Towards Situation-Aware Affordances: An Experimental Study

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Abstract

In the future interactive environments will offer more and more functionality. With this increased functionality the need for mechanisms enabling easy system exploration will grow. Designing object affordances is a classic way of influencing explorability. However, affordances can not give clues about the combined use of objects in tasks with higher complexity. Equally, they can not adapt themselves to the situation at hand.

In this paper we present and evaluate a system that extends the idea of classic affordances by presenting small amounts of instructions at the right time and at the right place. We evaluate this concept using the example of a standard flatpack wardrobe extended with light emitting diodes (LED's) on each board. These LED's display the assembly instructions in a proactive way by adapting the information with each movement the user makes. The experiment presented compares the use of paper instructions with the proposed LED based instructions. As result, LED's proved sufficient to even produce a measurable time gain. To test intuitivity and usability of the instructions a comparison between instructions in different modalities is carried out.

1. Introduction

Interactive environments such as the Aware-Home [5] and smart offices [6] introduce new and diverse tools into everyday life. It is crucial to design these environments in a way that people can explore, understand and predict functionality and effects. Beyond training and instruction manuals, appropriate design has proven a good technique to make such systems more usable and intuitive [10]. One way to approach this is to provide objects with clear affordances as populized by Norman in [8]. Affordances give people visual cues about how to use objects and thus offer a simple form of instructions. For example, buttons are here to be pressed, and a coffee-cup handle is here to lift up the coffee-cup with.

Although carefully designing objects with discernible affordances can lead to better results in many cases, affordances are mostly static and bound to one single object. In contrast to that, in interactive environments objects can incorporate different roles at different times and may be involved in multi-step tasks. Classic object affordances can display information regarding the use of single objects. However, what would be needed for interactive environments is a situation-aware notion of affordances, that can also reflect relations among several objects and changes in the environment.

Our approach in this paper is to show and evaluate how the notion of affordances can be exploited and extended by dynamic cues, such that work-flows, and relations among objects can be presented. As a running example we choose a furniture assembly task: a user has to manually join several parts of a flatpack furniture and attach the components by screws. Due to the physical properties of the parts, e.g. symmetry, several sequences of assembly steps are possible. However steps depend on each other, such that previous steps constrain the alignments of the parts in consecutive steps. Thus, the role of parts change during the assembly process and have to be visualised to the user.

In previous work [1] we showed how the states of assembly can be sensed using integrated sensors. Knowing the state of assembly instructions can be given to the user at any time. Presenting these instructions to the user in a proper way is crucial. Conventional paper instructions have the disadvantage of distracting the user from the original task: The user either focuses on the task or interrupts his task and reads the instructions. Thus, it would be a great achievement to integrate the instructions into the objects, so that the user only needs to concentrate on the task he is doing.

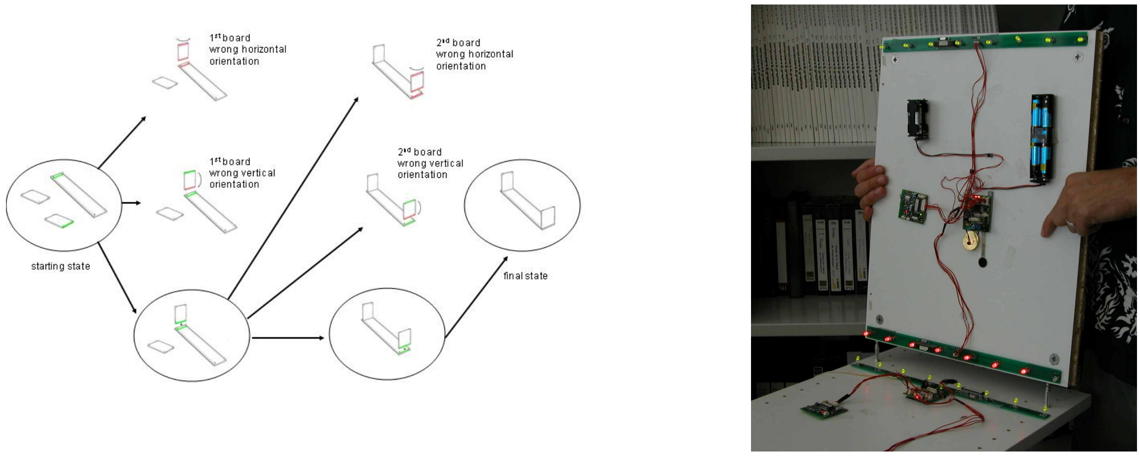
Augmented Reality (AR), as evaluated in [9, 11], is very established to visually integrate virtual knowledge into a user's physical environment. However, AR is cumbersome and typically computationally expensive. Audible instructions offer a cheaper way of immersion but have to tackle with the problem of addressing the appropriate parts by a vocabulary the user is familiar with or has to learn before. This paper studies how affordances of physical object can be exploited and enhanced by dynamic cues. In particular, we evaluate the effectiveness of LED's attached to objects as a way of extending static affordances. We use LED's in the furniture assembly task to guide users through the assembly process.

2. Making Affordances Situation-Aware

An ideal design of objects should not require any instructions at all: the user should be able to guess and understand the functionality at a glance. However, it is hard to eliminate instructions in general. It would already be an achievement to integrate them into the related objects. Instructions could be split into smaller portions - hints - that subtly but infallibly guide users toward correct conclusions. These hints should be tailored to the users momentary task. Each hint helps in one dedicated situation in contrast to manuals covering all error cases. As an overall requirement successful interactive instructions have to follow three principles [3]: explorability, predictability, and intrinsic guidance. *Explorability* enables users to explore, experiment, and discover functionality without penalization of unintentional or mistaken actions. In particular, this requires infinite-level undo and redo operations in a coherent and consistent manner. *Predictability* builds upon intuition: a user can draw conclusions based on first impressions without having to understand all details. Accordingly, familiar things must behave as expected and novel or unfamiliar things must behave in ways that are reasonable and immediately understandable. *Intrinsic guidance* is integral and inseparable of the user interface and provided as needed without requiring any special action or initiative on the part of the user.

Based on these principles we extend the notion of affordances by taking the situation of the user into account, resulting in *situation-aware affordances*. To guide the user through the flatpack furniture assembly we identified five types of feedback: 1.) direction of attention, 2.) positive feedback for right action, 3.) negative feedback for wrong action, 4.) fine grain direction, 5.) notification of finished task.

Users unwrap the flatpack and their attention gets directed immediately (feedback type 1) to the



(a) (b)

Figure 1. Figure (a) shows one of two correct assembly paths and all the wrong cases that can occur. All these states can be recognized using the sensors, thus enabling situation-aware affordances. Figure (b) shows a person assembling two boards with the LED instructions. The short board shows that its orientation is wrong by flashing the lower strip of LED's red.

parts they are supposed to start with. User's actions, such as turning and moving boards are sensed and blinking green light patterns indicate which edges have to be connected in which manner. If boards are aligned in the proper way, a synchronised green light pattern on both edges indicate a well performed action (feedback type 2). If the user takes a wrong action, a red light pattern appears representing a mistake (feedback type 3, see figure 1(b)). Additionally, a green flash pattern shows the alternative. After boards have been aligned together in the right way, individual green lights direct user's attention to the holes where the screws have to be inserted and tightened (feedback type 4).

In the following sections we examine if LED based instructions can supply sufficient information to enable the safe assembly of a piece of furniture. Further we study if this type of instructions are easier to understand than classic instructions, or even more intuitive. Finally we wanted to test if instructions integrated into the objects, have the potential of being less disruptive as they distract the users attention less than classic instructions.

3. Experimental Setup and Methodology

To evaluate the use of LED based instructions we set up an assembly task that users could complete in approximately 1-2 minutes. In this section we present the assembly task used for the study, specify some technical details of the system and give an overview over the used methodology.

3.1. Assembly Task

For our experiments we used a standard flatpack wardrobe, model PAX, from the IKEA company. To make tests with users possible we needed to use a setup complex enough allowing several assembly paths in a reasonable amount of time. Further the example set up should allow for errors during the assembly. To accommodate for these characteristics we decided on using only three parts of the full wardrobe: one side-board and the upper and lower horizontal boards. As the two horizontal boards are exactly the same they can be interchanged in their positions. Figure 1(a) shows the two possible ways of assembling the component and the wrong orientations of the boards that can be sensed.

3.2. System Implementation

The prototype implemented is based on custom technology developed in the Smart-Its project [2]. Multi purpose sensor boards equipped with pressure sensors and accelerometers are used to detect the orientation of the boards and the events of boards being screwed together (see figure 1(b)). Additional IR-sensors detect the location of the boards with respect to the long board. All parts communicate wirelessly using the Smart-Its communication board. To present instructions to the user we have developed a custom layout board carrying eight dual green/red LED's. (see figure 1(b)) For more details on the used hardware see [2, 4, 7]. Besides only presenting information using the LED's we have the possibility to provide visual and auditory instructions on a laptop computer.

3.3. Methodology

The study was carried out with 20 participants with different backgrounds. 14 of the participants are male, 6 are female. The average age of the participants is 26. The overall goal was to compare the usability and effectiveness of classic paper instructions with our situation-aware affordance approach. To this purpose the assembly time between an assembly conducted with classic instructions and one with LED based instructions was compared. To this extent the participants were divided into two equally sized groups, which either used classic instructions or our LED based approach. After the performance comparison the participants were encouraged to perform the setup again three times using instructions presented in different modalities. The first modality employed only the LED's to display the situation-aware affordances. The second modality displayed interactive instructions on a computer screen. The information for the instructions was based on the same sensor setup as with the LED's. The third modality extended the LED's with auditory spoken instructions. Finally, subjects completed a post-experiment questionnaire including questions comparing the different modalities and a comparison with classic paper instructions.

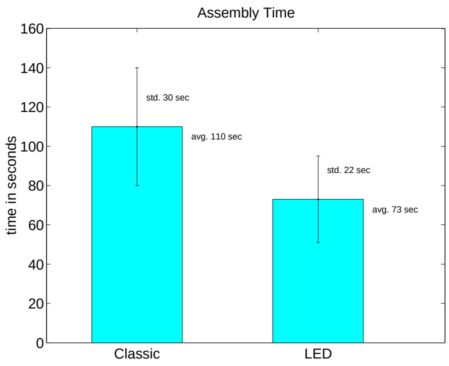
4. Results

4.1. Assembly Time and Errors

The assembly times the two groups of participants required were measured to check if there is a direct effect of the different instructions on the assembly performance. Figure 2(a) shows the average assembly times and the standard deviations measured. Using a between-subject one way Analysis of Variance (ANOVA) on the performance times, showed that the values are significant on the 0.01 level ($p=0.0067$). This statistical test shows that there is a strong tendency that the LED based instructions lead to a faster completion of the task. Besides measuring the performance time, all errors that occurred during assembly were noted. The only errors encountered were that four participants tried to tighten the screws in the wrong direction. Two subjects using the classic instructions ended up with an uncompleted assembly because of this error. The two subjects using the LED based instructions actually noticed that something was wrong as the LED's didn't turn off after the screwing. They then realised that they had been trying to tighten the screws in the wrong direction and corrected their error.

4.2. Results of the Questionnaire

After the experiment, all participants received a questionnaire on paper with free comment answer fields. In Figure 2 (b) a summary of the types of comments is given. To begin with we wanted to know



(a)

	Classic			LED			Screen		
type of comment	positive	neutral	negative	positive	neutral	negative	positive	neutral	negative
helpfulness	5	-	8	20	-	-	11	2	-
orienting parts	-	-	6	13	-	-	10	-	3
identifying parts	-	-	1	5	-	-	-	-	-
keeping to plan	-	-	3	3	-	-	5	-	-
screwing direction	-	-	1	-	-	8	4	-	-

(b)

Figure 2. Figure (a) shows the assembly times. Classic instructions were completed in an average time of 110 sec with a standard deviation of 30 sec. With LED based instructions the average completion time was 73 sec with a standard deviation of 22 sec. Figure (b) shows an overview of the comments in the questionnaire.

about common problems occurring in former assembly tasks: 6 participants out of 20 reported that arranging parts in the proper way had caused problems, 3 complained about unclear instructions and missing parts. Furthermore, we got single responses about problems with the order of the assembly sequence, unspecified screwing direction, and problems with proper orientation of single parts. A general comment was about the desire of having more hands. Further we asked, how participants like *today's paper instructions*, whether they are comprehensible and which steps are problematic. The quality of paper instructions supplied with DIY furniture was rated good by 5, unclear by 5 and problematic by 3 participants. Two subjects noted the additional effort of reading instructions, another subject admitted to ignore paper instructions due to that fact. Regarding the *LED based instructions* all subjects rated them helpful for the assembly task. Due to the relatively high expertise in furniture assembly of our participants this is a remarkable result. LED's helped in aligning and putting parts together (13 comments), identifying parts belonging together (5 comments), and keeping the right order of assembly (3 comments). About a third of all participants rated the *interactive screen instructions* to be very good, 4 participants judged them to be helpful, 2 viewed them to be very similar to the conventional paper instructions. 5 comments mentioned the stress of relating between physical parts and the displayed instructions. The effectiveness of *voice instructions* in addition to the LED's was controversial among the participants: 8 did not a see benefit, 10 were positive and 2 saw a little benefit. As an overall result 70% (14 comments) of all participants preferred the LED instructions over screen instructions 30% (6 comments).

5. Discussion

In the previous section we showed that there is a measurable time gain when using LED based instructions. Beyond that we saw how errors during assembly can be reduced using instructions in the right place. Designing the sensors and instructions for this purpose it may even be possible to totally prohibit errors during assembly. For applications beyond furniture assembly, such as airplane or power plant maintenance this is a critical issue.

Besides these performance related gains we found other problems solved through the LED based instructions. The questionnaire showed that determining *which part fits where* is one of the main problems using today's instructions. Astonishingly, 75% of the participants found that the LED based instructions help with exactly this problem. Because the LED's light up on both boards that need to be joined, finding out what goes where becomes a straightforward task. The instructions don't need to be mapped to the objects any more, they are simply integrated into them.

In this paper we evaluated a prototype of a system that uses situation-aware affordances to give instructions during assembly of flatpack furniture. In comparison to classic paper instructions we have shown that the presented situation-aware affordances are more intuitive, as the user does not have to make the link between the objects on the instructions and the ones in the real world. Further, we showed that the instructions integrated into the objects are less disruptive during the task, as the user does not need to keep checking the printed instructions. The performance evaluation gives first evidence that this is the case. We believe that this example can be generalized to different applications. Firstly, a set of security critical applications could benefit from information presented at the right time and at the right place. Secondly, we believe that situation-aware affordances have the potential to let the user explore the functionality in interactive environments in a more intuitive way.

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