Evaluating the use of Shadow Widgets and Rotation Controllers in Three-Dimensional Modelling Interfaces

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1. PROJECT DESCRIPTION

Three-Dimensional (3D) user interfaces (UIs) are interfaces that facilitate the manipulation and viewing of 3D shapes and scenes. These interfaces are relied upon by many 3D animation and modelling packages for authoring and displaying 3D scenes. They are found in many applications, including those used to create virtual environments such as 3DSMax [Autodesk 2015] and view medical scan results [Bade, Ritter, and Preim 2005]. See Figure 1 for an example of a 3DUI.

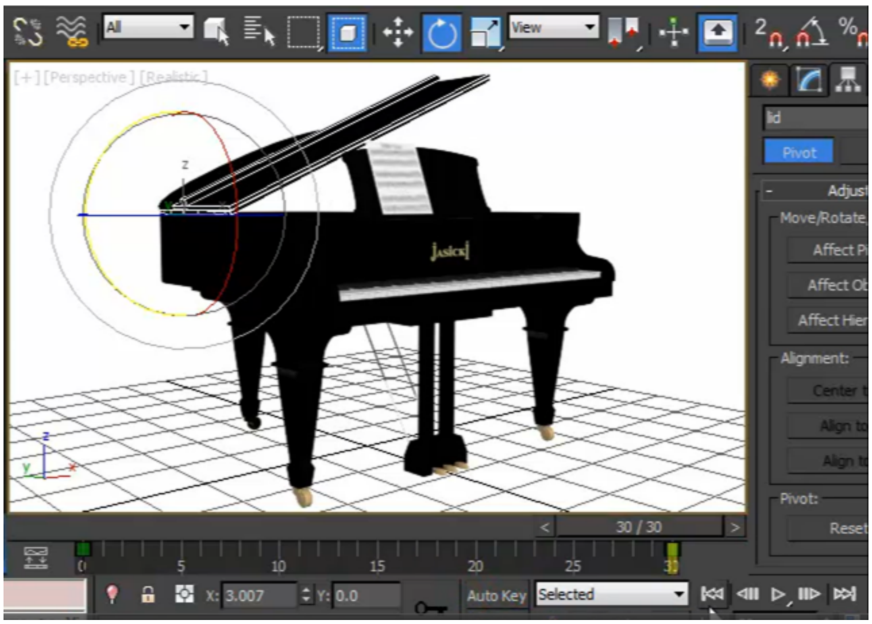

Fig 1: Illustration of a Virtual Trackball rotation method as used in 3DSMax [Autodesk 2015]

One of the main challenges facing the UI design of 3D modelling packages is the limitation of the physical technology. These programs are most prevalently used on desktop or laptop machines, which limits the user to 2D input (mouse) and output (display screen) devices to interact with the 3D scene [Herndon et al. 1992; Smith, Salzman, and Stuerzlinger 2001; Oh and Stuerzlinger 2005]. While there is evidence to suggest that 3D input or output devices can be more effective in certain 3D scene manipulation tasks [Bowman et al. 2004], the current standard in industry is still 2D input and output devices [Jáuregui, Argelaguet, and Lecuyer 2012]. Research into improving this specific area of 3DUI could have a significant impact on the industry.

Many alternative tools for common 3D tasks, such as positioning and orienting a model in a 3D scene, have been proposed in the literature specifically for 2D input and output devices. However, there has been surprisingly little evaluation of their relative effectiveness [Bowman et al. 2004; Jankowski and Hachet 2013]. Even when evaluations are completed, these tend to be narrowly focused on performance metrics [Henriksen, Sporring, and Hornbæk 2004]. Previous evaluations have focussed on how quickly and accurately a subject has been able to complete a task. This ignores important usability metrics that impact a user's ability to use the interface. These include metrics such as user comfort, learnability of the interface and the presence of the user in the virtual environment [Bowman et al. 2004]. These gaps in the literature highlight the potential for improving the usability of the 3D scene manipulation present in current 3D modelling systems. They also show a definite lack of formal evaluations to determine empirical relative effectiveness between 3D UI techniques in this area.

In this project, we will be evaluating the effectiveness of two separate 3D modelling techniques for 2D input and output systems. This will be done in two completely distinct, but similarly designed studies. O'Donovan will focus on critically evaluating and comparing the innovative "shadowbox" interface [Herndon et al. 1992; Zeleznik, Herndon, and Hughes 2007] with the current 3D modelling interface convention, namely an interface with a perspective and three orthographic views. Rybicki will be evaluating 2-4 state of the art 3D rotation interaction techniques. Our evaluations will be done through user experimentation. We will measure both the usability and task performance metrics in order to get a holistic view of each interface or interaction technique.

2. PROBLEM STATEMENT

The overarching aim of the project is to determine the efficacy of a number of 3D modeling interfaces through experimental evaluation. To accomplish this, we must build polished versions of these interfaces to evaluate and compare them effectively. Furthermore, we must design sound experiments that account for confounding factors that have affected past research.

When testing the comparative performance of 3D modeling interfaces, we must determine the appropriate task performance and user preference metrics to measure. Previous experimentation has focused on performance metrics on simple tasks. We will be investigating what complexity of tasks is appropriate and what performance metrics to gather. Additionally, we will be investigating what usability metrics are useful in determining user experience of these interfaces. Our preliminary research has indicated several possible candidates. For example, Bowman et. al. [2004] suggest that you should be testing 3D UIs for learnability, presence and user comfort. We have also seen previous studies use standard Human Computer Interface (HCI) questionnaires [Lewis 1995]. Ultimately, we will use this to ensure our experimental evaluations yield results that allow predictions of real world use of these interfaces.

Using these metrics, we will be attempting to answer two research questions. O'Donovan's study will answer the question: is the shadowbox interface an improvement over the existing 3D modeling interface convention of 3 orthogonal and one perspective view. Rybicki will be addressing the question: which state of the art mouse based 3D rotation interface performs best and is the most usable. These questions will be addressed by performing user experiments measuring the task performance and usability metrics we determined were effective.

3. PROCEDURES AND METHODS

Due to the nature of both studies carried out for this project, the procedures and methods will be very similar. The main difference between the studies is the number of experimental evaluations carried out. Currently, O'Donovan's study will compare two interfaces, whereas part of Rybicki's project is to determine which interfaces to compare, so the quantity of these is not yet confirmed.

3.1 Research Design

In both studies we directly manipulate the 3D UI the participants use to execute a certain number of tasks and experimentally measure the effect this has on the participants' task performance and user preference metrics. We have chosen to implement a repeated-measures experimental design, as we hope to measure the difference between the participants' scores for both types of metrics and quantitatively compare these.

We identify the independent variables as the type of 3D interface the participants are instructed to use, as this is what we will vary during the experiments. Our dependent variables are the task performance and user preference metrics we will measure. We have not yet identified exactly which metrics we will use. Related studies have measured speed and accuracy of task completion, as well as the presence and comfort experienced while using the interface.

Due to the subjective nature of HCI, it is important to consider the qualitative evaluations of a UI as well. This can give another dimension to the quantitative data by helping interpret the results more accurately [Jankowski and Hachet 2013]. We will collect this by asking a few open-ended questions to find out more about how the participants experience the process.

In our experiments we will have to control for the impact of extraneous variables on our dependent variables. The order and type of tasks carried out by participants for each study will remain consistent throughout the experiments. We will also only admit participants into our studies that fall within the average range of 3D interaction ability measured by the Mental Rotations Test (MRT) [Rizzo et al. 2005]. Furthermore, we will balance the participants according to gender, as studies have shown that males have significantly higher visuospatial abilities than females [Tory and Möller 2002; Hugdahl, Thomsen, and Ersland 2006]. Other aspects, such as a participant's experience with 3DUIs, will be recorded in a pre-experiment questionnaire and controlled for using statistical methods.

3.2 Participant Sampling

The ideal goal for participant sampling is to have a fully representative group of participants that allow us to generalize our results without reservations. However, in an experimental setting finding a large enough randomly distributed set of participants is expensive and time consuming. We have therefore opted to use the convenience sampling method to find participants.

We intend on finding enough participants for our experiments to have significant statistical power, split evenly by gender. We forsee this to be around 30 participants. These participants will be undergraduate students at the University of Cape Town. We are not interested in collecting any other demographics.

3.3 Materials and Procedure

This section briefly identifies how we aim to approach our studies for this project. As a number of our independent variables have not yet been strictly defined, we outline a loose procedure we aim to follow, which will dictate the overall study methodology.

Both studies will be carried out in a very similar way, so we intend on using the same basic procedure outline. The project's aim is to quantitatively evaluate performance and usability of various 3DUIs. To evaluate the interfaces, we will have subjects perform various tasks that are similar to real-world tasks faced in 3D modelling software. The tasks outlined must be long enough to be representative of our real-world usage of the interfaces. They must also be complex enough to allow for the testing of performance and usability metrics we identify. We must also ensure that our selection of the tasks does not induce participant fatigue. This will acomplished by limiting their number and length. These tasks could include activities such as orientation matching, where participants manipulate a model to match the view of an example given, and inspection, where participants have to identify properties of a given model by rotating it.

During our final experiments we will have to ensure a standardised environment for all participants. This includes measures such as running the experiments at the same time of day for each participant group and ensuring that all subjects use equivalent computing equipment. We also need to have a small number of participants in each experiment to reduce the risk of interaction effects between them. To control for learning effects with our interfaces, we will be using a latin square experiment construction which varies the order that the interfaces are tested.

Before we carry out our final stage of testing, we will dedicate time to run pilot experiments to ensure that there are no usability issues in the instructions, the interfaces tested, or testing environment. We intend on doing this three times, and incorporating feedback received to ensure that the experiments run smoothley with our actual participants.

4. ETHICAL, PROFESSIONAL AND LEGAL ISSUES

This project relies heavily on the user-evaluation results gained from human participants. Thus, we need to account for potential ethical issues relating to our participants. Our research does not intentionally have any effect on the physical, emotional or mental health of our participants. However, we must ensure that they are aware of what their participation entails. They must understand their role in the study, namely that it is voluntary and they can remove themselves at any time. We plan to pay our participants a nominal amount, and as such we must ensure that this is not a deciding factor in their involvement. We will do this by issuing an informed consent form which outlines the above-mentioned requirements. We will ensure we are conducting our experiments in accordance with the university's ethics policy by applying for ethics clearance from the Science Faculty

5. RELATED WORK

5.1 Current and Future 3D Scene Manipulation Evaluation Work

We found five publications that empirically evaluate mouse-based 3D scene manipulations in various scenarios. All required participants to select, position, resize, and/or rotate objects using the mouse-based system. They then evaluated the participant task performance on speed and/or accuracy. Most of the studies evaluated user preference metrics as well, with the exception of Hubona, Shirah and Jennings [2004], who focused purely on a qualitative analysis.

These evaluations all attempted to practice a rigorous scientific method, however they have certain weaknesses in their choice of participants. Firstly, the sample sizes for the majority of these experiments are quite low, with Oh and Stuerzlinger [2005] and Jáuregui, Argelaguet, and Lecuyer [2012] having only 10 and 12 participants respectively. Such a small sample size is useful for a pilot study to show that a research area shows promise, but the results cannot be used to infer anything about the general population. The second issue with the method of participant selection in these studies is the lack of standardization. Only Rizzo et al. [2005] intentionally balanced the genders in each experiment they conducted. They were also the only study we found that acknowledged and accounted for the effects of varying educational and cultural backgrounds. Rizzo et al. [2005] found that male and female performance in 3D interaction tasks are not significantly different, which means that the gender imbalances in the other studies may not have affected the results at all. However, it would have been useful to have data from the other studies supporting this claim.

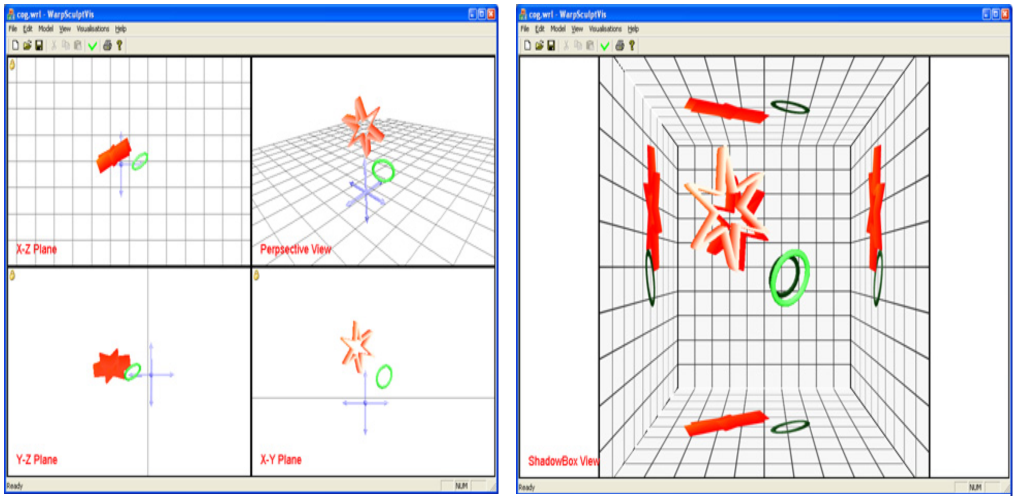

Fig 2: Conventional interface (left) and "shadowbox" interface (right) mockup

These studies are all helpful in understanding the problems faced by 3D UI researchers today. Due to their vastly different participant groups and overall research focus, their results are largely incomparable. However, there are two main findings that are applicable to future 3D UI research specifically in the area of improving the interfaces used by modeling software:

- Users find it difficult to perceive depth in 3D virtual environments. Using effects drawn from real-world interactions such as shadows and occlusion are significantly helpful reducing inaccurate depth perception [Hubona, Shirah, and Jennings 2004; Oh and Stuerzlinger 2005; Jáuregui, Argelaguet, and Lecuyer 2012].
- Interactions confined to a 2D plane are very helpful in ensuring quick, accurate selection and ordering tasks [Smith, Salzmann, and Stuerzlinger 2001].

Research on incorporating these two topics has already been done by researchers at Brown University [Herndon et al. 1992; Zeleznik, Herndon, and Hughes 2007]. They proposed a new interface style where the 3D scene is enclosed by a box, and the 3D object's orthogonal projections are displayed on the walls of the box (see Figure 1). These projections are called shadow widgets and can be manipulated along their 2D projected plane. Thus the user can manipulate both the 3D objects in a more conventional manner, as well as its 2D shadow projections.

5.2 Evaluation of 3D Rotation Interfaces

Mountford, and Sellen [1998], the first we found, was used as the prototype for many of the experiments that followed. They had users perform a simple orientation matching task - users had to match the orientation of a house with another on screen. They measured how quickly and accurately users performed these rotations, giving users feedback on how accurately they performed each task. They then quizzed users informally about how they felt about each method.

The three experiments performed after this – Jacob and Olivier [1995], Hinckley et al. [1997] and Partala [1999] - all used the same simple orientation matching tasks.

They did perform more formal usability analysis, with Jacob et al. capturing individual metrics while Hinckley et al. [1997] and Partala [1999] focusing purely on comparative usability. Zhao, Shuralyov, and Stuerzlinger [2011], published much later, collected more usability metrics but also had users perform similar orientation matching tasks. They used more complex rotations for their tasks but used simple models like the other studies.

Henriksen, Sporring, and Hornbæk [2004] analysed the first four studies done on rotation, from Chen, Mountford, and Sellen [1998], to Partala [1999], and found that they all shared similar flaws. They all biased users towards accuracy over speed. They all used the same task (orientation matching) and made this task much more simple than it would be in the real world. They only recorded limited usability information and did not do so comprehensively. As a response to this, Bade, Ritter, and Preim (2005) performed a study, which had users perform inspection tasks (user had to rotate a model to find particular features) on complex geometric objects. Unlike the other studies, users were told to prioritise speed over accuracy. Similar to the research on general scene manipulation, studies tended to have small sample sizes and not control for effects such as gender.

6. ANTICIPATED OUTCOMES

6.1 Systems Produced

We plan to produce a total of four to six 3D modelling interfaces. This includes an implementation of the Shadowbox interface, a comparable 3D interface to test the Shadowbox interface against and two to four state of the art 3D rotation interfaces. These interfaces will be designed with the minimal functionality required for the experimental evaluations. This means each interface will be able to: display the data required for a subject to complete a 3D rotation and translation task, enable a user to complete such a task in a virtual environment, and output logging data capturing how well a user performed that task. These interfaces will be designed using web technologies, including WebGL, to make them easy to deploy onto the testing computers.

As the interfaces are intentionally feature limited, the challenges for creating them are mainly low level and technical. While WebGL rendering in browsers is sophisticated enough to sustain these projects the ecosystem around this technology is still maturing. This means that we will potentially have to implement low level graphics and input logic. Such implementations are often complex and as such we anticipate that this will be the largest hurdle for system design in this project.

Another more minor challenge for the interface is the logging of user behaviour data. As we want to be able to assess how well a user is able to perform tasks using our interface, we will be collecting various metrics on their usage of it. This includes not only the task performance data, but the individual commands they issue. Having our interface process the hundreds of commands a user inputs, and output it a way that allows us to analyse it, will be a minor challenge we have to overcome.

We have decided to not implement these interfaces as plugins in existing 3D modelling systems. These systems are highly complex and incorporate a large number of features that could cause confusion for our participants and make it harder to analyse the effects of our interfaces. Additionally our systems are intentionally feature limited. Thus, we are confident that it would take more development time to learn how to integrate with an existing software system than to develop standalone implementations ourselves.

6.2 Expected Impact of the Project

We expect two major outputs from this project. The first are the systems outlined above. The other major output is the results of the research itself. We expect that we will be show that the Shadowbox interface is more usable than a comparable 3D interface. We also expect to determine which state of the art 3D rotation interface, out of those we are testing, is most usable.

Both of these findings will impact the design of 3D interfaces. Since the Shadowbox interface has not been experimentally verified, our experiments will be the first evaluation of its usability. Despite the previous evaluations of 3D rotation interfaces, there is no evidence suggesting which is most usable for real life tasks. If we find that Shadowbox outperforms a comparable interface and that one 3D rotation interface is most usable, then we would be able to improve the usability of existing 3D modelling interfaces. This would improve the user experience for users using these interfaces. Practically, this would mean lowering the amount time taken to complete tasks using these interfaces, increasing the accuracy of the tasks completed, and increasing user satisfaction while completing these tasks. As previously mentioned, these tasks include important applications such as the construction of virtual worlds or the viewing of 3D medical scans.

6.3 Success Factors

This project will have succeeded if we are able to complete the major outputs outlined in the previous section: the four to six 3D interfaces as well as an experimental evaluation assessing them.

The 3D systems we produce are important because they enable us to compare interface specifications in our experiments. We can therefore assess the success of these systems by examining whether they have the functionality and quality required to allow for an effective experimental evaluation. In terms of functionality, we consider an interface a success if it is able to manipulate objects, display the required information in a test to the user and record how a user accomplishes a task. In order for the experiments to be valid, these interfaces have to be of comparable quality to each other and real world interfaces. As such, we can judge a system's quality by whether it is as polished as the corresponding component of a comparable real world interface such as 3DSMax [Autodesk 2015] as well as being of comparable quality to the other correpsonding interfaces in the study. This will be done by submitting our interfaces for a formal heuristic evaluation with local HCI experts.

We deem our studies successful, if we are able to complete them in line with our experimental design. Our experimental design will be completed in colloboration with both a Computer Science and Psychology supervisors and we are confident that any experiment that fulfils this design will be of high quality.

7. PROJECT PLAN

This section identifies some important organizational aspects of carrying out such a large-scale project. We critically discuss these and how we plan to address them throughout the project life span.

7.1 Risks

Name	Likelihood	Impact	Priority for Management
1. Unable to complete interfaces to required level of quality.	Possible	Catastrophic	1
2. Insufficient number of participants want to participate in study.	Unlikely	Critical	2
3. Software or experimental design has flaw that harms experiment's results.	Unlikely	Moderate	3
4. Results obtained are not statistically significant.	Possible	Marginal	4
5. Group member drops out of honours.	Rare	Negligible	5

Risk 1: Unable to complete interfaces
Description: Due to time pressure or lack of expertise, we are unable to complete the interfaces to a reasonable degree of quality.
Mitigation: We are mitigating this by adopting an Agile approach, developing many iterations of the software early in the process, aiming to complete them before the experiment begins.
Management: If we do not complete these designs, we will use existing 3D interfaces that implement the aspects desired rather than using those we have developed.

Risk 2: Insufficient number of participants
Description: We are unable to recruit a sufficient number of subjects to participate in our experiment from the student population.
Mitigation: In our timeline, we have budgeted large amounts of time dedicated to just recruiting subjects.
Management: We will extend our search off of campus for participants, or adapt our experimental design to allow for remote testing.

Risk 3: Software or experimental design is flawed
Description: During the experiments, we find that there is a problem with our experimental design or software produced that causes our results to be affected.
Mitigation: We have scheduled a pilot study to test our designs. We have also scheduled our experimentation long before any related milestones, giving us time to conduct another one if needed.
Management: We will rerun the experiment, fixing any problems found.

Risk 4: Results are not statistically significant
Description: The results we obtain do not show any difference between the tested methods.

Mitigation: We will be powering our experiment to detect reasonably small differences.
Management: If we do not detect any significant differences, we see this as an indication that at this level of accuracy there is no difference between the interfaces.

Risk 5: Group member drops out of honours
Description: O'Donovan gets offered the job of her dreams or Rybicki's modelling career finally picks up. This causes them to drop out of the course.
Mitigation: We both share a large group of friends and are susceptible to guilt. The potential shame and guilt tripping should motivate both to stay.
Management: As the projects are very loosely coupled, one member dropping out does not affect the progress of the other.

7.2 Timeline, Deliverables and Milestones

We compiled a Gantt chart, attached in Appendix A, to illustrate the timeline of our deliverables and milestones for the duration of the project. Each deliverable is structured to be completed before each of the associated milestones, marked as "DEADLINE" on the Gantt chart. As some deliverables span multiple milestones, we omitted certain links where the relationship between deliverable and milestone was clear. Below we sketch out the major deliverables.

Draft Experiment Construction: Create a draft version of the experimental methods planned to be used. This must be done in enough detail to support starting the ethics application and the 3D interfaces.

Write Ethics Application, Revise Project Proposal and Web Presence Plan: For clarity on the diagram, as there is no dependencies between the three deliverables, we grouped them together. This deliverable group includes writing the application to undertake human experiments (ethics application) and working towards two milestones (revising the project proposal and writing the plan for web presence).

Wait for Ethics Approval: time allocated to wait for ethics approval, derived from the maximum time allocated on their form. This, while not a deliverable, is done to indicate that no experimentation can start until this has completed.

Design V1 of System Required for Testing: Design the 3D interfaces required to complete the experiments. This was devoted its own concentrated block to allow for a number of iterations to be done as per our risk management strategy.

Write up Experimental Design, Materials Required for Experiment: Complete a formal write up of the experimental design suitable for inclusion in the report. Additionally, write up all the materials required to be present during the experiment.

Recruit Participants for Pilot Study and Recruit Participants for Final Study: Find participants qualified and willing to join our studies. This was allocated its own time as per our risk management strategy.

Conduct Pilot Study and Process Results of Pilot Study, Run final Experiments, and Process results of Experiments: Run the experimental evaluations of the methods. These require us to be at the experiments in person as facilitators, and as such will require its own time blocked out. We have also separated the running of the final experiment from the processing of its results to show that we will have completed the experiments by the time the associated milestones are required to be completed.

Design of V1.1 of Systems (Response to Pilot Problems): This deliverable is focussed on fixing any bugs identified during the pilot experiments. This is to ensure that the final experiments go smoothly.

Write Background/Theory Chapter, Write Final Paper, Create Poster, Website and Write Reflection Papers: Complete the work required for these milestones.

7.3 Work Allocation

Each member of the project will be conducting their own independent evaluation. This means each member has to create at least two 3D modeling interfaces for testing, conduct their own experiment and analyse their results. Common work, such as intermediary handins and experimental design, will be shared equally.

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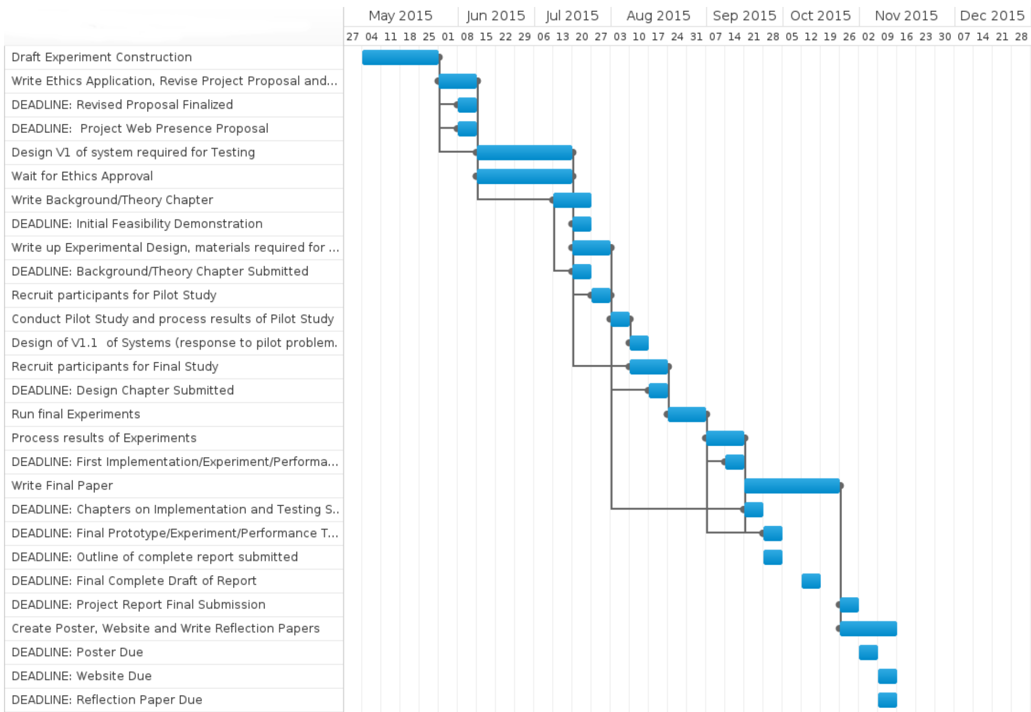
8. APPENDIX A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Draft Experiment Construction
Write Ethics Application, Revise Project Proposal and...
DEADLINE: Revised Proposal Finalized
DEADLINE: Project Web Presence Proposal
Design V1 of system required for Testing
Wait for Ethics Approval
Write Background/Theory Chapter
DEADLINE: Initial Feasibility Demonstration
Write up Experimental Design, materials required for ...
DEADLINE: Background/Theory Chapter Submitted
Recruit participants for Pilot Study
Conduct Pilot Study and process results of Pilot Study
Design of V1.1 of Systems (response to pilot problem.
Recruit participants for Final Study
DEADLINE: Design Chapter Submitted
Run final Experiments
Process results of Experiments
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