A cooperative approach to the design of an Operator Control Unit for a semi-autonomous grit-blasting robot

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Abstract

Due to the diverse range of applications that robots cover today, Human Robot Interaction interface design has become an equally diverse area. This diverse area is characterised by the different types of end users that make use of the robots. For robots to be useful to end users their needs have to be well understood by the robotics development teams. One approach that facilitates understanding the end users needs is Cooperative Design. This paper presents the results of a study that took a Cooperative Design approach to the design and development of a robotic Operator Control Unit. The results presented here demonstrate that end users involved in the cooperative design approach thought it added important value to the design outcome, that they enjoyed the process and that it helped build interpersonal relationships within the development team.

1 Introduction

Interface design for Human Robot Interaction (HRI) has its roots in the field of robotics engineering. This is due to the fact the engineers designing the robots also designed the interfaces through which their robots were to be interacted with. This approach was adequate as long as robotics engineers were doing the programming or teaching of the tasks to be carried out by the robots. In other words there was no need for operating interfaces being operated by engineers or technicians to cater for a broader user group that did not have the knowledge and skill to program and control robots.

Today the areas in which robots are being implemented are diverse and include industrial robots (e.g. for welding), professional service robots (e.g. for Urban Search And Rescue) and personal service robots (e.g. for vacuum cleaning). Different areas of application demand different modes of operation and different user interfaces to allow users to interact with robots. Interfaces for industrial robots tend to differ from professional service robots, which in turn differ from that for personal service robots [Thrun, 2004]. The user interfaces differ because the needs of the users operating the robots are different depending on the area of application. These different areas bring with them a diverse group of users that need to be able to interact with robots efficiently and safely.

For example robots designed to assist people with their work, such as remote controlled Urban Search And Rescue robots or robotic vacuum cleaners have two very different areas of application. In both cases the user will want to start using the robot as quickly as possible therefore the device and/or interface through which the user interacts with the robot needs to make sense to user and be, within reason, easy to learn. Because the areas of application are so diverse it is impossible for robotics engineers to have first hand knowledge of all the user groups for which they are designing the robots. Therefore engineers working in HRI must take an approach that considers the user group they are designing for as early on in the project as possible [Adams, 2005] to ensure the user interface makes as much sense as possible to the end users.

2 Relevant approaches

In the design of products, such as robotic systems, approaches that consider the end users needs to be of paramount importance are User Centered Design (UCD) and Cooperative Design (Co-Design) [Sanders and Stappers, 2008].

Regardless of the approach taken (either UCD or Co-Design) the design process doesn't change. The design process can be described as the path that is followed by the engineer in order to complete a project. The design process can be broken down into four stages:

1) Research
2) Concept development
3) Detailing
4) Implementation

UCD approach

During UCD the user is viewed as a *subject* [Sanders and Stappers, 2008] and the engineer controls all

four stages of the design process. The central aspect of UCD is that end users are considered research subjects that provide data. The design work is then done by the engineer without direct input from any end user. Many in HRI have utilised UCD approaches to solve various design problems of robotic systems [Mast et al., 2012; Burke et al., 2004; Casper and Murphy, 2003].

Co-Design approach

During a Co-Design approach the role of the engineer changes compared to that in UCD. The most notable difference is that engineers no longer make high level design decisions themselves but rather rely on direct input from end users. However in terms of the design process the four stages remain the same. E. Sanders and P. Stappers use the term Co-Design to *"… refer to the creativity of designers and people not trained in design working together in the design development process"* [2008]. This development process happens at the beginning of the design project during research (Stage 1) and particularly during concept development (Stage 2). During Stage 2 the engineer no longer makes high-level design decisions him or herself but rather will rely on the expertise of end users. This means that the engineer needs to take on the role of a mediator while designing cooperatively with end users [Manzini and Rizzo, 2011]. Although Co-Design approaches are not yet widely accepted in HRI there are studies being conducted such as one by C. Bogdan et al. that investigated cooperatively designing a robotic shopping trolley [2009]. This is not only the case in HRI. In other areas of product development such as Industrial Design, Co-Design approaches are not yet widely accepted. One reason that it has taken Co-Design so long to have an impact is that it has been seen as academic endeavor with little or no relevance for the competitive marketplace [Sanders and Stappers, 2008]. In many parts of industry, investment in research is looked upon as a non-obvious step, investment in user studies a big and expensive step, and user participation a radical step into the unknown [2008].

UCD or Co-Design?

The two approaches are utilized for different reasons.

UCD is particularly useful when designing products that will be used by thousands of users. Because such products need to appeal to many users the engineer designing the product needs data that covers a large spectrum of users. A UCD approach facilitates this because it allows the engineer to control the amount and type of end user data that is included in the project.

On the other hand a Co-Design approach can be useful in real-life work environments where robotic technology is being introduced for the first time. In these situations users that will be required to work with the newly introduced robots may feel threatened by the new technology and even fear loss of employment. Taking a Co-Design approach, by including all project stakeholders such as management personnel, workers and engineers in the design process, can help reduce workers fears of being replaced by robots. More importantly Co-Design can be particularly useful when the user groups' requirements are highly specific. This could be due to a work site being unique or the tasks to be completed being professionally specialised. Examples are site specific infrastructure maintenance, patient rehabilitation and robot assisted living in aged care. By asking users, that are familiar with a specific work environment and work tasks, to join in on the design process user friendly results can be achieved.

3 Aim and method

The primary aim of this research was to investigate if participants participating in a Co-Design approach thought the approach was of value to them or not. An additional aim was to investigate if a Co-Design approach would affect the attitudes of participants towards a newly introduced robotic system, which they would be required to operate. To achieve this a real-life project was selected as a case study and a Co-Design approach devised to suit the project.

To learn if participants thought the Co-Design approach was of value to them or not they were interviewed one-on-one to form a post-study impression. To measure if there was a change in participants' attitudes a pre-study impression was also conducted and compared to the post-study impression results (see Section 4). All data collected was qualitative.

4 Case study

The project selected as the study needed to full fill the following requirements:

1) Be a real-life project.
2) Have a site specific work environment.
3) Involve the design of an HRI device.
4) Be new to robotics technology.

The selected project was the design, development and implementation of a robotic Operator Control Unit (OCU). This OCU was designed to control a semi-autonomous robotic Grit-blasting Assistive Device (GAD) that is to be deployed on the Sydney Harbour Bridge (SHB). The purpose of the SHB GAD is to remove old paint and rust from the Harbour Bridge steel structure by blasting it with grit [Paul et al., 2010]. The development of the SHB GAD, including its OCU, is a real-life joint project between Roads and Maritime Services (RMS) in NSW Australia and the University of Technology Sydney's (UTS) Centre for Autonomous Systems [Liu et al., 2008]. The project was chosen as the study because it was a real-life project (req. 1.) and is to be used by a group of ten users on the Sydney Harbour Bridge (req. 2.) who had no previous experience

with robotic systems (req. 4.). This brought with it the concern of RMS management that grit-blasters might fear loss of employment once introduced to the concept of the SHB GAD. The study was conducted by designing and developing the OCU (req. 3.) cooperatively with five of the ten users who are all employees of RMS.

4.1 Case study background

The predominant motivation for initiating the SHB GAD project was to reduce health risks to RMS workers who are responsible for the task of removing old paint and rust from the Sydney Harbour Bridge. Workers have to not only spend long periods of time handling forces of 100N and above [Joode et al., 2004] but also need to protect themselves from the dust containing hazardous chemicals such as red lead and asbestos. This led to the development of enabling methodologies and system development of a Grit-blasting Assistive Device for assisting bridge maintenance workers [Paul et al., 2010]. The feasibility of this device, the developed methodologies and a proof of concept device were tested in the Sydney Harbour Bridge maintenance site from March to May 2010 [2010]. This test was successful and impressed RMS management so much for them to commission the University of Technology Sydney (UTS) to build two Grit-blasting Assistive Devices for deployment on the Sydney Harbour Bridge. Up to that point in time (June 2010) none of the RMS workers had been involved.

4.2 Case study setting

The study was conducted at the RMS Sydney Harbour Bridge Southern Pylon Maintenance Site located inside the southern pylons of the Harbour Bridge.

4.3 Participant selection

At the request of the researchers the selection of participants was conducted by RMS management. The reason was that RMS management is very interested to see the SHB GAD project succeed and would therefore select participants that were suitable to operate the robots. The five participants were selected from the grit-blasting team based at the Sydney Harbour Bridge.

The participants were all male, Australian trained trades people and were fluent in English. They were physically strong and accustomed to physically hard and dangerous work.

4.4 Stages of the study

The study ran for a period of 23 months commencing in September 2010 and concluding in July 2012. All Co-Design participants were involved right from the beginning. It ran in five stages:

1) *Knowledge building*
2) *OCU co-design*
3) *OCU prototyping*
4) *OCU implementation*
5) *Post-study impression*

Of these five stages Stage 2, *Co-design* is the most relevant to this research. However for the study to make sense as a whole all five stages need to be briefly explained. Figure 4.1 provides an overview of the co-design approach, its Stages and the project timeline.

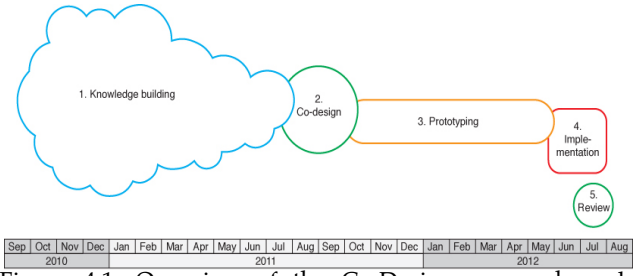

Figure 4.1: Overview of the Co-Design approach and project timeline.

Stage 1. Knowledge building

To build a concrete mental model of the SHB GAD and enable all stakeholders to contribute to the project a knowledge building stage was devised. This knowledge building stage was conducted through monthly meetings with all stakeholders. During the meetings the UTS team was able the gain and in depth understanding of RMS grit-blasters work process and work environment. It also involved the RMS team being updated by the UTS team on their research and development progress and seeking critical feedback from the RMS team. The knowledge building stage was fundamental in developing the SHB GAD prototype and helped to build trust and understanding between all stakeholders.

Stage 2. Co-Design

The Co-Design team was made up of five RMS workers and one UTS team member. The objective of the Co-Design stage was to design the external housing and features of the OCU:

1) Orientation e.g. portrait or landscape.
2) Ritual of use e.g. placement of handles.
3) Location of Emergency Stop (E-Stop).
4) Location of cable entry.

The Co-Design stage was conducted as a model making exercise in the form of a workshop and was scheduled as follows:

Introduction	10 min
Round 1 model making session	25 min
Short break:	5 min
Round 2 model making session	15 min
Review and final design decisions	15 min
Total duration	**80 min**

Participants had the following materials and tools available to them: Hot glue guns, masking tape, scalpels, play dough, cardboard sheets, cardboard

tubes, timber dowel and electrical cords. They were also provided with five identical cardboard housings (Figure 4.2). These housings were the minimum in size the OCU could be and were intended to provide participants with a "starting point" around which they were able to construct their own designs.

Figure 4.2: Cardboard housing to be used as a "starting point" around which to model the OCU.

Figure 4.3: The Co-design workshop in progress.

During the Co-Design workshop the participants made six models. The one shown in Figure 4.4 was the most relevant because it included most features and their correct location as designed by the team.

Figure 4.4: OCU model made by a participant.

The design features cooperatively decided on through model making were:

1) Orientation to be in landscape format.
2) E-Stop location to be top centre.
3) Grip rails on the back, both left and right.
4) OCU to be accompanied by a dock that would hold it when not in use.

Not all design decisions were resolved using models. Several were decided on through verbal discussion and noted on the white board such as:

1) Enable use with both right and left hand.
2) Cable entry to be bottom centre.
3) OCU to be a bright colour to make it easier to locate in the dark and dusty environment.

Of all design features the E-Stop location took the longest to resolve. Not because of differing opinions but rather to make sure that it was located in a place that made sense to all participants.

To avoid misinterpretations the researchers made one final sketch model of the OCU (Figure 4.5) and got the participants to evaluate it.

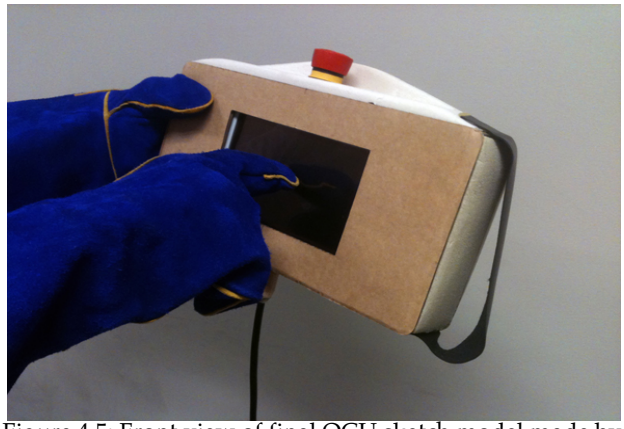

Figure 4.5: Front view of final OCU sketch model made by the researchers.

Stage 3 + 4. Prototyping and implementation

The OCU then went through a process of iterative prototyping. During this process two fully functioning prototypes were made and evaluated by the participants. Once no further changes were required the final version was manufactured for implementation (Figure 4.6).

Figure 4.6: Final version of the OCU, fully assembled and ready for implementation.

All features designed by the Co-Design team were included on the final version. All design detailing and design for manufacture was done by the UTS team.

Stage 5. Post-study impression
The objective of the *Post-study impression* was to give participants the opportunity to reflect on the Co-Design approach and evaluate it from their perspective.

5 Results

To measure if participants thought the Co-Design approach was of value to them or not it was necessary to establish what they thought of the SHB GAD project prior to being aware that they would later be involved in a Co-Design approach. This would provide a pre-study impression of the project against which their impressions post-study could be measured [Bui, 2009].

Pre-study impression
The *pre-study impression* data was collected by observing and questioning participants in most project meetings during *Stage 1* of the study (see Figure 4.1). The meetings were held monthly and as much as possible all stakeholders were present in these meetings.

The pre-study impression data analysis was conducted, by analysing comments made by participants during four project meetings held during the knowledge building stage, prior to the Co-Design stage commencing. Following are comments made by participants between October 2010 and May 2011:

> *"There is no advantage to blast an area that is flat with a robot, this is easy to do manually."*

> *"The 'cream' of the job is the easy part, flat sections, we [blasters] want to do these. We don't want to do rivets, edges and hard to reach areas."*

The analysis identified that participants wanted the robot to do the work that was hard for them to do, such as rivets, flanges and the roof. They were not very interested in using the SHB GAD if they still had to do this hard work manually. Participants were arguing, that such a time consuming setup process was not worth doing, just to blast flat and easy to do sections that manual blasting could do in a very short time.

Therefore it can be concluded that, due to the type of work that the SHB GAD would be capable of doing, participants were at the time, not convinced that it would be a useful tool for them.

(Please note: The UTS team was aware of these concerns and successfully resolved them by July 2012, 14 months after the comments were made.)

Post-study impression
The *post-study impression* data was collected by interviewing four of the five participants one-on-one and asking them to reflect on their experience of the Co-Design approach. The fifth participant was unable to attend his interview due to last minute professional duties and was unable to reschedule. Following is a selection of questions, Q, and answers, A , made by participants:

Q: Did participants think the co-design approach was worth doing?

A 1) *"At least everyone listened to everyone and it wasn't just one way dictating. So everyone had something to say and they were listened to; not discriminated against, it looks like a piece of everyone went in there [points at the OCU]."*

A 2) *"Well, yeah, I mean, you know, the process that we [participants and researcher] did, designing it and building it and everything, I mean you guys [UTS team] have taken everything into [account] what we have actually said. The end product is - you know, you couldn't really ask for anything else. You look at the end result here. I mean, in the group of four/five, however many of us were involved in the whole process, I mean you guys [UTS team] definitely listened because all the little things - you know, how strong this has to be and the environment it's going to be in and you guys really took that all in …"*

A 3) *"Well, I think it's important that this process was carried out because you [participant referring to himself] obviously have a better idea/understanding [better than the UTS team] what the environment is going to be like and the product [points at the OCU] shows how that's reflected in being able to put these together [manufacture of the OCU]."*

A 4) *"We [participants] told you [UTS team] what we want and everything just went there; on paper and design. It was fantastic."*

Q: Did participants enjoy the Co-Design approach?

A 1) *"Yeah, I did, actually. I thought it was really good. You know, having UTS sort of approach us - I mean, this [grit-blasting] is our [participants] job. This is what we do every day. To have you guys [UTS team] sort of include us in on that, you know, come up with a design and all the rest of it, I thought that was great, yeah. I enjoyed it. I really liked the modelling process [co-design workshop]. You know, with the cardboard and with the plasticine and all the rest of it and where the E-stop is going to go and - I don't know, it felt like we were really involved. I thought that was really good. Some people might take [your] ideas and run off with them and it's like, 'Hang on, where did that come from?', but we were really involved in the whole process and we still are, which is good."*

A 2) *"Oh, for sure, yeah. To see someone design and to see something like this [points at the OCU], and it's all real/physical [exists as a real device] and*

things like that, it's fantastic. You can see some of the ideas [from participants] in here, too. Yeah, I loved it."

The post-study impression results demonstrated that participants saw the Co-Design approach as worthwhile. They appreciated having been involved in the study and being able to contribute at a high level in the design process and were satisfied with the end result.

6 Discussion

The results from the pre-study impression showed that participants were unlikely to use the SHB GAD if the setup time was around 2 hours, when it would only be capable of grit-blasting flat vertical sections, sections that are easily and quickly done manually. Participants were quite clear about the fact that they wanted the SHB GAD to do the hard work for them, such as rivets, flanges and the roof. In comparison the pre-study impression results were not as positive as the post-study impression results. This increase in enthusiasm from participants is likely to be as a result of having taken a Co-Design approach. This is probably due to the fact, which it is inherent to the nature of Co-Design, that just being asked to contribute to something will increase ones enthusiasm for it. Therefore it can be concluded that the Co-Design approach and its resulting outcome had an overall positive effect on participants' opinion of the SHB GAD project.

The results also show that participants thought the Co-Design approach was of considerable value to the project. They realized that they had knowledge to contribute and appreciated that they were taken seriously as experts in their field and that all were treated as equals. However the positive responses made by participants are likely to be linked to the outcome. In other words if participants cannot see any evidence of their contribution in the end result they may no longer care about the approach. Therefore for a Co-Design approach to be worthwhile from a participant's point of view their contributions should be visible in the end result. This may seem obvious but it is intrinsic to the success of a Co-Design approach.

One has to appreciate how awkward it could have been to encourage five construction workers to sit down together in a room and make cardboard and play dough models, as was done in the Co-Design workshop. So getting to know each other during *Stage 1, Knowledge building*, was of utmost importance. Depending on the type of participants the planning has to be done well in advance and with a clear understanding of participants capabilities and personalities. If the workshops are not planned well and participants not well understood the results may be of little use and everybody's time wasted. This could be particularly detrimental if the project is real-life and participants' time is paid for by an employer expecting a useful outcome.

7 Conclusion and remarks

The researchers consciously chose to leave participant selection up to RMS management. In a real-life study this is important because the management structures have an interest in the project succeeding, which in turn, will influence the selection process. It also encourages management to see their employees as active collaborators in the process and makes the connection between employees and the project explicit.

This research demonstrates that for a Co-Design approach to be effective all participants need to be comfortable working with each other. Therefore, regardless of the type of participants, one of the most important tasks of the consulting engineer is to work actively at building a good team dynamic.

If the settings of future studies were to be in real-life, formulating a clear pre-study impression or baseline strategy as early as possible will be an advantage and is recommended by the researchers. It is understood that this can be challenging early on in the project especially if there are larger forces, such as management structures, at play. However getting as much information from all stakeholders at the beginning of the study will later provide a wealth of useful data to work with. This could be done by conducting one-on-one interviews with all stakeholders, using indirect lines of enquiry and discussing the study/project with them. The lines of enquiry would not need to be specific but could rather be general questions about stakeholders' expectations, concerns and ambitions for the study/project.

To evaluate the usability of the OCU the researchers would have liked to conduct a series of usability tests with end users who had not participated in the Co-Design approach. Unfortunately the study concluded before the entire SHB GAD system was ready for testing. If a similar study were to be conducted the researchers would recommend planning for usability testing.

Through this research, the following conclusions are made:

(1) Users that are involved in a Co-Design approach are likely to enjoy the process, and the results from the study suggest that this may occur at different levels. At an individual level, participants seemed to value that their own professional knowhow was seen as important and enjoyed being able to contribute to high-level design decisions. At an interpersonal level, participants appreciated that they had been involved in the co-design approach together and that they had managed to solve high-level design

details cooperatively. And at the project level participants were proud that much of the work they did while co-designing was implemented on the final outcome and that their contributions were visible.

(2) To successfully apply a Co-Design approach under real-life circumstances the preliminary stage should be used, amongst other things, to build relationships between all participants including other stakeholders and the researchers. While conducting a Co-Design approach it is important that participants feel comfortable to speak their mind during meetings and reviews. Especially if they may be contradicting the opinion of another participant or stakeholder that is higher ranked in the company than them. It is worthwhile for the person who is in charge of managing the Co-Design approach to keep this in the front of their mind and apply effort to build and strengthen interpersonal relationships.

(3) When one is working on a real-life project taking a Co-Design approach is likely to increase users understanding of and support for the project. Therefore if it is probable that users are anxious or unsure of how the project will affect their profession and or employment situation, planning a Co-design approach and involving users as participants in the process may assist in reducing such anxieties. As a strategy this is particularly likely to succeed if participants are involved in high-level design decisions that will affect the outcome in meaningful ways. However some, not necessarily all, of these high-level design decisions need to be visible on the final outcome. If they are not visible participants may be of the opinion that their contributions were not valued. Having said this if some design decisions are deemed inappropriate by the engineer, based on his or her expertise, this needs to be discussed with the co-design team. In other words at the end of the process all participants need to be happy with the outcome.

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