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# Testing Augmented Reality Systems for Spotting Sub-Surface Impurities

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**Abstract.** To limit musculoskeletal disorders we are working towards implementing collaborative robotics in strenuous or repetitive production work. Our objective is to evaluate augmented reality (AR) devices for assisting in near-distance tasks before applying and testing the displays in the context of human-robot collaboration in a production setting. This chapter describes the hardware setup and procedure for testing AR systems for showing sub-surface positions of foreign elements in an opaque mass. The goal is to test four types of setup in terms of user accuracy and speed, the four setups being a head-mounted see-through display, a mounted tablet-based see-through display, top-down surface projection and overlays on a static monitor. The experiment is carried out using a tracked HTC Vive controller with a needle attachment. Precision tasks are performed by 48 participants and each display is evaluated using the System Usability Scale and the NASA Task Load Index.

**Keywords:** Augmented Reality · Usability Testing · Human-Robot Collaboration.

## 1 Introduction

Repetitive actions at work can cause musculoskeletal disorders (MSDs), whether it is due to non-neutral body posture in an office environment or repetitive motion patterns on a production line[7]. Introducing human-robot interaction (HRI) and augmented reality (AR) can assist in strenuous physical tasks and present data in a seamless and non-obstructive ways, improving work flow and employee welfare by addressing and reducing causes of MSDs.

The main context of this study is cellular meat production in which employees stand on the meat processing line, performing one or few tasks each on every piece of meat. This type of work involves lots of repeated strenuous movement. The theories and experiments will, however, pertain to creating an efficient and sustainable workplace in the general sense, regardless of the type of working environment.

The robots will act as assistants, aiding in production by pointing out details such as impurities in the meat before moving on to human-robot collaboration where the robot will aid in physical tasks, such as flipping over the meat or

bending it for easy trimming and deboning of pork bellies. The overall goal is safe and efficient communication and collaboration between human and robot, aided by AR technologies.

Human-robot collaboration is an emerging field within HRI, as can be seen from dedicated workshops and track at HRI conferences[5]. A particular challenge in HRI is the asymmetrical communication capabilities of the human and the robot partner, creating a need for a multi-level coordination between them to achieve successful interaction: The communication level, the physical level, the social level and the task level, the communication and physical level being the main focuses of this experiment.

The objective of this experiment is to evaluate the utility of AR systems for close-distance tasks relevant to the meat production context before applying them to human-robot communication. In this case the task is finding impurities in pork bellies in the context of cellular meat production. In more general terms this means showing positions in space within and opaque mass. The display types used are an arm mounted see-through display, head-mounted see-through display, top-down surface projection and overlays on a static monitor.

We propose a method of helping workers maintain a healthy posture implicitly while directing their attention towards a target. One way of doing this is to use the arm-mounted display and placing it in a position that would require the user to correct their posture in order to properly utilize the display. This poster describes the procedure for an upcoming preliminary study in AR systems, the results of which will be used for further study in HRI.

## 2 Related Research

The communication from the robot to the human in the manufacturing context will involve conveying the details pertaining to current task, and for this study we seek to utilize the AR for this purpose. Elia et al. proposed a 4-step model for preliminary evaluation of AR devices to be applied in specific manufacturing processes, starting with a multi-criteria analysis for ranking the most effective AR systems for the purpose. This involves considering hardware and output modalities as alternatives and evaluating them in terms of reliability, responsiveness and agility using pair-wise comparison followed by analysis and ranking of the AR alternatives. Elia et al. categorize AR hardware as head-mounted displays (HMD), handheld devices, projectors and haptic force feedback systems[3]

Kruijff et al. classified potential perceptual issues with AR between environment, capturing the environment, augmentation, display device and user while pointing out whether they are predominant with particular display types: Head-mounted displays (video see-through or optical see-through), handheld mobile devices or projector-camera system (stationary or mobile)[6]. For this experiment each display type is evaluated.

Schwerdtfeger et al. go into depth describing the projected AR, specifically using lasers, pointing out the cons of HMDs; small field of view, limited resolution, swimming effect, multiple focus planes and eye fatigue. While laser-

projected AR can address some of these issues it is limited to displaying information on surfaces in the environment and the image must be pre-distorted to compensate for geometric surface distortion, whether the projector is head-mounted or stationary. In addition, it also introduces the challenge of occlusion by either the user or other objects[8]. In order to avoid surface distortion for this test an even and level surface is used.

Studies have shown that depth perception while using AR is affected by a bias; subjects tended to underestimate distance in AR when they are projected at less than 23 meters distance to the user, after which the bias switches to overestimation[10]. Singh et al. estimated a distance judgment error of -5.5 cm at most for distances less than 50 cm[9]. However, this was tested in 2010 using an nVisor ST display, so modern see-through displays may lead to different performances. Augmented reality has previously been used to imitate x-ray vision: Avery et al. emphasized that when showing the content beyond the surface using an graphical overlay it should include an edge overlay representing the surface as a depth cue, so the object does not appear to float in front of the surface[1].

### 3 Setup

Spotting sub-surface impurities is tested using a tray of sand where the impurities are virtually projected beneath the surface using each of the AR displays. Between test sessions the surface of the sand is smoothed out to hide the previous entry points.

The main component for measuring the user's performance is a six degree of freedom tracking space. For this an HTC Vive setup is utilized: One of the controllers is used to point to the virtual impurities with a needle mounted to it. The other controller is used to confirm when they are touching the impurity. This is to prevent shaking the dominant hand when confirming a target. The setup for the test is show in full in Figure 1.

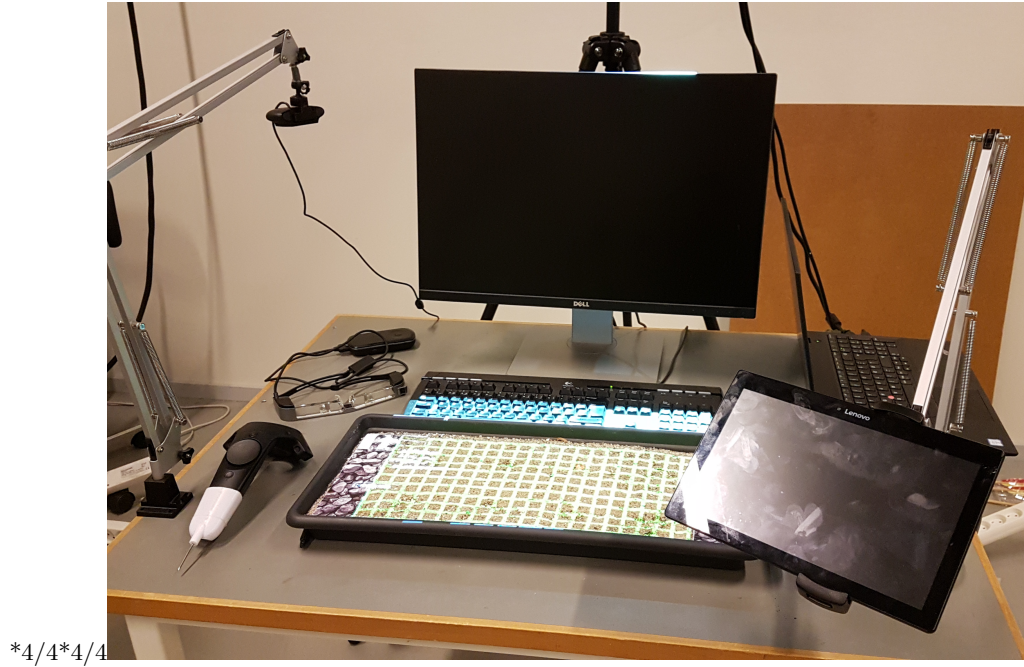
In order to display the targets on the mobile AR devices, the head-mounted display and the see-through display, the PC that runs the software and tracking also acts as network host while the mobile units act as clients and receive target positions as the tests are running.

The position and orientation of the sand's surface are calibrated using the needle mounted to the Vive controller along with a tracking guide printed on paper. This is also used to align the positions of the printed tracking markers used for the mounted see-through display and the HMD.

#### 3.1 Mounted See-Through Display

The concept of the arm-mounted display is that it should be held by a robot arm, allowing it to orient the screen towards the impurity, thereby guiding the attention of the user. However, for this test will be mounted to a manually adjustable mount. The see-through display is tracking the tray and the targets





**Fig. 1.** The full setup for the AR test.

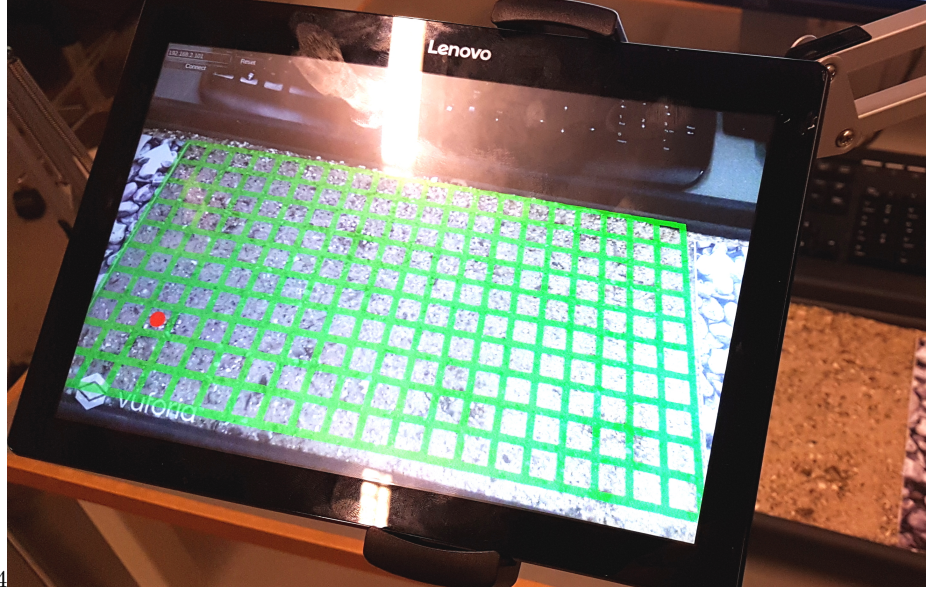
using the Vuforia AR framework running in the Unity game engine compiled to Android.

The tracking markers are printed on paper and are placed at either end of the tray so that they are not obscured by the participants' hands during the test. When positioning the screen for the participant, its camera is pointed toward the tracking opposite to the participant's dominant hand, making it unlikely for them to reach over it.

The display is an Android tablet showing the back-facing camera feed where the impurities are shown as a red sphere of 10 mm diameter projected into the sand. In addition, this view will feature an overlay aligned with the surface of the sand to assist in depth perception similarly to [1]. This setup is illustrated in Figure 2.

### 3.2 Head-Mounted Display

For testing see-through head-mounted displays an Epson Moverio Bt-300 is used. These are shown in Figure 3. Similarly, the AR glasses are running using an Android-based mobile unit acting as a client, receiving target positions from the host PC running the tracking space while tracking its own position using Vuforia and Unity.



**Fig. 2.** The arm-mounted see-through display setup with impurity projected into the sand as a red dot assisted by a grid overlay aligned with the surface.

The position of the impurity are shown on the glasses in a similar fashion to arm-mounted display while also utilizing the overlay grid. However, due to the limitation of not being able to track the gaze of each eye of the the participants and thereby determining the convergence point, attempting to render the position in stereo would leave the user with difficulty focusing. Therefore, the target is rendered as a 2D overlay similarly to the see-through display, and when analyzing the data the participants' dominant eye must be taken into consideration.

### 3.3 Top-Down Projection

The top-down display is implemented using a projector mounted to a tripod using a custom 3D-printed mount. It projects the position of the impurity in the surface of the sand using a 10 mm red. Because the projection does not allow for perspective rendering like the see-through display and the HMD, the red dot is rendered along with a number indicating the depth of the impurity.

The camera used is a Logitech C920. During the calibration of the setup, the position and orientation of the camera is calibrated using the needle on the Vive controller. The mounted projector is shown in Figure 4 and the top-down projection is shown in Figure 5.



**Fig. 3.** The Epson Moverio Bt-300 glasses used for the experiment.

### 3.4 Monitor

The static display involves a monitor positioned at the opposite side of the tray to the user showing a top-down camera feed of the surface of the tray while showing the position of the impurity, similarly to the top-down projection. Similarly to the mounted see-through display the user will be looking at their hands and the impurities through the monitor. This setup is shown in Figures 6.

## 4 Procedure

At the beginning of each test the participant is introduced to the subject of the experiment, the setup and the tasks they will be performing. User information gathered before the test starts will include sex, age, height, dominant hand and dominant eye.

### 4.1 Pointing Tasks

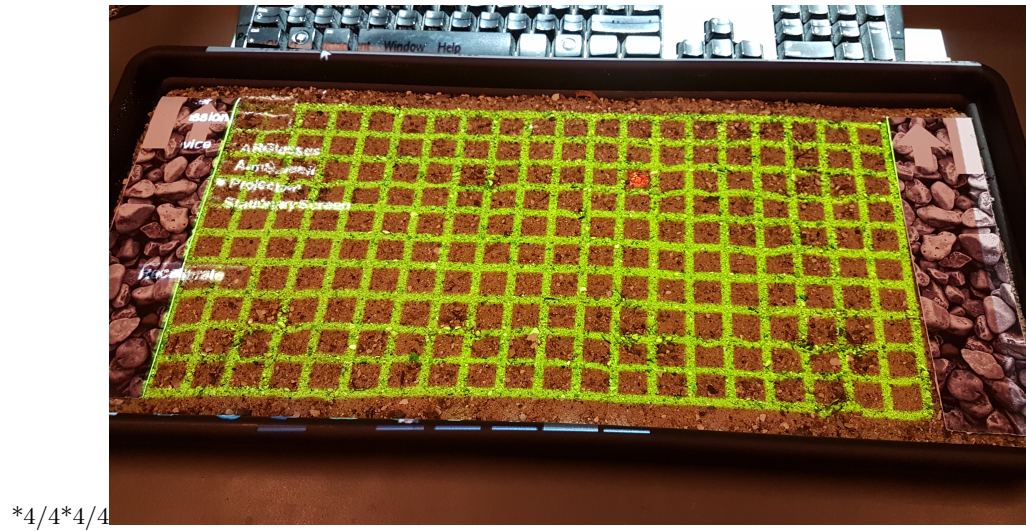
The experiment is run with 48 participants. This is to counterbalance the order in which the participant tries the display in order to counter bias or possible confusion at the start of the experiment, either pertaining to the pointing task or the questionnaires between test sessions. Four systems yield 24 possible combinations and going through them twice will yield an acceptable number of samples for analysis.

For each AR system the participant must point to 24 impurities projected into the sand by the AR display. They will do this by pointing into the sand

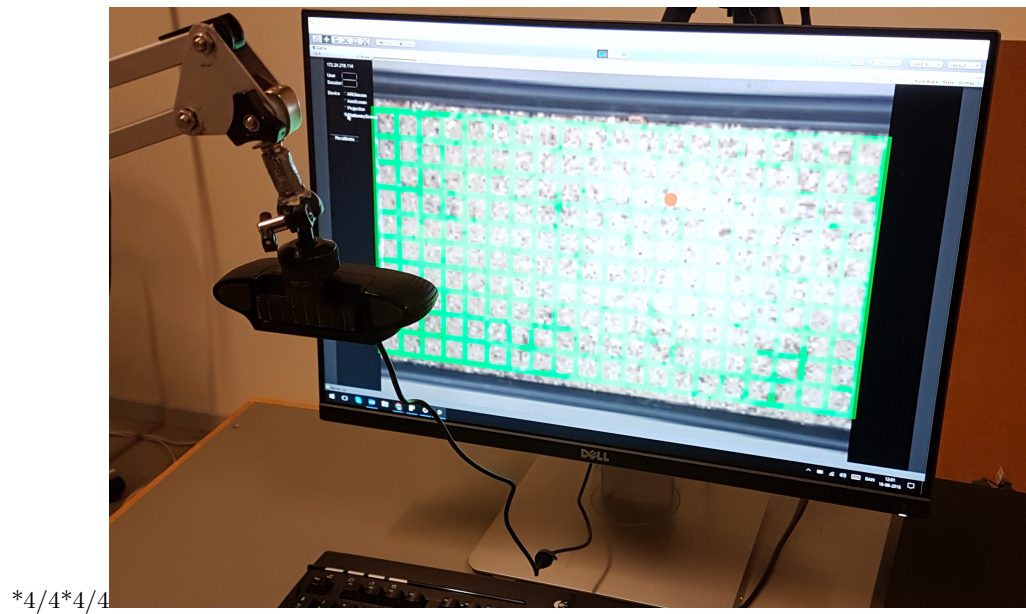


**Fig. 4.** The projector mounted for the top-down projection setup.





**Fig. 5.** The grid projected onto the sand with the targets shown as a red dot.



**Fig. 6.** The monitor and top-down camera.

using a needle-like object mounted to an HTC Vive controller in their dominant hand, shown in Figure 7. The participants are instructed to point as quickly and precisely as they can with the goal of getting the tip of the needle as close to the center of the impurity as possible. To confirm that they are pointing at the impurity the participants must press a button on the controller in the non-dominant hand while the needle is in the target before moving on to the next target.

In order to prevent participants accidentally confirming two targets in succession, new targets appear with a one-second delay. This also allows the participants to retract their hand to a neutral position before searching for the next target.



**Fig. 7.** The needle used for the experiment, made from a 3D printed mount and a nail and attached with a bolt in the loop designed for the wrist strap.

The body of sand is 25 cm wide, 55 cm long and 5 cm thick. Impurities in the meat most often occur on the surface, but can occur as deeply as 3 mm under the surface. The impurities will be projected at 24 predetermined position distributed between three layers, two row and four columns in order to test the effectiveness of the systems at various depths and in relation to dominant hand. The layer will be at depth 0 mm, 5 mm and 10 mm, and the layers and columns will be spaced by 10 cm on a square grid.

## 4.2 Measurements

The data gathered for each target in the experiment will be the distance between the needle tip and the center of the target as well as the time between target spawn and user confirmation. The distance measurement will include the distances on the X, Y and Z-axes as well as the direct distance.

In addition to the data gathered from the software, between testing the displays the participants are asked to fill in two questionnaire regarding their user experience: A System Usability Scale[2] and a NASA Task Load Index[4] are used to evaluate each of the AR displays in terms of user acceptance and ease of use.

## 5 Conclusion

This chapter presents the hardware setup and procedure for a preliminary comparative study of the usability of a collection of AR displays for showing subsurface impurities in meat by having the participants point to targets inside an analog made of sand. The goal is to determine suitable interfaces for augmented meat production while being able to implicitly correct the worker's posture while directing their attention towards the target. To this end, we expect that the collaborative robot arm will show the greatest impact, as it allows for dynamic display adjustments in relation to the workers posture.

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