[POSTER] Augmented Wire Routing Navigation for Wire Assembly

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ABSTRACT

Within modern manufacturing, digital solutions are needed to optimize and aid shop floor processes. This includes user-centered technologies that can be appropriately integrated into factory environments to assist in the efficiency of manufacturing tasks. In this paper, we present a dynamic system to support the electrical wiring assembly of commercial aircraft. Specifically, we describe the system design, which aims to improve the productivity of factory operators through the integration of wearable and mobile solutions. An evaluation of the augmented reality component of our system using a pair of smart glasses is reported with 12 participants, as we describe important interaction issues in the ongoing development of this work.

Keywords: Augmented reality; wire assembly; indoor location tracking; GPS navigation.

Index Terms: H.5 Information Interfaces and Presentation (e.g., HCI): H.5.1 Multimedia Information Systems

1 INTRODUCTION

In recent years, the demands for lighter and more efficient aircraft illustrate the importance of appropriately designed electrical wire infrastructures [9]. For example, a newly built Boeing 787 is estimated to consist of over 90 kilometers of wires and 10,000 connectors [9]. In a factory environment, specialized boards called formboards are used to assemble the electrical components of an aircraft [e.g. see 8]. However, as commercial wire assembly is often labor intensive, this can result in unforeseen human errors, resulting in significant delays in aircraft delivery [1]. To address these limitations, several technical solutions have been proposed.

In the 1990's Mizell [8] tested the use of head-mounted displays to guide factory operators through wire assembly tasks. However, task performance did not significantly improve, with criticism to the ergonomics and user interaction at the time [8]. More recently, Lewerenz and Willers [6] proposed the use of a backlit jigboard display from which wires are assembled upon. However, it is presently unclear how effective this approach is for large-scale tasks that involve hundreds of wires.

Alternatively, the robotic assembly of wire harnesses has been explored for the automobile industry, but with mixed results [5]. Notably, some physical operations were found to be difficult to be controlled by mechanical robots, as research findings identified that assembly speed was below expectations for industrial performance [5].

In view of these limitations, we were motivated to explore an alternative approach to assist in the productivity of wire harness assembly. Specifically, in this paper we focus on the integration of low-cost wearable solutions that do not require significant changes to the formboard tooling. Similar to in-vehicle navigational systems, we provide step-by-step guidance of route information, using a combination of graphic and voice modalities that aim to support cognitive workload, without affecting the accuracy of the operator. As such, our work aims to assist in the routing of wire sequences without modifying the physical structure of the formboards.

In summary, the main contributions of this work are:

1. To illustrate the development of a novel wire harness guidance system that integrates the use of mobile and wearable devices.
2. To describe the usability evaluation of the augmented reality component of the system with 12 participants, including key interaction issues in wire assembly tasks.

2 WIRE ROUTING NAVIGATION GUIDE

A growing body of literature has explored the use of wearables to support procedural tasks in industrial applications. From a HCI perspective, this includes the work of Henderson and Feiner [4] in their use of localization techniques to direct attention to target locations that require a change in head orientation, and Wille and Wischniewski's [11] and Guo's et al. [3] evaluation of head-mounted displays for use in object assembly and item selection processes. Alternatively, with large-scale initiatives advocating the need for dynamic technologies to help re-shape manufacturing industries [2], it is both relevant and timely to be investigating wearable solutions to aid in the construction of commercial aircraft.

A formboard is a type of board that is used to assemble large volumes of electrical wires together. During the wire harness process, wire bundles can extend many meters in routing length, as formboard assemblies can consist of hundreds, possibly thousands of individual wires. Given the complex structural design of an aircraft, custom-made formboards contain a schematic diagram that acts as a type of visual aid in the layering and placement of wires [8]. Once complete, wire bundles are transferred to the aircraft to be fitted, from which significant delays can occur if previous assembly errors are unidentified.

As wires are assembled along pre-defined paths or routes, and cross at certain junction points, formboard diagrams can be considered as a type of road map (see Figure 1). In-vehicle GPS navigational systems are designed to support a driver's orientation by drawing relevant attention to landmark features, routes and waypoints. Using a similar analogy, our system aims to support an operator's spatial awareness in wire routing tasks through the representation of appropriate wayfinding cues. This is perceived

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to be an important area of research given the largely unchanged process of formboard tooling over many decades, and a lack of known digital devices to aid in this process.

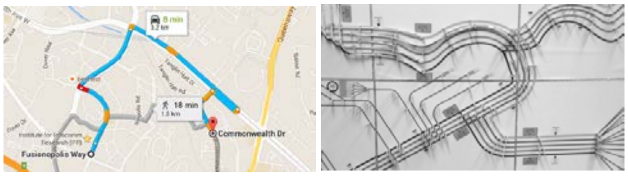

Figure 1. Google Maps (© 2015 Google Inc) (left) and section an aeropace formboard (right)[1].

3 SYSTEM DESIGN

The aim of introducing technology to the shop floor is to improve the efficiency of wire assembly with minimal changes to the factory environment. To achieve this, we use a combination of mobile, wearable and fixed location devices that are able to communicate wirelessly with a system server.

As illustrated in Figure 2, our hardware setup comprises of the following components communicating via a local network: 1) AR markers, 2) a mobile display in the form of a tablet or pair of smart glasses, 3) a smartphone attached to the operator to facilitate indoor positioning and voice commands, 4) wireless beacons to compute operator distance approximation, 5) a system server that handles the overall data processing and synchronization, and 6) a wireless router. AR markers are placed at 2 meter intervals along the top of the formboard. These markers are used to recognize the size, distance and orientation of the formboard, which is used for compositing AR digital content with a live camera feed from a tablet or pair of smart glasses.

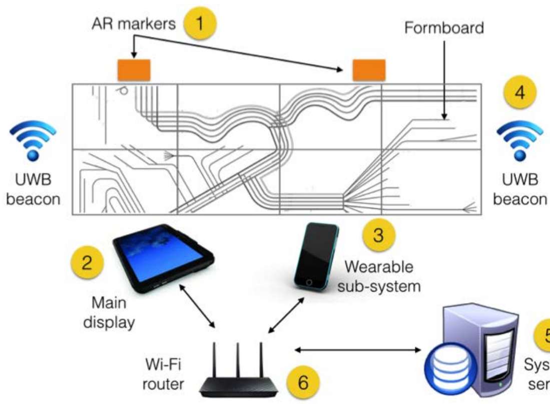

Figure 2. System setup.

Specifically, the design of our system emulates a GPS navigational approach through a combination of identifiable route paths, context sensitive information that reflects the position of the operator to the formboard, and the facilitation of hands-free interaction using audio cues. As illustrated in Figure 3, this is achieved through a combination of graphic and augmented interfaces, wireless location tracking and speech recognition software. Using a network setup, our system is scalable as different types of devices can be added to support multiple operators simultaneously. Devices can also be replaced or upgraded without adverse impact to the overall system. For example, a tablet display can be substituted with a pair of smart glasses, or synthesized speech redirected to other devices with audio output (Figure 4a-c).

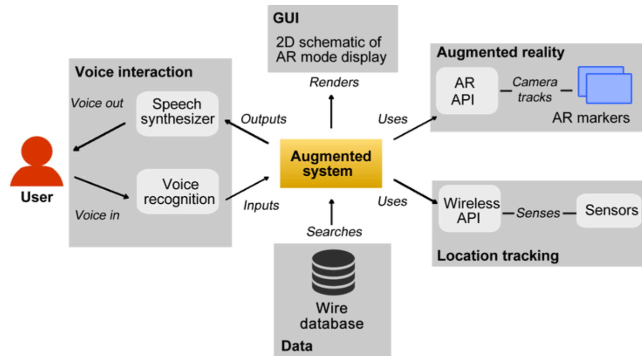

Figure 3. System components and interaction modules.

The following sections describe the system components in more detail.

3.1 Pre-navigation

At the start of the assembly process, an operator first identifies a wire bundle, which consists of a group of wires. Using identification numbers pre-printed on these wires, this information can be barcode scanned into the system for registration. The system then queries a database of wire hierarchies, and promptly renders the graphic routes on the user interface.

3.2 User interaction

In addition to voice commands, our prototype facilitates alternative modes for interaction such as: 1) button presses via touch on a tablet display, 2) voice command input through a smart phone microphone, and 3) smart glass input, such as a touch pad located at the side of the device.

3.2.1 Visual display

Using an on-screen selection button, operators can easily switch between *Schematic* and *Augmented Reality* (AR) interfaces. The Schematic interface consists of a 2D graphical map of the formboard from which colored routes are displayed. Alternatively, as hundreds of wires are potentially assembled to the formboard, the AR interface front project's routing information that might otherwise be occluded (see Figure 5). As previously mentioned, to overcome camera alignment inaccuracies, two-dimensional AR markers are used. Developed using the Vuforia platform, the software resizes and skews the AR projection to achieve a matching overlay on the view of the formboard diagram. This allows for a realistic multi-angle view of the augmented scene.

In both interfaces, the cluttering of graphical information is avoided by sequentially displaying route sequences. This consists of essential routing information, such as the start and end points of the wire routes, the route color and the route ID. For consistency, the ratio and color of the graphical features are designed to directly correspond to those on the formboard, and include a small set of graphical symbols to highlight navigational features (e.g. route direction, intersection points, etc.) (Figure 5).

[1] Due to commercial restrictions, all the colored formboards have been converted to black and white images in this paper.

Figure 4. Examples of input/output technologies used: (a) smartphone for voice interaction, (b-c) tablet with stand and AR glass devices

3.2.2 Voice interaction

In addition to the visual display, a predefined set of voice commands have been designed using small chunks of information (e.g. “start point”, “next wire”, “repeat”). A voice recognition module in the smartphone utilizes the Google Android speech recognition service (Android 4.2 onwards). When speech is detected through the smartphone microphone (see Figure 4a), the service automatically attempts to translate it into words, and in turn, pass it to the system server for command execution in the display application. The speech recognition service in the smartphone relies on downloadable language packs for its translation algorithms, and our current implementation includes both English and Spanish.

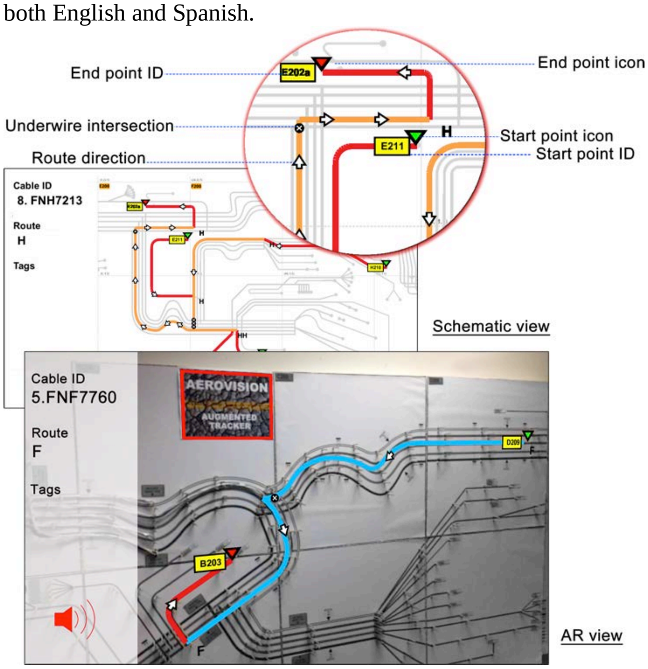

Figure 5. Examples of the (top) 2D schematic and (bottom) AR interfaces with navigational features.

3.3 Indoor location tracking

To help with the orientation of long and complex wire routes, information is displayed in relation to the operator’s formboard position. Unlike GPS systems that use satellite to triangulate a driver’s position, in-door location tracking can be accomplished using radio transmissions. When using the *Schematic interface*[2], routing information in the tablet display automatically adjusts, by animation, to reflect the directional position of the operator to the formboard. To achieve this, we currently employ the use of Ultra-Wide Band (UWB) beacon transmitters placed at each end of the formboard. These lightweight 4 x 4 cm beacons transmit UWB radio signals that are detected by an Android subsystem in the wearable smartphone, from which information is passed to the system server to calculate the operator’s location proximity (Figure 2).

Based on our observations, UWB is a stable and reliable radio technology that is an ideal candidate for precise indoor location tracking. It is resistant to interference from other radio signals, and does not require a direct line of sight to operate [10]. In addition, the small and lightweight transmitter size makes it a less intrusive technology that can easily be placed away from busy activities, such as behind the formboard.

4 Initial Evaluation

We conducted an initial evaluation of the AR interface using a pair of stereoscopic see-through glasses. The purpose of the study was to assess the usability of the AR interface, independent of the voice interaction and location tracking features. 12 participants (9 males and 3 females) were recruited with a mean age of 28 years from the Institute for Infocomm Research. As non-experts, all of the participants were inexperienced in wire assembly.

For the evaluation, there were three routing tasks with an additional practice task, which were assembled on a non-occluded version of the formboard (480 x 120 cm in size) similar to Figure 1. A pair of smart glasses was used to display the AR content, comprising of a front-facing camera, with a 960 x 540 screen resolution. Each session lasted approximately 30-40 minutes, and involved a single participant. Two of the recorded tasks consisted of routing from a single start to end point, and one task consisted of two start points and one end point.

Once all the tasks had been completed, participants answered a short usability questionnaire, followed by a 10 minute semi-structured interview to elicit subjective feedback (e.g. perceived ease of use, understanding of the assembly process, and clarity of the display). Video recordings of each session were reviewed to help analyze the user behavior.

5 Results

From the questionnaire data, the wearable concept was more positively than negatively received. The visual information on the AR interface was reported to be clear, although mapping information to the formboard drew some concerns. In contrast, a lower rating in confidence using the AR interface suggests more prolonged exposure may be necessary to better adapt to its usage, despite considerable agreement by the participants that the interface was easy to learn (see Figure 6).

Following on, from the interviews and video observations, a selected summary of the interaction findings are provided below:

[2] The use of UWB is not implemented in the *AR* interface (only *Schematic*) due to the use of AR markers for object tracking.

- While nobody reported eye strain or nausea, 50% of the participants indicated some mild discomfort from the weight of the smart glasses after 15-20 minutes of testing.
- From the projected AR image, it was difficult to view the full length of a wire sequence when at arm's reach to the formboard. Subsequently, all of the participants were observed to repeatedly step back to gain a wider perspective of the wire route, requiring them to physically disengage from the task at hand. On average, stepping back from the formboard accounted for a third (34%) of the task time.
- In threading wires at intersections, participants had a tendency to move closer to the formboard (e.g. within a proximity of less than 30 cm), often resulting in a loss of augmented information at that distance. Suggested improvements included using more AR markers on the formboard for object tracking.
- In terms of route planning, the augmented interface was commonly used to identify start and end point information and route color. While assembling, individuals indicated that they were likely to draw route knowledge from memory (i.e. focusing more on what they were doing than what they were seeing) until they 'lost track', or reached a more complex wire ordering stage (e.g. at an intersection).
- Uncorrected routing errors were low (averaging at one error per task), and typically consisted of either failing to route under another wire bundle at an intersection, or routing on a wrong board peg.

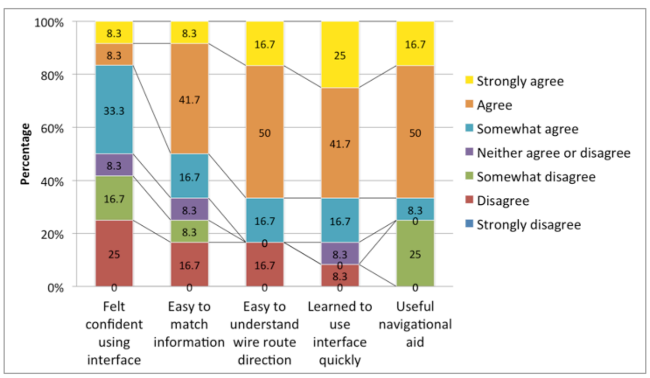

Figure 6. Results of the usability questionnaire (n = 12).

6 Conclusion

In this paper, we present an augmented system to help factory operators navigate wiring schematics akin to a GPS guidance system. Our results confirm with Mizell [7] that tracking accuracy is critical in this domain. However, we also identify that to avoid task disruptions, it is necessary to ensure the complete route sequence is visible at a close proximity to the formboard.

In terms of route planning, user feedback indicates a need to focus less on 'turn-by-turn' assistance, compared to the specific ordering of information (e.g. at an intersection). This suggests a need for more contextual cues that can intelligently prompt users when work demands are higher in the task. Similar to a GPS navigational system that can calculate an optimal route when driving, this could also include start point recommendations for more complex wire sequences.

Specifically, given the number of features in our system, more detailed user evaluations are required to address the following questions:

- Is there a measurable workload difference between using visual and audio cues to aid in wire guidance?
- How does the wire routing process differ using an augmented display compare to a traditional paper-based list?
- What are the potential trade offs between using mobile and wearable augmented solutions?
- How will task complexity and operator experience change the interaction and errors observed?

For next steps we aim to explore improvements in the AR tracking component of our system, including visualization approaches to assist in better situational awareness (e.g. the support of macro/micro views). Given the ergonomic concerns of the smart glasses used in this study, it is imperative that follow-up research tests across multiple head-mounted displays. Further research will also validate the efficacy of the tablet and voice modalities, as well as through more complex setups, gather additional information on how the navigational system can support spatial awareness.

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