the motion platform of the Max Planck Institute for Biological Cybernetics (MPI), see a depiction in Figure 2a. In reality, the cabin is completely enclosed such that participants do not have visual information on the surroundings. The platform is a mid-size Stewart-type motion system with electrical actuators (Maxcue 610-450, Motionbase, England). A 166 by 112 cm projection screen has been mounted on the motion base. This results in a field of view of approximately $72^\circ$ horizontally and $52^\circ$ vertically.

The simulator has the ability to move in all six degrees of freedom, but for this experiment only the roll and lateral degrees are used. The conversion from the roll angle $\phi$ to acceleration in $y$-direction is given by $\ddot{y} = g \cdot \sin (\phi)$, where $g = 9.81 \text{ m/s}^2$. For small angles this can be simplified to $\ddot{y} = g \cdot \phi$.

The motion platform at the MPI is driven by position signals and for this task the motion workspace is not sufficient to supply the participants with the full motion cues. Therefore the motion cues are filtered.
with a gain of 0.15 for the roll motion and 0.12 for the lateral channel. Additionally, the lateral motion channel features a first order high-pass filter with a break frequency of 1 rad/s to drive the platform back to its neutral position.

The dynamics of the simulated helicopter are taken from an experiment performed by Schroeder. Only the roll and lateral degrees of freedom are present, the others degrees of freedom are kept constant. The helicopter model is given as:

\[
\ddot{\phi} = -4.5\dot{\phi} + 1.7\delta_{\text{lat}}, \tag{1}
\]
\[
\ddot{y} = g \cdot \sin(\phi), \tag{2}
\]

where the unit of \(\delta_{\text{lat}}\) is inches. These equations show that the inner roll stabilization loop behaves like an integrator up to 4.5 rad/s, which means that the roll angle rate \(\dot{\phi}\) is proportional to the control input \(\delta_{\text{lat}}\). This control loop can be closed with ease. The control of lateral position \(y\) in the outer control loop in fact behaves like a third order integrator as the lateral acceleration \(\ddot{y}\) is related to the roll angle \(\phi\). This can only be controlled because information on the current roll angle is presented to the participants. However, pilots need to generate lead, i.e., perceive the lateral velocity \(\dot{y}\), which is done through the visual presentation or the motion system.

Pilots use an Omega.3 haptic device (Force Dimension, Switzerland) for their input into the control system. This device has three translational degrees of freedom. The haptic feedback capabilities of the device are not used and thus it can be seen as a passive position stick. Only the lateral degree of freedom is active for control of the helicopter model.

II.D. Independent variables

The independent variable in this experiment is the motion feedback. The condition without motion serves as a baseline. Other motion conditions include roll motion only, lateral motion only, and combined roll-lateral motion. The visual display is the same during all experimental trials and thus the experiment has four conditions in total.

II.E. Experimental procedure

The experiment is performed in two phases: training and measurement runs. Each run lasts 110 seconds, of which the first 28.08 s are run-in time, so the participants can get used to the task, and the last 81.92 s are actual measurement time. Data are recorded at 100 Hz. Participants perform at least 2 hours of training without platform motion depending on their performance. Once acceptable performance is reached, participants perform several trials with motion feedback before progressing to the measurement phase.

During measurements each condition is repeated five times. The order of the condition is randomly generated and checked for unwanted repetitions of conditions. In principle all measurements are performed during one 45-minute session, but participants can take breaks in between trials.

II.F. Dependent measures

During the experiment, the roll angle \(\phi\), the lateral position \(y\), the pilot control signal \(u\), and the forcing functions \(f_t\) and \(f_d\) are recorded. From \(f_t\) and \(\phi\), the error \(e\) can be reconstructed. These signals are used during identification and parametrization of the describing functions of the pilot model, see Figure 1. The identification procedure is elaborated in Section III.

The dependent measures can be subdivided into three groups. The performance measures are the RMS of the error \(e\), which is a measure of pilot performance, and the RMS of the control signal \(u\), which indicates pilot control activity. The second group constitutes the parameters of the identified pilot responses.

II.G. Hypotheses

Based on the results from previous research, it is expected that the condition with combined roll and lateral motion results in superior performance. Further, it is hypothesized that performance is increased with feedback of roll motion relative to the condition without motion. This is expected because the pilot has additional information on the inner stabilization control loop in terms of the roll angle.
When the participants are supplied only with lateral motion cues, performance is expected to increase slightly or not at all, as the additional motion cues only act on the outer position control loop. This makes it harder for the participants to attain a performance increase as the inner stabilization loop is not affected.

III. Pilot modeling and identification

Based on the task, subject instructions, and the helicopter dynamics, it is clear that the roll-lateral helicopter hover task consists of two different control loops. The first loop is governed by the roll angle and is the inner control loop. The dynamics of this control loop are described by Equation 1. The control of the lateral degree of freedom constitutes the second, or outer, control loop. This control loop is dependent on the inner loop and is described by Equation 2. Pilots first need to stabilize the inner roll angle loop, before they can attend to the outer lateral position loop and this is exactly what is observed in the control task discussed here. Participants first learn how to keep the helicopter horizontal with the disturbance forcing function and only when this is achieved can they attend to the lateral position and follow the target.

The conditions in the experiment have an influence on how the control loops are processed. In the condition without motion, participants perceive the roll angle for the inner loop and lateral position and velocity for the outer loop from the visual display. When conditions with motion are performed, the motion cues substitute or support the perception of visual cues. For example, in conditions with lateral motion, the lateral velocity can easily be perceived from the motion of the simulator.

In order to identify the dynamic properties of the human visual and motion perception, a cybernetic approach is taken. This entails the identification of two pilot frequency response functions in the frequency domain as a first step and the estimation of the parameters of a pilot model as a second step. It is not possible to identify the inner and outer control loop separately and thus a distinction between these is not considered here. Figure 3 gives the structure of the closed loop control task that is investigated. By introducing a disturbance forcing function, $f_d$, and a target forcing function, $f_t$, into the control loop, two separate pilot describing functions can be identified.

The identified describing functions describe the quasi-linear part of the human behavior. This is only the case when the pilot is properly trained and when all variables that affect human behavior are maintained at the same level during the experiment. The non-linear part of the behavior is captured by the remnant signal $n$, which accounts for the difference between the causal model output and the experimentally measured output of the pilot. In this control task, the pilot model consists of a response to the visually presented error signal, $H_{sp,e}$, and a response to the state signal, $H_{sp,m}$, which is presented to the pilot by the motion system as depicted in Figure 3.

Different identification techniques are available for multi-loop identification of the pilot response functions in the first step of the cybernetic approach. All methods relate the output signal of the pilot to the input signal $e_s$ and $\phi_s$ or $\phi_s$. However, these input signals are not available, as they are generated by the simulator, only the signals $e$, $\phi$ and $u$ that were generated by the experiment program can be saved. Thus, the pilot describing functions $H_{pe}$ and $H_{pm}$ can not be determined directly, only a combined simulator-pilot response can be found. For the identification procedure, an ARX model identification technique is used. This method gives a continuous estimation of the pilot responses and their variance in the frequency domain.

In the second step of the cybernetic approach, the pilot model, which is given in Figure 4, is fitted to

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Figure 3: The closed-loop control task with system dynamics $H_c$, combined simulator-pilot describing functions $H_{sp,e}$ and $H_{sp,m}$, and the pilot remnant $n$.  

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the identified frequency response functions $H_{sp,e}$ and $H_{sp,m}$. In this step, also the simulator dynamics are separated from the total identified response by fixing the parameters of the simulator transfer functions during the optimization. The simulator dynamics consist of a pure scaling of the motion cues in both channels, but for the lateral channel an additional high-pass filter is used to drive the platform back to its neutral position. Time delays of the motion and display systems are not taken into account as these are not known precisely.

As can be seen in Figure 4, the motion response consists of two paths. One path takes into account the contribution of the semicircular canals and another path includes the otolith response. These perception paths are only included in the model when it is appropriate for the experimental condition. For example, when driving the simulator in roll, only the response of the semicircular canals is taken into account.

The pilot model consists of the pilot equalization, the pilot limitations and sensors. The pilot equalization is described with the following parameters:

- $K_v$ the visual perception gain,
- $\tau_{lv}$ the visual lead time constant,
- $K_{scc}$ the semi-circular canal perception path gain,
- $K_{oto}$ the otolith perception path gain.

The pilot limitations consist of the perception time delays and the neuromuscular dynamics. The time delays are given by:

- $\tau_v$ the time delay of the visual perception path,
- $\tau_{scc}$ the time delay of the semi-circular canal perception path,
- $\tau_{oto}$ the time delay of the otolith perception path.

The combined neuromuscular and manipulator dynamics are based on the widely accepted precision model by McRuer\(^7\) and are given by:

$$H_n(j\omega) = \frac{\omega_n^2}{\omega_n^2 + 2\zeta_n\omega_n j\omega + (j\omega)^2}, \quad (3)$$

with:

- $\omega_n$ the neuromuscular frequency,
- $\zeta_n$ the neuromuscular damping.

The sensors in the model consist of the semi-circular dynamics and otolith dynamics in the motion perception response. These are modeled by:\(^10,\,11\)

$$H_{scc} = \frac{1 + j\omega\tau_{scc1}}{1 + j\omega\tau_{scc2}}, \quad H_{oto} = \frac{1 + j\omega\tau_{oto1}}{1 + j\omega\tau_{oto2}}, \quad (4)$$

Figure 4: The parameter model with a distinction between the pilot and simulator part and between a visual, a roll motion, and a lateral motion perception path.
where the time constants for the semicircular canal and otolith dynamics are taken from previous research:

\[ \tau_{sc1} = 0.11 \text{ s}, \quad \tau_{sc2} = 5.9 \text{ s}, \quad \tau_{oto1} = 1 \text{ s}, \quad \text{and} \quad \tau_{oto2} = 0.5 \text{ s}. \]

The parameter model given in Figure 4 consists of \( \tilde{H}_{sp,e} \) and \( \tilde{H}_{sp,m} \). These frequency response functions are fit to the identified frequency responses, \( \hat{H}_{sp,e} \) and \( \hat{H}_{sp,m} \), by minimizing the following criterion:

\[
J_f(\theta) = \frac{1}{N_f} \sum_{k=1}^{N_f} \left( \frac{|\hat{H}_{sp,e}(\omega) - \tilde{H}_{sp,e}(\omega; \theta)|^2}{\text{var}(\tilde{H}_{sp,e}(\omega))} + \frac{|\hat{H}_{sp,m}(\omega) - \tilde{H}_{sp,m}(\omega; \theta)|^2}{\text{var}(\tilde{H}_{sp,m}(\omega))} \right). \tag{5}
\]

Here, \( N_f \) is the total number of frequency points on which the frequency responses \( \hat{H}_{sp,e}(\omega) \) and \( \hat{H}_{sp,m}(\omega) \) are defined and \( \theta \) is the parameter vector. The error between the modeled and identified frequency responses is scaled at every frequency point with the estimated variance of the frequency response at that frequency point. This is done in order to put less emphasis on frequencies where the identified responses are uncertain.

The total pilot dynamics give an insight into the total response of the participants for a particular condition. Due to the control task, which entails two forcing functions, direct calculation of the total pilot model is not possible. However, an approximation of the total pilot model can be made. One can argue that the control task is essentially a disturbance-rejection task and consider the disturbance forcing function as the major input signal into the control loop. In this case, the total pilot model is given as:

\[
H_{pt} = \tilde{H}_{sp,e} + \tilde{H}_{sp,m}. \tag{6}
\]

IV. Results and discussion

The results of the experiment are presented below in two main categories. The first category encompasses the results from analysis on the signals measured in the time domain during the experiment. In the second category, results from the modeling effort, that is described in the previous section, are presented. All statistical results presented here are generated with a repeated-measures analysis of variance (ANOVA). All error bars given in the figures are confidence intervals for the mean value that are based on the standard error and are corrected for between-subject variability.

IV.A. Pilot performance and control activity

The pilot performance is analyzed with the RMS value of the error signal presented to the participants. This signal consists of the difference between the target forcing function, \( f_t \), and the roll angle of the helicopter, \( \phi \). The means and their confidence intervals for each experimental condition are given in Figure 5a.

The statistical analysis shows that there is an overall effect of motion on the RMS of the error signal, or pilot performance. This effect is highly significant, \( F(3, 15) = 7.791, \quad p < 0.05 \). A post-hoc test, based on tests of within-subjects contrasts and pairwise comparisons, shows that this significant effect is mainly found between the conditions without motion or with partial motion and the combined motion condition. In the latter case, performance is significantly improved. This indicates that the partial cues are integrated. Also a trend is visible for the condition with roll motion only, showing better performance with respect to the condition without motion. These results are clearly visible in Figure 5a, where the means for conditions with roll motion only or with combined motion are lower than the means for conditions without motion or
with lateral motion only. It is very clear that the variance in the condition with combined motion is much lower than in conditions with partial or no motion.

The pilot control activity is calculated by taking the RMS value of the pilot control signal, \( u \). This is the lateral displacement of the input device, as displayed in Figure 2a. The means and confidence intervals are given in Figure 5b.

Comparing the results to the values for the RMS value of the error signal, one can see similar results. Again, an overall highly significant effect is found, \( F(3, 15) = 4.259, p < 0.05 \). The post-hoc analysis again shows that this significant effect is found between the conditions without motion or with partial motion and the combined motion condition, comparable with the RMS of the error signal.

The pilot performance and control activity show that in the combined motion condition the participants can perform significantly better in reducing the error, but at the same time they exhibit a significant decrease in the control activity. A similar trend is observed for the condition with only roll motion, which indicates that the roll angle is used first to increase performance. The lateral movement does not help to increase performance by itself and similar control activity is exhibited compared to the condition without motion. However, when lateral motion is presented together with the roll angle, it can be used to perform the task better and with lesser activity.

**IV.B. Pilot control behavior**

As discussed in Section III, the cybernetic approach taken here consists of two steps. In the first step the simulator-pilot describing functions are identified using an ARX model identification method.\(^9\) In the second step, the pilot model from Figure 4 is fit onto the identified describing functions by estimating the model parameters.

The parameters of the simulator dynamics are taken constant. These include the gains used to scale the motion cues with respect to the visual cues and the high-pass filter that drives the motion platform back to its neutral position in case of lateral movement. Also the parameters of the sensor dynamics are fixed as discussed in Section III.

The pilot model contains a model for the dynamics of the vestibular organs: the semicircular canals and the otoliths. These models are generally valid and should not change between participants. Therefore, the parameters of these models, given in Eq. 4, are fixed during optimization.

**IV.B.1. Total pilot model**

In Figure 6, the total pilot response of a typical participant is shown. There is a clear distinction in terms of the magnitude of the response between the conditions without motion and lateral motion only on the one side and the condition with roll motion and combined motion on the other side. The phase of the total pilot response does not show any clear distinctions between the conditions here, but analysis of the pilot model parameters provides further details.

![Figure 6: The total pilot response \( H_{pt} \) for different conditions for one participant.](image)
IV.B.2. Pilot model parameters

The means of all estimated pilot model parameters and their 95% confidence intervals are given in Figure 7. These data are analyzed with a repeated-measures analysis of variance to determine if the motion conditions have a significant effect.

As can be seen in Figure 7a, the visual perception gain $K_v$ is affected by the addition of motion. This effect is highly significant, $F(3,15) = 58.825, p < 0.05$. Post-hoc tests show that this is a consequence of a difference between the conditions with motion and the condition without motion. In the latter case, the visual perception gain is significantly higher. Apparently, participants shift their attention away from the visual cues when they are supplied with motion cues and use the motion cues to acquire the information relevant for the task.

![Figure 7: Means and confidence intervals of the identified pilot model parameters.](image)
Also the time delay of visual perception path, $\tau_v$, is affected significantly, $F(3,15) = 3.244$, $p = 0.05$. Post-hoc tests show that this difference can be attributed to a difference between the condition without motion and with motion feedback. In conditions with motion, the time delay is higher, see Figure 7e, indicating that pilots actively use the motion perception channels and rely less heavily on the visual perception path.

The gain of the semi-circular canal motion perception path is the same in the condition with roll motion only and the combined motion condition, see Figure 7f. However, the otolith perception gain is lower in the combined motion condition compared to the condition with lateral motion only. This effect is marginally significant, $F(1,5) = 5.145$, $p = 0.073$, and indicates that pilots primarily use the cues from roll motion and utilize the lateral motion cues less when the cues from roll motion are present.

The neuromuscular damping $d_{nm}$ and frequency $\omega_{nm}$ of the pilots, and therefore the steering behavior, did not change for different motion conditions. However, the control activity does change significantly and apparently the pilots can use changes in the perception paths to increase performance and regulate control activity.

**IV.B.3. Pilot remnant and coherence**

The pilot remnant accounts for the difference between the causal model output and the experimentally measured output of the pilot and is an indication for the amount of non-linear behavior of the pilot. In Figure 8a, the frequency response of the remnant is given for one typical subject. The remnant is determined on the frequencies $\omega_1$ and $\omega_2$ of the forcing functions, see Table I.

A clear distinction can be made between the different motion conditions. In case of the conditions with motion, the pilot remnant is noticeably higher than in the condition without motion in the lower and middle parts of the frequency range. This can be attributed to the increase of performance and the fact that the pilots are presented with more cues to process. In the higher frequency range, the remnant is identical for all experimental conditions.

The coherence functions for one typical subject are given in Figure 8b. Coherence functions determined between the pilot control signal, $u$, and the forcing functions as input into the control loop. They are used as a measure for the statistical validity of the estimated transfer functions and reveal the presence of non-linearities, extraneous noise or the existence of uncorrelated inputs. If the coherence functions is close to a value of one, the behavior captured in the estimated transfer functions is mostly linear behavior.

The coherence function for the disturbance forcing function, $f_d$, indicates mostly linear behavior. Only for higher frequencies non-linearities appear, but this is expected as the signal becomes harder to control. The coherence drops off much faster for the target forcing function, $f_t$, and shows that the task of following this signal is harder than compensating for a disturbance on the pilot’s control signal. This indicates that, overall, participants attend more to the disturbance-rejection when performing the control task. This is also expected, as this relates to the inner control loop that participants have to close in this experiment. Furthermore, the coherence plots indicate that the condition with only roll motion or lateral motion induce more non-linearities for the target forcing function for the middle range of the input frequencies.

**Figure 8:** Properties of the pilot response.
V. Conclusions and recommendations

Summarizing, the conclusions are as follows:

- In the case of combined roll and lateral motion feedback, participants showed a significant improvement in control performance compared to conditions without motion or with partial motion cues. This indicates integration of the roll and lateral motion cues. The same trend is observed for the condition with feedback of roll motion only.

- The control activity is affected similarly as the pilot performance. This indicates that roll angle is used first to increase performance and lateral motion is only useful after the inner stabilization loop feedback is already established.

- The gain of the semi-circular canal perception channel is not affected by the motion conditions, whereas the gain of the otolith perception channel is significantly lower in the combined motion condition. Therefore, this indicates that pilots primarily use cues resulting from roll motion.

- The time delay of the visual perception channel is significantly higher in conditions with motion feedback. This indicates that pilots are actively using the motion feedback.

In future research, focus must be put on more veridical feedback of the motion cues. With the current setup, motion cues had to be scaled considerably in order to be able to perform the task on the simulator. The limiting factor in this case was the combined roll-lateral motion task where cues have to be presented in two degrees of freedom, severely limiting the motion workspace of the parallel Stewart platform. In the future, we envision using the MPI Motion Simulator, an anthropomorphic robot with a large motion range. Additionally, it is foreseen to change the input device allowing for a better control of the device properties and locking of the degrees of freedom that are irrelevant to the task at hand.

References