Preliminary Investigation of Wearable Computers for Task Guidance in Aircraft Inspection

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Abstract

This paper describes a preliminary investigation of how the capabilities of wearable computers may be used to provide task guidance in mobile environments. Specifically, this study examined how the capabilities of wearable computers may be used to aid a user in an inspection task, using as a case study the procedural task of preflight inspection of a general aviation aircraft. Two different configurations of a computer-based, voice-activated task guidance system and the current method of preflight inspection were compared and evaluated. Initial results demonstrate an over reliance on the computer by the pilots and indicate the importance of the user interface design to the performance of the inspectors. The paper concludes with recommendations on promising directions of research.

Keywords
task guidance, procedural tasks, aircraft inspection, computerized procedures, decision aiding, wearable computers

1. Introduction

Wearable computers combine portable, voice-activated, wireless-networked computers with personal auditory and visual displays. Wearable computers make it possible to access a large amount of information at the job site without the use of the hands. The information can be in the form of text, graphics, videos, animations, or sounds.

Wearable computers have been suggested for many uses: for medical applications (e.g., surgery, EMT) [5, 10, 13]; to aid inspection and maintenance workers (e.g., aviation) [3, 18]; for navigation (e.g., tour guides, military applications) [1, 8]; for communication (e.g., military operations, remote collaboration) [11]; and as memory aids in everyday life [4, 19].

There have been field tests of wearable computer systems for mobile tasks [18, 2]. However, these studies have generally focused on the capabilities of the hardware. Often, paper-based manuals are scanned into the wearable computer for the field tests. With the increasing capability and affordability of wearable computers, in terms of display and computing power, studies are warranted into how wearable computers can be used to change and enhance user performance at mobile tasks.

This paper describes a preliminary study of how the capabilities of wearable computers might provide task guidance to aid an inspector, using as a case study preflight inspection of a general aviation aircraft.

2. Background

This section describes the wearable computer used in this study and the characteristics of preflight inspection.

2.1. Wearable computer

The wearable computer was designed to help a mobile user perform information-intensive tasks. Figure 1 shows the major components of the wearable computer used for this study. The computer is worn on a belt around the waist. The computer is an older 486 75 MHz Via FlexiPC with 24 MB RAM and from 320MB to 1.2GB size hard drive depending on the number of 320MB

PCMCIA hard drives used. The headset, manufactured by Kopin, combines a visual display, microphone, and earphone in one integrated component. The 640 by 480 monochrome visual display provides visual information to aid the user in completing a preflight inspection. The earphone allows the user to hear explanatory audio narration such as the current procedure. The microphone and voice recognition software (Listen for Windows by Verbex) allow the user to control the computer via voice. Two custom-built packs of commercial Nickel Metal Hydride (NiMH) rechargeable batteries power the computer and headset (one for the computer and one for the headset). The battery packs are worn with the computer at the waist. All the components combined weigh approximately 5 lbs.

Figure 1: Major Components of Wearable Computer

2.2. Preflight inspection

Preflight inspection is a task done to ensure a plane is airworthy. In general aviation, it is performed by the pilot who will be flying the plane and is concentrated primarily on the condition of the exterior of the plane. Preflight inspection is a procedural task that is generally memorized, although pilots may choose to refer to a paper checklist.

This task was chosen for three reasons. Most importantly, this task is a procedural task that requires an inspector to examine the plane in a pre-specified manner. Second, from a practical standpoint, this task provided the ideal conditions for a quick, preliminary study; a realistic environment, with experienced personnel, in a short time frame. Third, this task is a mobile task that might benefit from the use of a wearable computer, as will be described below.

Although pre-specified procedures are useful for maintaining safety and consistency, there are a few problems that can occur with their use [6, 7]. First, memory lapses may be a problem. For example, if there are no physical reminders of the steps, then one or more of the steps may be forgotten. The use of paper checklists may guard against forgotten steps; however, studies have shown that there are also problems with using paper checklists [12]. Paper checklist users can still get distracted or may be interrupted and skip one or more steps.

In addition to remembering the steps involved in a procedure, an inspector also needs to make a decision at each step as to whether that item is suitable for flight. Two types of decisions have been identified. Some decisions are discrete, because they concern items that have a finite (usually small) number of distinct states. For example, the ignition switch is a discrete item: it has two states, either on or off. The other type of decision is continuous. Continuous decisions concern items which can vary across an infinite number of states. For example, tire pressure is a continuous item: it has an infinite number of states and at some point the states switch from acceptable to unacceptable.

In addition to creating a hands-free version of the paper checklist to aid memory recall of the steps, wearable computers may be able to aid the inspectors in their decision making, thus providing complete task guidance. Aiding each decision type requires a different technique. For discrete decisions, the user needs to know what the correct state is supposed to be, often provided by the procedural step. For continuous decisions, the user needs a standard of acceptable and/or unacceptable conditions.

3. Inspection systems to be evaluated

These considerations guided the design of the task guidance inspection systems to be evaluated. Two inspection systems were developed for this study. One system contains only text and will be referred to as the ‘text system’. The other system has text and pictures and will be referred to as the ‘picture system’. Both systems support the memory recall task that the pilot must use to complete the procedure correctly. The text system is intended to aid the pilot with discrete decisions by making clear the desired state for discrete items. The picture system additionally supports continuous decisions by providing standards of the desired state of continuous items. Both systems incorporate the procedure as it appears in the Cessna 172 pilot’s operating handbook.

However, the pilot had the opportunity to go to any step s/he liked by using voice commands, and to review which steps had not been completed. Both systems have identical wording for each procedural step.

The text system served as a basic electronic checklist by presenting the steps involved in preflight inspection. A list of steps guides the pilot through the inspection task, aiding in memory recall and helping to ensure that nothing is missed by allowing the pilot to "check-off" the items that have been completed. As each step is shown on the screen the pilot hears the text of the step on the personal auditory display. A sample display is shown in Figure 2.

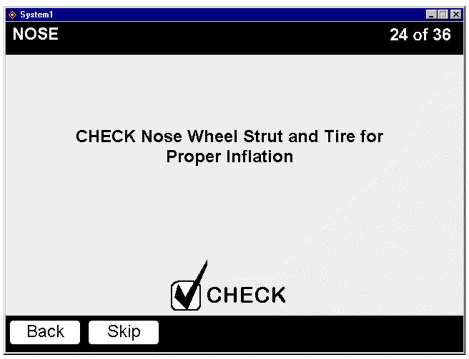

Figure 2: Sample Display from Text System

The picture system has the same electronic checklist capability as the text system but also contains digital photographs of the items on the aircraft to be checked. In addition to aiding in memory recall of the steps of preflight inspection, the picture system also provides specific examples of each inspection step to aid in the accuracy of the pilot's decisions as to the acceptability of the aircraft for flight. Figure 3 contains an example of a display from the picture system.

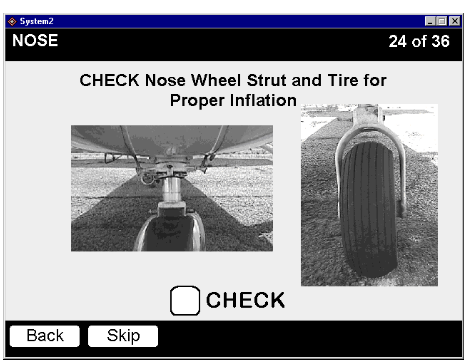

Figure 3: Sample Display from Picture System

4. Evaluation method

The pilots were required to do a preflight inspection, either with or without the use of one of the wearable computer preflight inspection systems. The preflight inspection was conducted on a 1978 Cessna 172 in a hangar. The pilots reported any problems they perceived.

There were many constraints presented in the development of this preliminary study: the pilots could only volunteer a short amount of time (precluding the use of a within-subject design), the plane was only available for a weekend, and the plane could not be damaged in anyway. These constraints limited the design of the experiment from a statistical standpoint but still allowed for the discovery issues that require further research, the intended purpose of this preliminary investigation.

4.1. Preset faults

The aircraft had ten preset unacceptable conditions in order to evaluate the pilots' thoroughness. These faults were selected to fit into the three categories listed in Table 1. In the first category are faults that are not identified by the procedures listed in the pilot's operating handbook and thus are not on the wearable computer. Because the wearable computer would not aid pilots in detecting this type of fault it may provide an indication of how much the wearable computer users were relying on the wearable computer. The other two categories are faults on items listed in the handbook: one category is discrete faults and the other category is continuous faults. More serious faults were not used in this investigation as they would have resulted in costly or permanent damage to the aircraft.

Table 1: Preset Faults on Experimental Aircraft

Not on Computer
Missing Certificate of Airworthiness
Paper towel in cowling
Discrete - On Computer
Alternate static source selected
Baggage door unlocked
Ribbon on left elevator hinge
Oil low
Tape covering static source
Continuous - On Computer
Ailerons binding
Fuel low
Tire pressure low on left wing tire

4.2. Participants

The participants consisted of 15 licensed pilots who currently fly the Cessna 172. Below is a list of their characteristics, showing them to be experienced pilots.

- The pilots had been licensed for an average of 10.41 years (range 2 months to 27 years).
- The average total flight time was 373.6 hours (range 70 to 2149).
- The average total flight time in a Cessna 172 was 187.1 hours (range 10 to 800).
- Eleven of the 15 pilots learned how to do preflight inspection on a Cessna 150, 152, or 172.
- All of the pilots were male.
- The average age was 37 years (range 22 to 61).

The pilots were randomly assigned to one of the three experimental groups: current memory-based procedure (control group), text system, and picture system.

4.3. Procedure

The wearable computer users first trained the wearable computer on their voice. Next, they went through an abbreviated task guidance program to learn about the full-blown task guidance inspection system they would use. The abbreviated program led them through the inspection of a simple “widget” and had only 5 steps instead of the 36 of the experimental systems. The pilots not using the wearable computer went straight to doing the preflight inspection.

Before the preflight inspection, all of the pilots were given identical instructions that contained sufficient information for them to judge specific aircraft requirements for the flight, such as fuel requirements. The wearable computer users were also told that the inspection system was an aid, with content identical to the pilot's operating handbook, that they could use as they saw fit.

While the pilots did preflight inspection they were video taped for a subsequent debriefing of their actions. During the video debriefing the researcher took notes on what the pilots said they were doing and what they thought the faults were.

After the debriefing, all the pilots completed a background questionnaire to gather demographic information and determine their level of experience with the Cessna 172. The pilots using a wearable computer system were also surveyed about the system (e.g., how useful they thought it was, where it gave them problems). Finally all the pilots were interviewed to elicit free responses and opinions about their normal method of preflight inspection. The entire process took about an hour and a half for the pilots in the control group and two hours for the wearable computer users.

5. Results

This section covers three different types of results. The first section reviews the fault detection results. The second section discusses the processes that the pilots used to conduct this preflight inspection. The last section provides the results of the questionnaires and interviews with the pilots.

5.1. Fault Detection Results

The first measurement is the percentage of pilots who detected each fault, as shown in Table 2. A fault was considered detected if the pilot formed a justifiable opinion about the fault. In most cases, pilot decisions followed the suggestions of the wearable computer task guidance system; however, some exceptions were found. For example, all but one of the pilots opened the baggage door and realized it was unlocked. The wearable computer specifies that the baggage door should be locked, however, some of the pilots stated later that they leave the baggage door unlocked as another escape route.

Table 2: Fault Detection Results

	Control	Text	Picture
Not on computer			
Missing Cert. of Airw.	20%	20%	0%
Paper towel in cowling	40%	20%	20%
Average	*30%*	*20%*	*10%*
Discrete-On computer			
Alt. static source on	0%	80%	100%
Baggage door unlocked	80%	100%	80%
Ribbon on elev. hinge	80%	40%	60%
Oil low	80%	80%	80%
Static source covered	100%	100%	100%
Average	*68%*	*80%*	*84%*
Continuous-On computer			
Aileron sticks	40%	20%	0%
Fuel low	80%	40%	75%
Tire pressure low	60%	80%	100%
Average	*60%*	*47%*	*58%*

Overall, there were no statistically significant differences between the experimental conditions for the different fault types. The ‘Not on computer’ faults, which were expected to be found more frequently by the control group, had a low detection rate for all the groups. The primary determinant of detection appears to be the conspicuity of the fault.

One exception, however, was the fault 'Alternate static source on.' Checking the alternate static source valve was one of the steps on the computer and all but one of the wearable computer users at least tried to check it, while none of the control group looked at it. This may indicate that the wearable computer users were following the procedures given by the wearable computer, even though this has evolved to not be a part of external preflight inspection by many general aviation pilots.

5.2. Process Results

In addition to the fault detection analysis, the videotapes of the preflight inspections were reviewed. One aspect of the videotapes, which becomes apparent, is the discreteness of activity and lack of physical contact with the plane by the wearable computer users. The wearable computer users jumped from one item to the next as the computer told them to do, whereas the pilots who did not use the wearable computer had continuous activity. The non-computer users were nearly always looking at and touching the plane. Even though the wearable computer users had their hands free, and commented that they thought a hands free reminder was a good idea in the questionnaires, they rarely touched the plane. They infrequently ran their hands along the skin of the plane or touched a part of the plane not explicitly mentioned on the wearable computer.

As such, there were several critical steps which all or a majority of the control group performed that were not explicitly listed in the wearable computer procedure. The top of Table 3 shows some of these differences. Many of these inspections are important to flight and do not represent administrative checks, such as the presence of particular paperwork.

There were statistically significant differences between the control group and each of the wearable computer groups ($p<0.05$, with a one-tailed t-test). There was no statistical difference between the text and picture wearable computer groups. However, in some cases there is a noticeable difference between the two wearable computer groups. For example, three of the text group did check the control cables on the tail section compared to only one of the picture group. The difference is even more pronounced for inspection of the flaps: all of the text group checked the flaps compared to only one of the picture group.

From this data two possible explanations emerge for why these differences might have occurred. The first explanation is that the pictures were used as an absolute, complete list of required steps, instead of providing a reference reminding the pilots of some of the steps. The other explanation is that the picture system was inherently confusing, as three of the users of the picture system got very confused about the order of the steps. However, it is not clear why the picture group was confused; this requires further research.

In contrast, there are a few things that were explicitly mentioned by the wearable computer, which only pilots in the control group forgot to check. The bottom of Table 3 provides the details. The control group is statistically significantly lower than both the text and picture group for these three inspections ($p<0.05$, with a one tailed t-test). Three of the control group pilots forgot to check the fuel vent opening for stoppage, one pilot forgot to check the stall warning hole for stoppage, and two pilots forgot to look at the air filter for cleanliness.

Thus, the procedures can help to ensure that items are checked. However, as illustrated, if the procedures are impoverished then it is likely that items not explicitly mentioned will be left out. Tempering this heavy reliance on the computer procedures is a fruitful area for innovations in computer aid design.

Table 3: Process Analysis of Items Done During Preflight Inspection

	Control	Text	Pictures
Not on computer			
Inspect control cables	100%	60%	20%
Inspect flaps	100%	100%	20%
Shake elevators	80%	0%	0%
Shake wings or struts	60%	40%	0%
Check antennas	60%	40%	20%
Check exhaust pipe	60%	20%	20%
Examine tops of wings	60%	0%	20%
Average	*74%*	*37%*	*14%*
On computer			
Fuel vent clear	40%	100%	100%
Stall warning clear	80%	100%	100%
Air filter clean	60%	100%	100%
Average	*60%*	*100%*	*100%*

5.3. Questionnaires and interviews

Information from the questionnaires indicates that the pilots liked the idea of the hands free checklist, but felt changes to the current hardware or system design were needed to make it an effective aid. Their suggestions touched on both the hardware changes and changes to the computerized procedure. In general the pilots thought that the wearable computer was cumbersome and would like it to be lighter in weight. Nine of the wearable computer users could see the visual display "okay" to "very well." The other pilot said he could not see the entire screen.

Three pilots thought the visual display got in the way of their inspection. This was lower than expected for this highly visual task. The visual display could be moved out of the way to check something carefully with both eyes but this was rarely done. Only three pilots ever moved the display and only one of these moved it more than once.

Ninety percent of the wearable computer users said they could control the computer with their voice “okay” to “very well.” One of those nine had to retrain the computer on his voice just after starting. One pilot had a very difficult time. However, given the environment, a large metal hangar next to a runway, these are remarkably good voice recognition results.

Looking at system design, when asked if they used the auditory information, six pilots said “somewhat” to “yes,” while the other four replied “not really” to “no.” Compared to the visual information, seventy percent said they used the audio information less, twenty percent said they used audio information more, and one pilot said he was not sure.

For the five pilots who had pictures included in their system, three said they were useful. When asked what other pictures might be helpful, the pilots responded with pictures with trouble spots labeled and pictures of bad items. Both of these types of pictures could conceivably aid in decision making by providing clearer references as to what can be wrong.

All the pilots using the wearable computer wanted to be able to customize the procedure to their own way of doing preflight inspection (i.e., order of steps and items inspected). From the interviews, it was learned that ninety percent of the wearable computer users did preflight inspection differently than the procedure listed on the computer. Four pilots reported that they did things in a different order than usual, two said that the procedures prompted them to check items they do not normally check, and four pilots said they checked fewer items than usual. In addition, it was determined that five of the 15 pilots normally carry a paper checklist around with them when doing external preflight inspection. Twelve of the 15 pilots said they always do preflight inspection in exactly the same way, in an effort not to forget anything. By always doing the preflight in the same way, they can rely on habits to ensure everything is checked.

These results imply that some of the pilots who used the wearable computer changed their method of preflight from that they would normally employ. When asked why, few specific responses were found. Pilots may have felt a need to use the wearable computer based on novelty or the experimental conditions. One pilot said that it was easier to follow the system than think about what he normally does.

5.4. Discussion

This preliminary investigation has some limitations: there were a small number of participants, who did only one experimental task, and the wearable computer systems were being used for the first time. These limitations and the few profound differences found between the experimental groups makes it impossible to draw definitive conclusions.

However, some observations can be made about this investigation. One aspect of this task that seems likely to have had an effect on the outcome is the fact that pilots rarely find anything wrong with their aircraft. In this study there were ten things wrong with the plane, therefore, reminding a pilot to inspect a particular item does not necessarily mean that s/he will see a fault. As one pilot from this study said, you have to try to “see what you are looking at.” That comment corresponds with other studies which found that, when a person is not expecting a fault, it is less likely that s/he will see it [14]. It appears the rarity of an event can have an impact on the perception of an inspector.

A second observation is that the wearable computer system was compelling enough to make its users not do as thorough a preflight inspection as the control group pilots or, by extension from the control group and from the comments of the computer users, as they themselves would have done without the wearable computer. This effect appears to be even more exaggerated with the picture system. It seems as if the greater specificity of the pictures makes the system even more compelling on what should be inspected.

This reliance on the computer procedure is supported by the results obtained in a Carnegie-Mellon University (CMU) wearable computer field test [18]. The CMU researchers found that their inspectors were more thorough with the wearable computer procedures than with the required paper procedures even though the procedures were identical. The CMU researchers surmised this occurred because the wearable computer guided the inspectors through every step of the procedure. The CMU field test is the flip side of this study and provides an altered view of the computer being a compelling leader; even users who are required to follow a given procedure are more likely to follow a computer procedure step-by-step than a paper procedure.

If the procedures are complete and thorough, such as the military procedures used by CMU, performance is enhanced. However, when the procedures are minimal, such as the pilot’s operating handbook, in this investigation performance is diminished. This trend also matches studies in other domains, which showed that users tend to follow a computer’s advice rather blindly, often ignoring their own knowledge or not taking the time to check the accuracy of the computer [16, 9]. This behavior becomes particularly obvious in cases where a computer's knowledge or logic is incomplete or faulty. Complete compliance with the computer is only good when the computer's procedures are guaranteed correct and complete.

It is more difficult for the computer to be correct and complete for some tasks than other tasks depending on how standardized the task is. Although preflight inspection is a procedural task, it is not a highly standardized task. Preflight inspection is done in a similar manner by different pilots but the number, type, and order of items being inspected differs slightly from pilot to pilot. These differences were apparently disrupting to pilots who have developed an inspection pattern that is different from the one prescribed by the wearable computer.

6. Conclusions and recommendations from preliminary investigation

Drawing from the discussion of the results, recommendations can be made for further research into the use of computerized inspection aids.

One area that needs exploration is in the design of computer inspection aids for environments with rare events. It is often assumed that if a person looks at a fault, that person will recognize the fault as a fault. However, due to the human tendency to overlook or discount events that are not expected, an inspection aid needs to do more than remind an inspector to look at an item that might be faulty. Wearable computer display and computing capabilities should be explored in regard to this issue.

A second area that could use some additional investigation is the design of computer inspection aids that do not cause the user to rely solely on the computer. For many of the proposed uses of wearable computers, the user is expected to get instructions from the computer. However, if these directions are not correct and thorough, these results and other studies indicate that the users may not detect errors or faults. In fact, in this study several of the pilots mentioned just after completing the preflight inspection that they should have checked several other things, indicating they were not as thorough as usual. Only one of the ten pilots using the wearable computer did extra checks after the computer said the checklist was complete.

A last area to examine is the ability to aid users who are not doing highly standardized tasks. The use of the computer as an aid should not limit the methods of completing a task to one, the computer's method. The ability to flexibly aid users needs to be emphasized to broaden the applicability of wearable computers.

7. Implications for Task Guidance

Wearable computers have been suggested for many applications, but one of the similarities between these applications is the use of the wearable computer to provide task guidance. As such, it is important to consider what the characteristics of good task guidance are.

Task guidance may be developed with two different philosophies of use [15]. One philosophy of use is that the user only needs to understand and be able to follow the provided instructions verbatim, that is, understand the syntax of the provided procedures. This philosophy will be referred to as the syntax philosophy. The other philosophy is that higher-level cognitive activities, such as situation awareness, evaluation, and planning, are essential to competent performance with procedures, that is, an understanding of the form and meaning of the provided procedures. This philosophy will be referred to as the semantic philosophy. These two philosophies dictate the design of the task, and accompanying procedures and training [15].

It appears that implicitly task guidance has been conceived of in the context of the syntax philosophy. It is assumed that the instructions are complete and should be followed closely. However, as this investigation and other studies have shown this can be a dangerous method if the system's knowledge is not sufficiently complete. This suggests that the semantic philosophy of task guidance should be pursued. The user should be encouraged to use higher level cognitive abilities to assess the current situation to determine the adequacy of the task guidance.

There is some evidence that higher level cognitive skills are sometimes present with the use of paper procedures, resulting in higher performance than if these cognitive abilities were not used [15]. Although it is not clear what encourages this behavior and how it may be adapted to wearable computers providing task guidance, it is clear that this type of behavior needs to be encouraged.

Research from other domains suggests that it is important to keep the user actively involved in the process [17, 16, 9]. The user needs to assess the appropriateness of the instruction, plan for future instructions, and decide if additional actions are required. In order to do all this the user needs to be aware of how the present instruction is meant to be used and its relationship to other instructions and the environment. In other words, the user needs to know how the present instruction fits into both the task context (preceding, succeeding, and related instructions) and the environment context. How to provide this information to the user requires further research.

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