Axis- plus Content-based Control for Camera Drones: Design and Evaluation of User Interface Concepts

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ABSTRACT

It takes movie camera operators years of professional training to follow an object in an aesthetically pleasing way, both by classical means (boom, slider) and by drones. As this complex task requires a high workload and situation awareness while controlling the camera, an uncluttered and efficient user interface (UI) is preferred. The emergence of mobile devices and motion control devices incorporating automation made touch-based UIs attractive to operators. Much work has already been done on UI adaptation strategies. However, little work is trying to solve the problem of combining manual control and automation within a UI. Especially with a central premise of minimising occlusion and visual clutter in a cinematic context. We, therefore, conducted a first user study (N=15) to evaluate different design alternatives regarding occlusion and preference. Afterwards, we created a functional prototype of the most promising design. To further reduce the occlusion we applied a progressive reduction adaption strategy. We evaluated the influence of different reduction levels on workload, control, creativity support and precision in a second user study (N=24). While we could reduce the clutter, due to our design decisions we found no negative effects affecting the measured variables.

CCS CONCEPTS

- **Human-centered computing → Interface design prototyping**; *Empirical studies in HCI*;

KEYWORDS

User interface, camera motion, motion control, camera drones, content-based control, visual clutter, progressive reduction.

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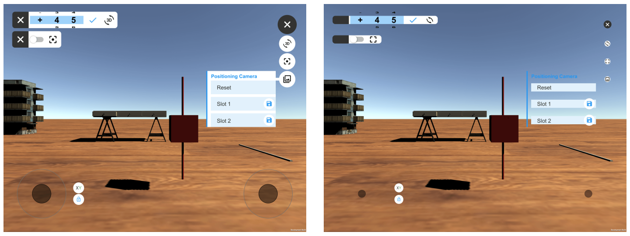
1 INTRODUCTION

Today an enormous amount of images and videos are created and manipulated on mobile devices. Furthermore, mobile devices got adopted in the field of cinematic motion control. Also, drones often use mobile devices to display the live video stream and to control the drone itself. They often use virtual joysticks and combine them with automation features also controlled via touch user interfaces (UI). For example, an on-screen person may be selected, whom the drone then follows automatically. Further, touch-based UIs can also be used to control the settings of movie cameras remotely.

It takes operators years of training to follow an object in an aesthetically pleasing way. As this complex task has a rather high workload and requires to maintain situation awareness during control, an uncluttered and efficient UI is preferred. However, only little is trying to solve the arising problem of combining manual control and automation within a UI. Especially with a central premise of minimising occlusion and visual clutter. Therefore, we believe that addressing this issue is necessary. Touch interfaces in combination with automation are gaining importance due to their general versatility. Furthermore, providing the camera stream and allowing control on the same device is particularly interesting in a mobile usage context, such as movie sets. Therefore, developing and evaluating design concepts that support users and reduce occlusion in the UI will benefit professional and enthusiast users alike.



(a) Baseline of PR **(b) Full reduction level of PR**

Figure 1: Reduction levels

In the example of controlling a drone, a UI with a live stream of the drone's view supports the operator with constant feedback on the framing. We, therefore, opted for a tablet as the main controller. Not only because of its already significant utilisation in the field but also because it allowed us to implement content-based algorithms for controlling the camera motion without sacrificing manual control while having visual feedback. In a first step, we need a menu structure to combine manual control with automation features. As this menu setup may get complex relatively fast, a logical grouping

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of similar features may be better for the operator. Further, unnecessary information should not be displayed at any time to prevent clutter. Moreover, the user interface should be designed to minimise unavoidable occlusion.

Contribution

We wanted to investigate how to design, organise and arrange manual controls as well as automation features of a touch-based camera control interface. The UI should further be designed with the central premise of minimising occlusion and visual clutter in mind. To create a coherent concept, we followed a user-centred design process incorporating two user studies. We first evaluated design alternatives regarding occlusion and preference in a study to identify the most promising alternative (within-subject). This alternative was further improved and tested in a second study (between-groups). In the second study, we took subjective as well as objective measurements to determine the effects of our design decisions. Consequently, this research contributes insights regarding the user interface design of cinematic UIs, which combine manual control and automation and also focus on minimizing occlusion inherent to touch-based UI elements.

2 RELATED WORK

The following paragraphs cover related work regarding interface design, cinematographic vocabulary, camera automation and evaluation methods.

Focusing on user interfaces, much preceding work is being considered essential to the goal of designing minimalistic user interfaces. Maximising screen space is a well-researched area in the field of human-computer interaction (HCI) because often an occlusion-free view is desired. This may be accomplished through methods like hiding controls [12, 13] or reducing their appearance [8]. These concepts will complement the goal of designing a minimalistic UI. We consider the following two concepts especially important: Progressive Disclosure [13] defers rarely used or advanced features to a secondary screen. It, therefore, minimises occlusion by the UI, lowers the learning curve, and prevents errors. Other recent work evaluates the effects of Progressive Reduction [8] as an adaptation strategy for a camera-based cinematographic UI. For elements that cannot be hidden, their visual appearance becomes gradually reduced. Studies indicated that this could be done without a major negative impact up to a certain limit.

Endsley and Kaber [11] proposed a Level of Automation Taxonomy, which describes different levels of division of control between human operator and automation. In the context of cinema motion, we are interested in the levels 1 (manual control) to 4 (shared control). Regarding physical camera motion, specifically automation, many concepts have been published, as there are many desired behaviours of how the camera should react. In many setups, cameras have six degrees of freedom (6DOF) for orientation and pacing, which allows complex sequences to be shot. Therefore the automation of straightforward and complex shots has been gradually advancing [1]. Because our work combines manual camera control with content-based automation, some work of this research field may be used in our prototype. For example, TrackLine [9] allows its operator to specify an intended location in the frame for an incoming, but still off-screen object. As soon as the object reaches this spot on the screen, the camera follows it by keeping it in the same spot in the frame.

The authors compared the automation approach with established techniques such as a software joystick and concluded that this concept lets operators be more efficient while at the same time being more precise. It, therefore, marks a great example of content-based control of camera motion while minimising occlusion and visual clutter.

Besides HCI concepts, a solid basis of explicit cinematographic vocabulary is essential, as the automation features have to be grouped by some logic and described by a discipline-specific terminology [3, 14]. This also counteracts occlusion by countless options and increased workload through a possibly slower navigation process.

Evaluating cinematic user interfaces is not trivial. Researchers have used different metrics to identify various relevant aspects in the past. These can be (among others) the workload that a system provokes [6, 7], the creativity support that it provides [2], the sense of control a user perceives [4] or the precision that a participant can achieve given a narrowly defined cinematic steering task [9].

3 USER STUDY 1: EXPLORING OCCLUSION IN OUR DESIGN ALTERNATIVES

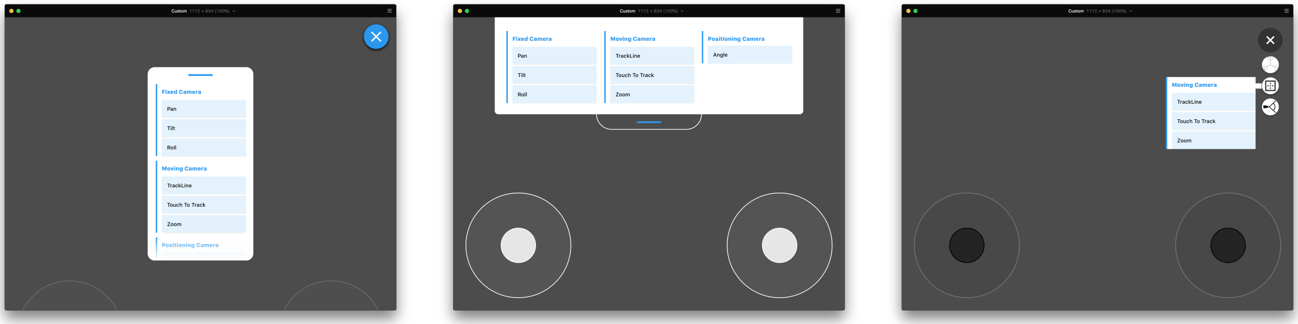
After paper-prototyping five design alternatives, we discarded two and, therefore created three clickable design alternatives (Figure 2) in Framer v102. These featured different menu structures, which shared the premise of minimising occlusion and combining manual control with automation features. The main menu is grouped into three submenus the features of which share the same characteristics regarding the manipulation of the camera. We conducted the first user study to identify the most promising concept regarding occlusion and preference.

3.1 Study Tasks

After 30 seconds of free exploration, the participants were asked to follow our instructions. These included actions such as opening and closing the main menu and its sub-menus, moving a particular dialogue to a specific location on the screen, or adjusting the placement of the TrackLine or toggle position of the joysticks. During the whole time, we instructed participants to pay attention to the occasionally appearing bubbles in the background. As soon as the bubbles appeared, they should search for the green bubble and announce the number it displayed aloud. The bubbles remained visible for 1.5 seconds, as this retention time was suggested by the work of Eng et al. [5] on visual search tasks. We placed all 13 bubbles near points of interest of camera operators.

3.2 Study Design

Hence this study was designed within-subject in a controlled laboratory. We provided three design prototypes to each participant. To prevent ordering effects, we randomised the sequence of design alternatives presented to each participant. All design alternatives featured an animated video clip. It displayed a recording of an aerial



(a) Design A **(b) Design B** **(c) Design C**

Figure 2: Design alternatives (Menu opened)

drone top shot in the background to simulate a consistent distraction and movement, which are likely to appear in cinematic drone operation as well.

3.3 Participants

We recruited 15 participants (3 female) for this user study. The median age was 24, with ages ranging from 21 to 34 years. All of our participants had normal or corrected to normal vision. On a scale from low (0) to high (6), our participants rated their prior experience with tablet devices with 4.87 on average (ranging from 2 to 6). Previous experience with camera control tools averaged at 0.80 (ranging from 0 to 4) on the same scale. One participant was left-handed.

3.4 Procedure

First, we welcomed the participants, gave them a brief introduction to the procedure and handed out consent forms. Having declared consent, they were asked to fill out a demographic questionnaire. Next, we introduced the first design alternative. We asked the participants to carry out the tasks while sitting. After 30 seconds of free exploration time, the participants were asked to carry out instructions until a 2-minute timer expired. Then the second user interface was introduced and the procedure repeated. After the third and last design alternative, a semi-structured interview about perceived occlusion, personal preference, ranking and menu handling followed. To support their memory, we gave them printed screenshots of the three interfaces they interacted with minutes before. At last a short debriefing followed.

3.5 Measurements

Because we wanted to collect data on occlusion objectively and subjectively and on preference explicitly, we implemented a continuous test, which was running while the participants performed the tasks. In a random time interval (6.5 - 10 seconds) bubbles were displayed on top of the video stream but underneath all user interface elements. We asked the participants to tell us the number in the green bubble. We post hoc derived the error rate by matching the provided answers with the correct values stored in our database.

3.6 Data Analysis and Results

To test for statistical significance, we used non-parametric tests (Friedman's ANOVA and Wilcoxon Signed-Rank). To compensate for pairwise comparisons in the posthoc tests we additionally used a Bonferroni correction. With an aspired alpha level of $\alpha = 0.05$ and having three distinct hypotheses, we corrected the alpha level to $\alpha* = 0.0166$ in the posthoc tests. Only after we confirmed significance with Friedman's ANOVA, the Wilcoxon tests were applied. We calculated the median error ratio of every participant, detecting the green bubble and announcing the number inside correctly per design alternative. Resulting in three error ratio medians per participant, one for each design alternative. Therefore the dependent variable was "error ratio in announcing the number in the green bubble correctly", and our independent variable was "design alternative", which consisted of the three groups: *Design A*, *Design B* and *Design C* (Figure 2). Friedman's ANOVA on this data revealed statistically significant differences between the designs. $\chi^2(2) = 6.107$, $p = 0.47190$, $df = 2$, $N = 15$. Post hoc analysis was performed with Wilcoxon signed-rank tests. Through the Bonferroni correction, the resulting significance level was set at $p < 0.0166$. Median (interquartile range) of error ratio for *Design A*, *Design B* and *Design C* were 0.1765 (0.1176 to 0.2778), 0.0833 (0.0588 to 0.2308) and 0.0714

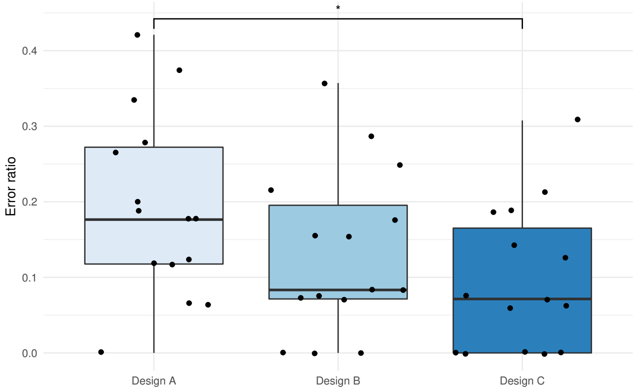


Figure 3: Implicit error ratios regarding occlusion

(0.0000 to 0.2143). There were no significant differences between *Design A* and *Design B* ($Z = -1.363$, $p = 0.172848$) or between *Design B* and *Design C* ($Z = -0, 549$, $p = 0.582920$). Yet, there was a statistically significant reduction in the error ratio between *Design A* and *Design C* ($Z = -2, 418$, $p = 0, 016$). Figure 3 visualizes our findings.

Moreover, we analysed the data from our semi-structured interviews. The participants ranked the design alternatives from first to last. *Design B* and *C* got most votes in the first place, each 6 (*Design A* got 3). In second place *Design B* got 7 votes, *Design A* got 5 and *Design C* 3. Furthermore, in the last place *Design A* got voted seven times, Design B two times and *Design C* six times.

Lastly, 9 participants felt that *Design A* obscured overall most of the stream, the remaining 6 participants, on the other hand, perceived the occlusion by *Design B* as highest. The perception of lowest occlusion by a design alternative was led by *Design C* with 12 votes (*Design A* got 3 and *Design B* 0 votes).

4 USER STUDY 2: EXAMINING THE EFFECTS OF PROGRESSIVE REDUCTION

After the evaluation of our design alternatives in the first user study, we implemented an improved version of the most promising design, *Design C* in Unity 2017.2. The main menu was expandable as in our first user study by clicking the blue action button but gained drag-and-drop functionality to grant the operator freedom concerning the placement within the screen. The virtual right joystick controls rotation; the left joystick controls translation. Furthermore, we improved the main menu icons for clarity and added and replaced some features offered in the main menu to offer a sound feature set. Lastly, the sub-dialogues gained drag-and-drop functionality too.

To further minimise the occlusion by our user interface we implemented a modified version of the adaptation strategy, *Progressive Reduction*, as described in [8]. To determine whether the strategy affected our measurements we decided to use a between-groups design in this study. Consequently, we created three prototypes, a baseline prototype (Figure 1a) which was not affected by progressive reduction at all. The level of reduction used in our first prototype was also used as the starting level in our second prototype. This prototype would additionally reduce over time. We capped progressive reduction at a certain level, to be sufficient on its own for proper operation. This end reduction level (Figure 1b) of our second prototype was used as the start level of our third prototype which would not reduce any further.

4.1 Study Tasks

We designed a set of tasks (total 3) to give the participants a chance of utilising all manual and automation control features.

Task A Similar to the tasks featured in *TrackLine* [9] this task consisted of three different product shot scenarios. During the whole task, we displayed a grid overlay. In sequence, after a short countdown, three cubes entered the screen on the left side from an off-screen location. We instructed the participants to keep the cube each time within the left third of the screen while following the cube and keeping the framing steady. *Cube 1* slowly entered the screen and moved horizontally to the right; the cube reverted its direction two times. *Cube 2* moved at a much faster speed horizontally to the right without any direction changes. Lastly, *Cube 3* followed a lying 8 (similar to an infinity symbol). Therefore this part not only required a translation right-to-left but also up-and-down.

Task B In this task we demanded that the participants occupy in sequence three different positions facing a table within the 3D world. Therefore we hung up three printed screenshots on a wall at eye level as a reference. As soon as they were satisfied with their framing, we logged the position of the camera, and they continued to the second position. The procedure repeated until no time was left or until completing all three still product shots.

Task C Being the most challenging task, *Task C* required the participants to make use of the Advanced Settings to change the translation of the left joystick from the x-axis (left-right) and y-axis (up-down) to x-axis and z-axis (up-down). In this task, the cube entered the screen again from the left-hand-side and moved horizontally to the centre of the screen and stopped for a second. Then the cube moved at a steady pace along the z-axis further away in the direction of the horizon. The participant's task was threefold. At first, we instructed the participant to follow the cube within a certain distance along the z-axis. After completion, we reset the scene, and the participant was instructed to follow the cube again but from a different perspective (Birdseye, 45-degree angle from above). The final task consisted of while following the cube in a birdseye angle orbiting the cube 360 degrees while keeping the cube in the centre of the screen.

4.2 Study Design

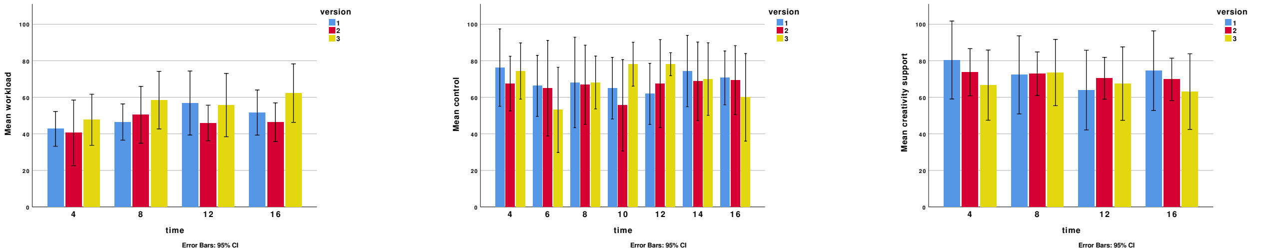
We used a between-groups study design in a controlled laboratory environment; we presented eight participants the no-reduction prototype, another eight the progressive-reduction prototype and the remaining eight the full-reduction one. To prevent ordering effects, we randomised the task order for each participant.

4.3 Participants

We recruited 24 participants (4 female) for this user study. The median age was 23, with ages ranging from 19 to 31 years. All of our participants had normal vision or corrected to normal vision. On a scale from 0 to 6, our participants rated their prior experience with tablet devices a 4.58 on average (ranging from 1 to 6). Prior experience with camera control tools averaged at 1.42 (ranging from 0 to 5). One participant was left-handed.

4.4 Procedure

First, we welcomed the participants, gave them a brief introduction to the procedure and handed out consent forms. Having declared consent, they were asked to fill out a demographic questionnaire. Next, we granted a 4-minute guided exploration phase. We asked the participants to carry out the tasks while standing. Thereby we mimicked the context of on-set usage. After the exploration phase, the participants filled out a questionnaire rating their perceived workload, sense of control and creativity support for the first time. Then the first task was carried out within a 4-minute window. After



(a) Mean of workload by group by time **(b) Mean of sense of control by group by time** **(c) Mean of creativity support by group by time**

Figure 4: Clustered bar charts regarding workload, control and creativity support (version 1 = baseline, version 2 = progressive reduction, version 3 = full reduction level)

2 minutes we collected a perceived sense of control rating, and at the 4-minute mark, another extended NASA-TLX followed. Then the second task was introduced and the procedure repeated. After the third and last task, a short questionnaire about conceived occlusion and strategy of usage followed. A short debriefing concluded the second user study.

4.5 Measurements

We utilised an extended version of the NASA-TLX [6] to collect quantified data at the 4-, 8-, 12- and 16-minute mark. The questionnaire measured workload, sense of control and creativity support. The Task-Load Index (TLX) from NASA [6] measured the subjective amount of workload experienced by the participants. The sense of control scale by Dong et al. [4] adapted to a 20-point rating scale measured perceived control. Lastly, Creativity Support Index by Cherry et al. [2], limited to exploration, motivation and enjoyment dimensions measured the creativity support. At the 6-, 10- and 14-minute mark, we also collected the perceived control [4] separately. This evaluation approach was informed by the work of Hoesl et al. [10]. In addition, we collected data concerning precision of all three adopted positions in Task B, which we later used to calculate the offset to the target position.

4.6 Data Analysis and Results

To analyse our data and test for statistical significance, we applied a two-way ANOVA. Thus we changed the scale of the workload from 0-600 to 0-100 and the scale of creativity support from 0-300 to 0-100. Therefore the scales of our extended NASA-TLX on workload, control and creativity support were the same. We conducted a two-way ANOVA to examine the effect of the reduction of the user interface and time on workload. There was no statistical interaction between the effects of user interface reduction and time on workload, $F(6, 84) = 0.417$, $p = 0.866$. We, also, conducted a two-way ANOVA to examine the effect of reduction of the interface and time on the sense of control. There was no statistical interaction between the effects of user interface reduction and time on the sense of control, $F(12, 147) = 0.706$, $p = 0.744$. Lastly, we conducted a two-way ANOVA to examine the effect of reduction of the interface and time on creativity support. There was no statistical interaction between the effects of the user interface reduction and time on creativity support, $F(6, 84) = 0.351$, $p = 0.907$. We visualised these findings in Figure 4. Because we could not confirm significance with the two-way ANOVA tests within workload, control and creativity support, we did not apply any further posthoc tests. We also conducted a two-way ANOVA to examine the effects of user interface reduction and the three product shot positions of *Task B* on precision. There was no statistical interaction between the effects of the user interface reduction and position on precision, $F(4, 63) = 0.463$, $p = 0.762$.

5 DISCUSSION AND FUTURE WORK

Our goal was to design and evaluate user interfaces for manual camera control features as well as automation features in respect of drone control in cinematic camera motion. Additionally, our central premise consisted of reducing occlusion by the user interface. At first, we designed three alternative designs which thrived for minimal occlusion. An implementation as click-able prototypes followed. In conclusion, we were able to find a UI which was reasonably and minimally designed. We found a significant difference between *Design A* and *C* in implicit occlusion in favour of *Design C*. Our data regarding explicit occlusion correlates with the implicit findings. Even though *Design B* and *C* tied at the first rank in personal preference within the participants, we chose *Design C* to build upon, because throughout our user study *Design C* created less occlusion. As a result, we implemented a revised version of *Design C* as a functional prototype and evaluated it in our second User Study.

Following our second user study, we concluded that the progressive reduction element was unnecessary in our case. This outcome does not imply that this technique does not yield benefits in general; instead, it demonstrates that within our limited time frame we worked with a formulated but limited feature set. Within this short period, we were unable to determine significant differences. Therefore the reason may be our sample size or the fact, that we capped the progressive reduction at a certain level, which we assumed did not reduce the sense of control. In our case, the full reduction level turned out to be already feasible.

An apparent limitation may be the absence of a status quo baseline, with which we could compare our collected data. However, the way in which we obtained data is easy to implement and thus reproducible without great effort. In a further study, it would be possible to get a state of the art baseline by utilising available SDKs (e.g. by DJI) and test it in a more realistic environment than the virtual one, because our approach is not limited to an entirely virtual environment.

Evidently further UI questions matter, such as searching. We did not investigate this issue, as it should be tested individually. Another question arises, as to how the menu concept behaves and scales to more menu options. Because the design of menus forms a field of research of its own, further studies should examine the expression of a more feature rich system.

6 CONCLUSION

We designed and evaluated touch-based user interfaces, which combine manual controls with automation features regarding camera motion. These interface concepts can be used for camera drones, but are general enough to be transferable to classic camera motions using a boom or slider. The importance of this research lies in the emergence and preference of touch-based interfaces, as well as on the fact that only little scientific work surfaced researching the user interfaces combining manual controls with automation in the context of cinematography. Because operating a camera demands situation awareness an uncluttered and minimal user interface is preferred. We, therefore, conducted this research with the central premise of minimising occlusion and visual clutter. As a result of our design and evaluation process, we present a functional user interface with regards to our premise as well as our research question. This research attributes to the context of human-computer interaction, in particular to the interaction in the field of cinematography. Because to the best of our knowledge, little research has yet surfaced regarding user touch interfaces combing manual control and automation features in the cinema motion context; we suggest that further research, should be conducted since this scope of application is getting gradually broader usage in the professional cinematography business as well as on consumer level.

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