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Evaluation of Wearable Visual Assistance System for Manual Automotive Assembly

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Abstract

Automotive manual assembly cannot avoid operations with limited sight for the associate. To complete the process, the associate often must rely on tactile feel or to assume ergonomically challenging positions. This work aims to provide a wearable camera system which can record a field of view near an associate's hand and display it remotely to the associate and determine user preference and acceptance. We present three camera systems: (1) wearable camera with arm wearable display, (2) wearable camera with external stationary display, and (3) wearable camera with smart glasses screen. The conducted evaluations included novice user evaluation of accuracy, timing, user preferences, and other performance results conducted on and off the assembly line providing insight on accuracy, timing, user acceptance, preferences, and performance potential in the production environment. This work is intended to assist assembly associates to better view their work area and to complete tasks faster, more reliably, and with higher quality. Our results show an improvement in performance metrics for novice users, with them experiencing increased accuracy and reduced timing with a positive acceptance rate for assistive technologies.

Keywords: Cyber-Human Systems, Maunal Assembly, Assembly Assistance, Wearable System

1. Introduction

Advancements in technology and communications are making substantial ubiquitous computing a reality in the consumer market with the computing power of a modern consumer cell phone quickly matching the power of traditional stationary computing systems. The advances made to mobile computing are enabling the emergence and increasing acceptance of consumer wearable devices in daily life and acceptance as tools for improvement of oneself [1], [2].

The unique nature of automotive assembly resulting in a high-value high-complexity product is characterized by high levels of manual value-added content which results in up to 40% of total defects arising from human error, defects which are not always obvious or simple to detect [3]–[5]. Organizational and technological structures have been enhanced, but the human worker has changed very little since the days of the first automobiles while remaining a major player in their production [6]–[9]. Non-obvious human errors have been shown to be difficult to control, and continual generation of new defect sources such as increased self-inspection and assembly guides that alternate attention between instructions and assembly have shown a negative impact on assembly performance and may result in costly defects [4], [10].

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With the automotive manufacturing industry embracing the push toward future Cyber-Physical systems and Industry 4.0, which traditionally tend to displace the human worker in favor of less flexible automated systems, automotive assembly has demonstrated a pushback towards increasing the number of assembly associates as current automation cannot yet handle the continually increasing variety and complexity in vehicles from manufactures such as BMW AG, Tesla and Mercedes [11], [12]. More humans in the manufacturing environment highlight the need for and potential influence of worker improvement and assistance programs which harness the flexibility and natural intelligence of the associate to learn from past mistakes and be guided towards higher quality and enable them to not only make better decisions and understand their assembly processes deeper but also to motivate their active participation in quality improvement.

The target assistance application is manual assembly processes which require limited sight assembly situations where the human associate relies on tactile feel and experience to locate and complete the process. This can create difficult and wasted time for less experienced associates or unusual circumstances (i.e. a cable not routed to the same place every time). Augmenting the associate's sight with a camera near their fingers allows them to see rather than guess and complete tasks faster and with less uncertainty. This work details efforts to evaluate a potential associate assistance system in the form of visual assistance for blind or obstructed assembly and the subsequent impact on the assembly process time.

2. Background

Glove based wearable sensor systems have evolved from early research in the late 1900's such as the LED based computer vision body and limb tracking system from MIT-Media Laboratory which was used to create real-time animation of computer graphics [13]. More prevalent were hand focused sensor systems such as the Digital Entry Data Glove which incorporated touch, proximity, and bend sensors at the knuckle joints, tilt sensors, and inertial sensors for measuring twist of the forearm to recognize hand signs performed by the user and output the accompanying ASCII character [14]. The Digital Entry Data Glove influenced many derivative research works including the commercially available "Power Glove" which was marketed as a unique control for the Nintendo Entertainment System. Much of the existing glove based wearable systems are non-visual sensor based and can be found detailed in [13]–[15]. Visual based wearable recording systems typically take the form of body worn camera such as those used by emergency response personnel and typically do not rely the visual feed to the wearer. A search of online patent repositories returns less than ten wearable camera or display devices and the authors could not find evidence of any having been used in manual assembly assistance.

3. Hardware system

For testing purposes three different hardware configurations were chosen: Arm mounted screen, Lineside screen, Smartglasses screen.

3.1. Arm mounted screen

The arm mounted screen configuration consists of a display module enclosed inside a plastic casing. The display is powered by a 6V battery source. The display module consists of a LCD screen to which a probe type camera is connected. The display module is Wi-Fi enabled which allows the video from the probe type camera to be cast onto another screen (discussed later). The specifications of the arm mounted screen are as follows in Table 1.

Table 1. Arm mounted screen specifications:

Parameter	Specification
Diameter of the camera	8 mm (0.31 in.)
Camera field of view	54°
Camera resolution	640 x 480 pixels
Camera Light Source	Four white adjustable brightness LEDs
Display Type	Color TFT LCD
Display Size	69 mm (2.7 in.)
Display Resolution	640 x 480 pixels
Power source	4 "AA" batteries

The display screen is placed on the preferred arm of the associate. An elastic strap is wrapped around his/her arm and buckled. The camera is mounted on a ring type mount and is worn by the associate. The output from the camera is visible on the arm mounted screen. A prototype of the arm mounted screen is shown in Figure 1 and the borescope style camera in Figure 2.

3.2. Lineside screen

In this configuration, a very similar setup to the one mentioned above is followed. The display module and the camera used are the same as the one used for the arm mounted screen. The only difference being that the output from the probe type camera is cast

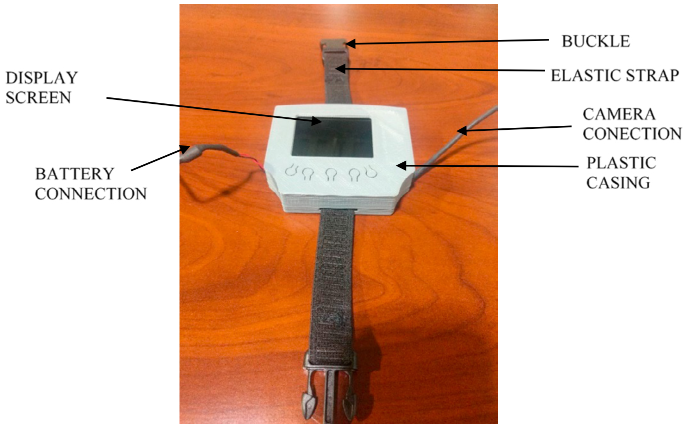

Fig. 1. Arm mounted screen

onto a large screen display (50 in.) which is placed beside the assembly line through the Wi-Fi enabled display module. To simulate this for the experiment, the output from the camera was cast onto an iPad screen which is placed at a location that is convenient for the associate to look at whilst working on the task assigned. This allows for the user to have much more of a hands-free approach.

Fig. 2. Ring type mount for camera

3.3. Smartglasses screen

To allow for an even more a handsfree approach, a smartglasses display was chosen. A wearable camera system which is readily available in the market, Realwear HMT-1 is used in this configuration. This system is voice controlled and runs on an Android 6.0.1 operating system. A borescope type camera is connected to the Realwear HMT-1 headset through a micro USB port, which is mounted on the associate's finger using the ring type mount. The headset has an LCD display on which the output from the probe type camera is seen. A custom android application was developed to obtain the output from the USB borescope camera and display it on the screen. The hardware specifications of the Realwear HMT–1 device are shown in Table 1.

Fig. 3. Smartglasses screen

Table 2: Smartglasses screen specification

Parameter	Specification
Operating System	Android 6.0.1
Memory	16 GB Internal Storage/ 2 GB RAM
Wi-Fi	802.11 a/b/g/n/ac - 2.4 GHz and 5 GHz
Battery Capacity	3250 mAh Li-ion rechargeable
Display	20 ° field of view
Display resolution	854 x 480 pixels

4. Experimental evaluation

The experiments were conducted at the Clemson Vehicle Assembly Center. In the assembly center, there is a car frame on an elevated platform to conduct research for student use. Locations with minimum sight on the car were chosen for conducting this experiment. A total of three locations were chosen to perform these tests. The frame was adjusted at an optimum height to accommodate for all the novice users performing the experiment. Boundaries were identified for the users so that at any point in the test, the users were not supposed to cross boundary. Users were briefed on how each of the prototypes was to be used.

4.1. Pre-test practice

Users were instructed to practice using all the different types of camera set-ups to ensure that they get acclimated with the device before the actual test. The demo setup consisted of a carton box of dimensions: 1ft x 1ft x 2 ft. Inside the box, a wooden plate was fixed which consisted of four bolts such that the threaded portion of the bolts was facing outward. The four bolts were of different dimensions. Beside each bolt, a symbol is printed such as star, circle, triangle and a square. During testing, the box was placed at such a height that the user had no direct vision of the inside of the box.

The users were asked to identify different symbols printed at various locations inside the box. Once the associate successfully identified the symbols, a nut corresponding to the bolt is provided with the name of the symbol beside the bolt. The user was asked to find the symbol and fasten the nut into the threaded portion. Similarly, the user was asked to repeat the task for all the bolts. No two bolts/nuts were identical. This task was repeated for each type of hardware setup and performed before the actual test.

4.2. Test area 1

Test area one was located at the front of the frame. Two connector blocks each consisting of two ports were used for this test. Different types of connectors were used on both the blocks, one block had a 4-pin and a 6-pin connector and other had a blue colored port with a white cover and a purple color port with black cover. These connector blocks were secured to the underside of the hood of the car via zip ties and were placed at distance of 1 ft. from the tip of the hood to ensure that the users had no direct vision of the connector block. The connector block with a 4 pin and 6-pin connector had a yellow and blue sticker beside them to assist users to visually identify the appropriate connection.

Fig. 4. (a) Test area 1 (b) Underside of the hood

4.3. Test area 2

Test area two was located inside the rear passenger door on the driver side. A metal plate as shown in Fig.5. (a) was chosen and 8 holes of diameter 7 mm were drilled at different locations. Each of these holes were numbered and the number was printed beside each hole. The metal plate was then attached to the inside panel of the rear passenger door using a magnet. The metal plate is placed at an appropriate height so that the user would not have to extend their hand too deep into the panel.

Fig. 5. (a) Metal plate with four screws for inspection (b) placement inside door cavity for obstructed assembly

4.4. Test area 3

Test area three was located inside the vehicle near the dashboard. Similar to test area one, two connector blocks were placed at an angle of 30 degrees with the horizontal and facing upwards away from the sight of the associate. Each connector block consisted of two ports quite like the one used in Test area one. The only difference in this case is the color of the stickers used for 4-pin connector as shown in Fig.6. The corresponding connectors were given to the user to locate and fit to the appropriate position.

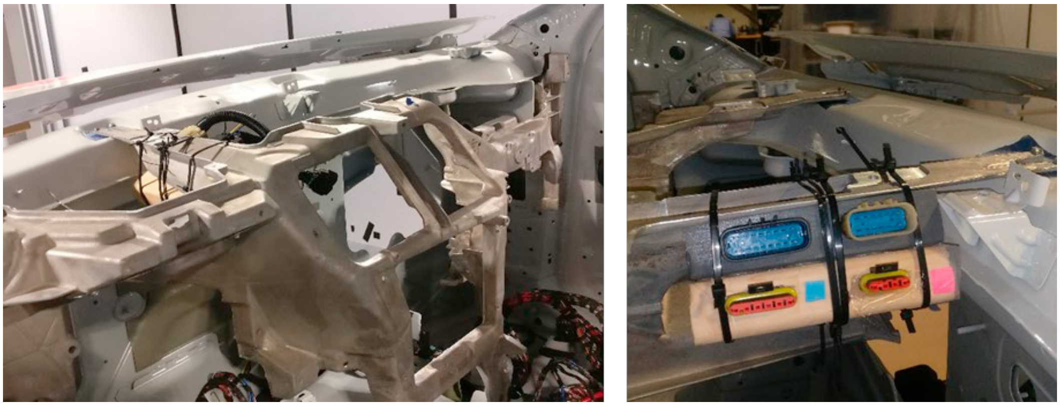

Fig. 6. (a) Metal plate with four screws for inspection (b) placement inside door cavity for obstructed assembly

4.5. Test procedure

For all tests, there were five participants with no prior knowledge of the test setup and with no prior assembly experience. All participants were considered as beginners to manual assembly processes. Each visual assistance case and trial was completed in a random order so that users were less likely to memorize the test setup while using a given device. Test locations were chosen in a such a way as to simulate an obstructed view assembly process. All the three devices capture the image using a similar same ring mounted camera, the only difference being in where the image is received. However, Test 2, consists of more significant hand movements, which might affect the orientation of the image for the handheld device. This aspect cannot be taken into consideration in the results obtained. Three trials were completed for each test area with each of the three visual assistance device and compared with the control case without the device. Users were provided with an initial obstructed view scenario of locating shapes and running various size nuts onto stationary bolts to become accustomed to each device and allowed to practice until they felt comfortable using the device.

For test one, the user was provided with the arm mounted screen and was asked to stand at an appropriate location to perform the task. The user was instructed not to assume a non-ergonomic position to view the connection ports. They were then given the appropriate couplers and were shown both the connected and the unconnected state of the connectors on both the blocks. The timer was started when the user was at a fixed distance away from the vehicle body and verbally instructed to start and was stopped when the user completed the task successfully. The user was asked to connect different connectors during each of these trials. Using three separate connectors for each trial helped to ensure that the user completed the task only with the aid of the device and not from memory of where the connectors were located.

For test two, the metal plate was supported using multiple magnets that allowed adjustment of the plate between trials. The position/orientation of the metal plate was varied between trials to better replicate a non-standard process. The aim of the test was for the user to insert the given screw into the verbally instructed hole. Three trials were conducted, and for each of these trials the user was asked to insert the screw into a different hole (specified to the user by the number printed beside the hole). The stop watch was started when the user was verbally informed to start the task and stopped when the screw was inserted into the right hole.

For test three, the user was instructed to only make the connections from the vision acquired through the camera. The connections need to be made appropriately, i.e. until a 'click' sound was heard. The same procedure as that of test one were followed.

5. Results from novice users

After conducting the tests, the users were asked to give a feedback to help us better understand the benefits and shortcomings of each of these devices. A summary of the results is provided below:

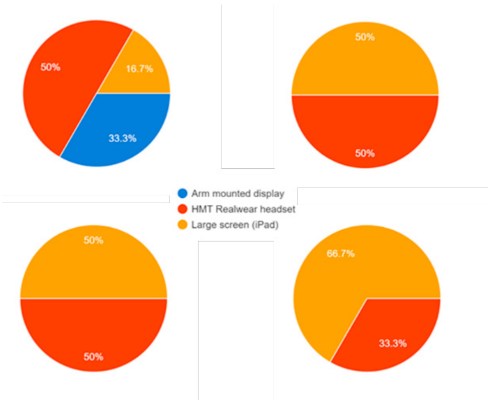

Fig. 7. (a) The device most robust to use (Top left) (b) Device easiest to use when holding something (Top right) (c) Device which allowed more dexterity (Bottom left) (d) Most comfortable device to use (Bottom right)

Results from the feedback survey indicated that users felt that the large screen device was the best among the given devices in numerous categories. This could be because, the large screen provides a much better view of the test area and allows for a hands-free approach thus the users could perform tasks with more freedom and better vision. The users also rated the device as the most useful when completing Test 1 and 2. One of the primary reasons for this could be the fact that since the display size is large and unaltered during the entire task, the users did not have to pay much attention to the movement of their hands. Also, this can be justified by the fact that it was rated by all users as the device which had the clearest vision.

From the user feedback, it was noticed that, in some of the aspects, the smartglasses device has been quite useful. Fig. 7. (a) shows that the users rated the smartglasses screen to be the most robust to use. The hands-free capability of this device has made it the one of the preferred devices when holding onto something and as the one which allowed more dexterity. Further it can be observed that the arm mounted display has not been voted by any user in the categories which allowed more dexterity and comfort-level.

Some of the suggestions provided by the users to improve the tests are given below:

- With respect to the smartglasses screen, users felt constantly concentrating on the small display over a long period of time was painful and users preferred the larger screens.
- Increase the light intensity of the camera used on the smartglasses screen.
- Increase frames per second of the smartglasses screen.
- The arm mounted display gave a glare effect which affected their vision. Also, consistency of the angle of view has been an issue. This is because while performing tasks, the user had to rotate the arm to maintain line of sight to the screen which hindered the handheld device.

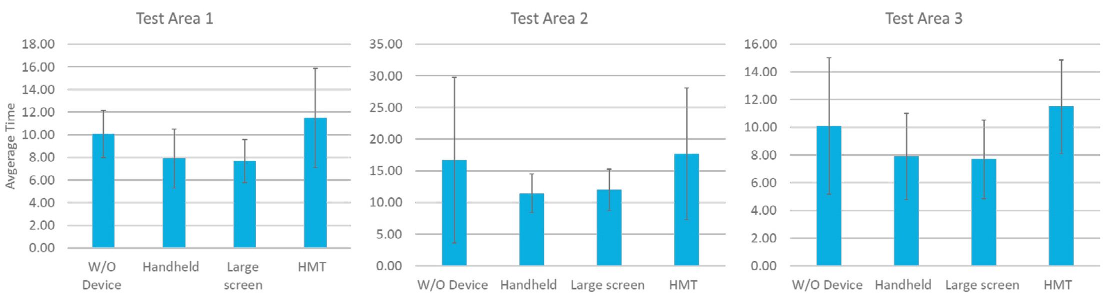

Fig. 8. Mean task completion time with standard deviation of each vision assistance system (left) Test area 1, (center) Test area 2, (right) Test Area 3

From the mean task completion times shown in Fig. 8., it can be seen that the handheld (arm mounted) and the large screen devices appear to have a lower mean task completion time as compared to the control case without visual assistance device. To determine if there is a statistically significant difference between the mean task completion times for the three devices and the control case, Kruskal Wallis test was used. A non-parametric test was used to compare the mean task completion times because of two reasons: 1. The data was non-normal. 2. The sample size of the data was too small. Hence, parametric tests such as ANOVA cannot be performed. Kruskal Wallis test was performed using SPSS software. The conditions necessary for performing Kruskal Wallis test such as homogeneity of variance was checked before performing the analysis. Homogeneity of variance was checked using a non

– parametric Levene's test by comparing the difference of ranked means. A reference significance value of 0.05 was chosen (95% confidence interval). The results indicated that there is no statistical difference between the variance of process times between the devices for each test. Thus, Kruskal Wallis test can be performed. A reference significance value of 0.05 was chosen for the Kruskal Wallis test as well.

Table 3: Kruskal Wallis Test – Significance Values

Test Number	Significance Value
Test 1	0.01
Test 2	0.499
Test 3	0.04

Results from the Kruskal Wallis test (Table 3) indicated that the mean process times obtained in Test 1 and 3 for various devices are statistically different from each other. But the mean process times obtained in Test 2 for various devices are not statistically different. This can be seen from the significance values shown in Table 3.

6. Conclusion

This work demonstrated multiple visual assistance systems for manual obstructed view automotive assembly of less repeatable tasks and the subsequent impact on process time and relevant user feedback. From the results, it can be seen that the inclusion of a visual based assistance system decreased the mean task completion time for Handheld device and Large screen display when compared to the case without the device for Test 1 and 3. The mean task completion time increased when the users used the smartglasses device for the tests. From user feedback, this increase in time can be attributed to the limited field of view on the display screen, limited acquaintance in using the device and low illumination level of the camera used in smartglasses screen. From this, it was found that the method of visual feedback played a significant role in the user acceptance and the mean task completion time. Future work will include additional feedback methods such as a larger display or visual overlay method of visual feedback, replicating the test areas with experienced assembly users, and examining the effect of various illumination levels and frames per second on the task completion time and stability.

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