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Hybrid Information Presentation: Combining a Portable Augmented Reality Laser Projector and a Conventional Computer Display

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Abstract

We present a three dimensional, user centered instruction placement system that is geared toward supporting high quality ubiquitous information presentation in industrial environments. Our system uses a hybrid information presentation approach that combines low resolution three dimensional displays with high resolution two dimensional displays. To this end, we have designed and built a portable laser projector to augment a real environment. The information that is provided by the final system is separated into two aspects: where-to-act *and* what-to-do. *The laser projector displays simple where-to-act information directly in three dimensions on an object in the environment while an additional standard screen displays the more complex what-to-do information. To appreciate an initial proof of concept, a first user study of the system has been conducted in the context of a quality assurance scenario.*

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Multimedia Information Systems]: Augmented Reality H.5.2 [User Interfaces]: User-centered Design

1. Introduction

A significant number of current industrial Augmented Reality (AR) applications involve the use of head-mounted displays (HMDs) (e.g. in the ARVIKA project [Fri04]). Up to now, such systems have not yet been brought to full industrial use, due to the demanding industrial requirements and the limitations of current HMDs (users' focus either on the image or real world, fatigue of the eye, small field FOV) [LW02].

In this paper, we explore an alternative to HMD-based augmentations. At the example of a quality assurance scenario, we investigate how well workers can inspect the quality of welding points on white (raw) car bodies when these are indicated by a laser directly on the car. The first prototype of this projector is mobile and will be head-mountable in a future version - a Head-mounted Laser Projector (HMLP).

Our system can project augmentations on 3D tracked objects in the environment. The complexity of the augmentation is limited by the surface onto which it is projected. For example it is difficult to project long texts onto a white body, because the door has deep dents and significant surface structure, reflecting light mainly in the specular direction. Since the diffuse reflection is very small, only a minimal amount of light is reflected omnidirectionally towards arbitrary viewer positions. Therefore we keep the projected and 3D aligned augmentations on the surface as simple as possible. We only project the information *where-to-act* into the environment. Other, more complex, information *what-to-do* is provided on a standard stationary computer monitor.

To evaluate our system, a first user study was made. In the experiment the subjects had to perform a quality assurance task. They were guided by our system using three variations of hybrid and non-hybrid information presentation schemes.

2. Related Work

A number of stationary projector-based AR systems have been developed. Underkoffler and Ishii have presented an augmented optical workbench – a table with a series of mockup optical elements, with the virtual optical path of light through the elements being projected onto the table [UI98]. The *everywhere-displays* projector by Pinhanez [Pin01] omnidirectionally augments an environment with graphical information using a movable mirror that is attached to a stationary projector. Bimber et. al. [BR05] are using conventional projectors that are placed in suitable locations in the environment to generate spatial AR scenes. They are able to show seemingly undistorted video and graphics on arbitrary surfaces in the environment, pre-warping and color-adjusting the virtual data to counteract the reflection and perspective projection effects of the physical surfaces.

Recently, several mobile, head-mounted projecting devices have been developed. Head-mounted Projective Displays (HMPDs) [HGB*01] project light onto retro-reflective surfaces to generate a 3D view. Projective Head-mounted Displays (PHMDs) [KT97] present images on regular ceilings. Their principle of operation can be compared to optical see-through Head-mounted Displays, as used in augmented reality. With Telepointer [Man00], a remote user controls a laser pointer that is worn by a user on site, thereby drawing his attention to objects of interest. A similar approach was developed by Kurata [KSK*04] et. al., using a wearable and remotely controllable combination of a camera and a laser pointer. Wearable laser projectors have already been presented by Maeda et al. [MA04] and Kijima et. al [KG06]. Kahres et. al. [KRW06] have developed a handheld laser projector for computer-assisted surgery.

There are a few approaches toward using laser projectors in industrial applications. Zaeh and Vogl have developed a stationary laser-based AR system for robot teaching [ZV06]. The system is arranged and calibrated for a specific, static scene. The surfaces onto which information is projected may not be moved. MacIntyre et al. [MW05] have developed a stationary laser projector that augments chickens in a processing line with automatically generated slaughter instructions.

In this paper we present a laser-based projection system that is intended to be mobile and head-mounted. It can project onto tracked movable surfaces. The system is designed for industrial applications requiring continuous use over long time periods. To this end, we have developed a hybrid information presentation approach, which projects only minimal information in three dimensions using an augmented reality projection for the simple information. Further information is shown on a nearby desktop or PDA display.

3. Hybrid Visualization

In this section, we introduce a quality assurance scenario and discuss how it can be supported by our hybrid information presentation concept.

Figure 1: *Different symbols projected on the welding points. Compare Fig. 3*

3.1. Quality Assurance for Car Production

In the series production of cars, the quality of welding points needs to be inspected in regular intervals on the white (raw) car bodies. For example, a simple car door (see Fig. 6) has more than 50 welding points. The points have to be checked randomly from one door to the next, even if the same type of door is checked - this has statistical reasons dealing with the occurrence of false negatives. Points have to be checked with a variety of different methods: visual inspection, ultrasonic test, destruction test. In the current process the worker has a drawing of the white body. The points to test are marked in this drawing. First, the worker has to find the point in the drawing. Then he has to find it on the door. After this, he has to choose the corresponding control method to finally perform the test.

3.2. Hybrid Visualization for Quality Assurance

We have developed a concept to support the information presentation in the quality assurance processes. Our system is intended to speed up the whole process and to ensure that the correct points are tested with the right test instrument.

A typical, *pure* augmented reality system would provide the information on a single display – typically an HMD. Such HMDs are not easily usable under industrial working conditions. Instead, we have developed an AR-enabling laser projector. It is not straightforward to realize a projection-based AR system that operates on non-planar metallic, specular surfaces since they do not reflect light evenly (diffusely) in all directions. For example, long texts cannot be displayed on a white body in a readable way. Therefore, we have divided the information in *where-to-act* and *what-to-do* components. *Where-to-act* information refers to inherently three dimensional content, whereas *what-to-do* instructions are usually less dimensional - for example a text or an image. The information *where-to-act* can be provided via simple marking of the position on the object (see Fig. 1). The complex information *what-to-do*, which in our current scenario indicates the associated testing method, does not have to be displayed directly on the object. We provide this information on a separate computer display, placed in close vicinity to the object. This separation of information allows us to benefit from the 3D interactive nature of augmented reality systems without using HMDs.

4. Portable Augmented Reality Laser Projection

This section introduces the movable laser projector that has been developed.

4.1. Hardware

The first prototype of our portable laser projector is shown in Fig. 2. It currently weighs about 1 kg, due to the low-budget hardware used. The control unit is mounted inside the helmet. Users thus can not yet wear the system. In the next version, smaller parts will be used and the control unit will be attached to the workers' body, resulting in a Head-Mountable Laser Projector (HMLP). The system uses a standard laser pointer (green light, low power: <1mW). The power of the laser is sufficient to produce small augmentations which are easily viewable under daylight conditions. We use a green laser since the human eye is most sensitive in this wavelength area.

Figure 2: *Portable laser projector.*

At the projector's core is a galvanometer consisting of two mirrors, one for the x- and one for the y-deflection of the beam. The mirrors are pivot-mounted in an electromagnetic field. Each mirror can stop at 4095 positions in an angular range of 40 degrees. This results in a resolution of 4095 x 4095 pixels and a FOV of 40 degrees. The projector can stop at up to 65.000 positions per second. If we do not switch off the laser while it moves from one point to the next, a line is drawn. Fig. 3a) shows a projected circle. The projection consists of 8 points which are drawn at a speed of 8000 points per second. Due to the high speed of motion, the projector draws a circle instead of an octagon. The control unit is connected by a D/A-adapter to a standard computer via the USB-bus. The D/A-adapter is currently the bottle neck, since it only allows update rates of about 15 frames per second. Retro-reflective markers are attached to the laser projector. These markers can be tracked by the ART Dtrack optical tracking system at 60 Hz, generating precise (1 mm) pose data (position plus orientation) of the HMLP.

Figure 3: *a) Circle on door. b) Misplaced triangle*

4.2. Software

To project an augmentation with our portable laser projector onto a welding point on a movable white body, we have to calculate several positions and their spatial relationships. Fig. 4 shows the spatial relationship graph [PHBK06] of our setup. The *White Body* and the *Helmet* have retro-reflective markers via which the ART Dtrack system can determine their pose. The position of the *Welding Points* (in the white body's origin) were defined off-line by a tracked pointer that was also equipped with retro-reflective markers. For a concrete implementation we would use the CAD model (which we did not have) to obtain such points automatically.

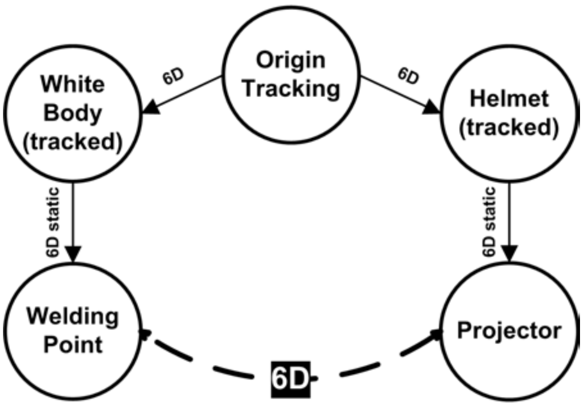

Figure 4: *Spatial Relationship Graph*

To estimate the position and orientation of the *Projector* inside the *Helmet* we use the Single Point Active Alignment Method (SPAAM) [TN02]. The calibration is based on the alignment of projected image points with a single 3D point in the world coordinate system from various viewpoints. Based on the ART Dtrack system we use a calibration board with a trackable position. From different view points we project several 2D sample points with the laser projector onto this board. This provides a set of 2D/3D relationships from which the intrinsic laser parameters can be calculated using a singular-value-decomposition. 20 sample points are sufficient for the estimation.

5. Evaluation

We have conducted a first usability study to test our system and the concept of hybrid information presentation.

5.1. Experimental design

The experimental setup is shown in Fig. 6. We placed the laser projector (A) on a table two meters in front of a white body (a car door, B) such that the projector could cover the entire door with its field of projection. The car and the projector were tracked by the ART DTrack system. Both could have been moved during the experiment, but they were not. The 2D computer display (C) was placed to the right of the car door. A button (about 5 cm in diameter) was placed next to the display (D), allowing users to switch to the next point to check. Two special areas were arranged on both sides of the car door: one on its left side (red square, E) and one on its right side (blue square, F). That way, the blue area (F) was close to the computer display (C), and the red area (E) was distant to it.

Figure 5: *Three mockup control tools.*

The task which the subjects had to accomplish was an abstraction of the quality assurance for welding points. The mockup tools were represented by three pens. They were marked with a cross, a triangle and a square (see Fig. 5). During the test the subjects had to apply the proper quality assurance check to the correct welding point, i.e. they had to select the proper pen (cross, triangle, square) and touch the welding point which was highlighted on the door. In the first experimental design we just varied one variable: the way of indicating which tool to apply (i.e which pen to use). The first condition used no information separation whereas the second separated information into *where-to-act* and *what-to-do*. Under the first condition the 3 different symbols where projected directly onto the door (see Fig. 1). Thus, the laser projector presented both the information *where-to-act* and the information *what-to-do*. In the second condition the two types of information were separated. The welding point on the door (*where-to-act*) was indicated by a circle, as shown in Fig. 3a). The information which pointer to use (*what-to-do*) was shown on the stationary monitor screen (C in Fig. 6). In order to investigate whether it could make a difference where the pens were placed w.r.t. the stationary monitor, we considered two subcases for the second condition and placed the pens either far away from the monitor (in the red area E) or close to the monitor (in the blue area F). In total, we evaluated the following three conditions:

- Test 1: no information separation; pens on the red area
- Test 2: hybrid information; pens in the red area
- Test 3: hybrid information; pens in the blue area

We had 10 subjects in a within-subject design. The subjects performed three tests (each with 8 samples) for each scenario. For all scenarios the subjects went through an introductory session consisting of 3 samples. The sequence of the tests was permuted between subjects in order to compensate for learning effects. For each point to check, the subjects had to take the pen, tip on the current welding point, place the pen back in the marked area and then press the button to advance the next welding point. The first dependent variable was the *task time*. After each scenario the subjects had to fill out a NASA TLX questionnaire [Har88] as an indication of *mental workload* - our second dependent variable. The result is a value between 0 (no workload) and 100 (full workload). After the experiment the subjects went through a short interview.

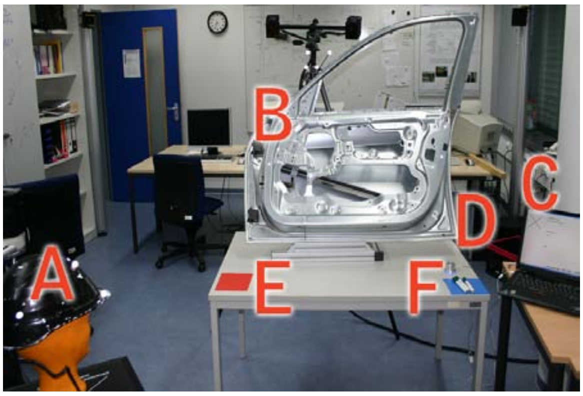

Figure 6: *Experimental setup.*

5.2. Experimental Results

Analysis of variance (ANOVA) computations did not identify significant differences in the workload (p>0.1, alpha=0.05, see Fig. 7 for details). This could be due to the fact, that TLX is a subjective test method with a high variance, and we had only a small number of subjects. However, we did measure a significant difference in the execution time, as shown in Fig. 8. In condition 1 (no information separation; pens on the red area) the mean time per checked point was 5.52s (std dev 2.09s). In condition 2 (hybrid information; pens on the red area) the mean time per checked point was 5.9s (std dev 1.9s). In condition 3 (hybrid information; pens on the blue area) the mean time per checked point was

4.52s (std dev 1.26s). People under condition 3 acted significantly faster than under condition 1 (p>0.9, alpha=0.05) and condition 2 (p<0.01, alpha=0.05).

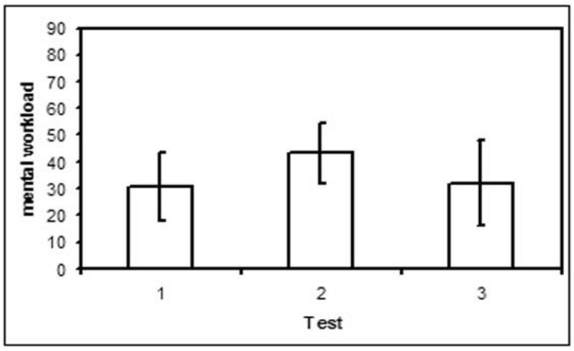

Figure 7: *Mental workload. No significant differences due to high standard deviation*

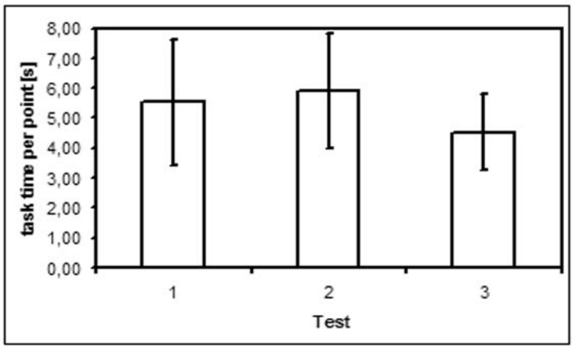

Figure 8: *Task times. People act significantly faster under condition 3*

This first user study shows that people easily understood all information presentation schemes. Only very few mistakes were made. Some symbols were misinterpreted because the welding point lay at a surface border such that only half of the augmentation was viewable while the rest was projected onto another surface (e.g., the wall) in the back (see Fig. 3b).

People could work efficiently with all three presentation arrangements. In particular, we were able to show that hybrid information separation is not worse than showing all information in one place. However, in our scenario, the *what-to-do* information was not complex and consisted of only three values (triangle, cross or square). If the complexity of the information increases, the concept of presenting all information on the door reaches its limits. Additionally, it is very critical, where the information *what-to-do* is placed. People mentioned in interviews that they preferred having a stationary monitor for such information. The reason may be that, in a hybrid setup, they can pursue their work as an ordered sequence of steps: they first look to find out which tool to apply (*what-to-do*), then they search for the tool and pick it up, finally, they look to find out where to apply the tool (*where-to-act*). This is particularly interesting in scenarios where it is not possible to place all tools close to the monitor because they are too voluminous. This may result in a future setup placing many monitors ubiquitously in the environment.

In a few cases, the participants had to search for a welding point for several seconds. This had two reasons, which would not exist in a truly head-mounted setup. Either they occluded the projection with their own body or the welding point was on the side of the door and not viewable from their current viewing position. However people never applied an instrument to the wrong welding point. In another project we evaluated an HMD-based augmented reality system in logistic commissioning scenarios [SFPK06]. In that system the users often misinterpreted picking (i.e., *where-to-act*) instructions .

We have presented the HMLP-based quality assurance system at an industrial fair (SYSTEMS 2006). Many workers performing such quality assurance tasks on a daily basis provided very positive feedback.

6. Discussion and Directions of Future Research

We have presented a system to display information in an augmented reality manner without using HMDs. This concept has the potential to present information robustly under industrial conditions for all day use. Yet, there are many opportunities for improvement.

Positional precision is a inherent problem of our current setup. Even at small distances (e.g., 1 meter), small angular imprecisions (e.g., 1 degree) in tracking the HMLP result in significant misplacements (e.g., 17 mm) of the augmentations on the white body. Therefore we plan on fusing the currently used outside-in optical tracking with lightweight inside-out optical tracking [Hof98].

Another topic of future research will be a comparison between head-mounted and stationary laser projection systems. The main benefit of using a stationary system is that the users do not have to carry anything around. Yet, a major drawback is the potential for occlusions when users stand in the line of projection. This can be solved by using multiple projectors augmenting the same welding point – yet such systems require very high calibration precision. A Head Mounted Laser Projector has the benefit of being mobile and providing personal and unshared displays. With an HMLP we can guide the user to look in the proper direction via individually placed arrows. Since the projector is mobile, there are no places that are principally out of reach (as can be the case for stationary projectors).

We will also further explore and evaluate concepts of hybrid information separation in various scenarios. This includes the use of several ubiquitous computer displays showing different *what-do-do* information.

7. Conclusion

We have developed a user centered 3D instruction placement concept for industrial applications. It makes use of a mobile augmented reality laser projector, which was also developed in this work. The main idea is to make use of a hybrid information presentation approach: separating information into *where-to-act* and *what-to-do* components. To have a clear and readable visualization we use the augmented reality projection only for the *where-to-act* information. This concept was successfully tested in a first experiment. Additionally we have shown that hybrid information presentation is performing at least as well as presenting all information in a single three-dimensional scheme. This concept can be applied to many other augmented reality scenarios, especially when HMDs have been identified as being the currently limiting factor.

7.1. ACKNOWLEDGEMENTS

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