Usability of Pictograms As An Automated Information Input Mechanism In Graphic User Interface (GUI) for Mobile Computing Devices On Construction Sites

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ABSTRACT

Field documentation is an important link in the construction industry on the individual project basis and for the entire company operations. The information contained in the field documentation is the primary source for the management to monitor the status of the project and perform various analyses. This information also provides the basis to establish the historical cost data used for securing future work. The advancements in the information technology industry especially in the mobile computing technologies have provided many opportunities to computerize and automate the field information flow. Over the years studies have examined various hardware technologies on their usability for fulfilling this task. This paper examines the past research from a usability point of view and focused on the Graphic User Interface (GUI) part of the system. The study evaluated the usability properties of pictograms and pre-determined text lists as mechanisms for automated data entry on mobile computing devices. Results showed foremen and construction professionals performed visual search tasks faster with pictograms than with pre-determined text lists.

INTRODUCTION

Construction field supervisors play a pivotal role in the information flow process on construction sites. The information contained in the field documentation is one of the primary sources that the management uses to monitor the project progress and keep track of issues and action items that would impact the project performance. This information is often used for a variety of project management analyses such as earned value analysis and profit center analysis. It also provides the basis to establish the company historical cost database used for bidding and estimating to obtain future work. Field documentation is often the first go-to source during the dispute resolution process between the project stakeholders. For this important reason, integrated project delivery (IPD) and lean construction (LC) systems recognize and leverage the important role of field supervisors in the supply chain management.

With the challenging characteristics of their job and a busy work schedule, construction field supervisors often devote most of their attention to field problem solving, crew supervision, coordination with suppliers, agency inspectors, and other contractors. Field documentation is often relegated to the bottom of their priority list. As the result, field documentation is either haphazardly completed or deferred. Consequently the field documentation often contains incomplete or inaccurate information that makes it difficult for the management to fully exploit its value. The deficiency in the information collected in the field, though clearly desirable to be corrected, is often sacrificed by the management as a trade-off to a smooth running project. This dilemma was long before recognized in the construction industry (Borcherding 1977).

Since 1990's there have been ongoing efforts by the researchers and commercial solution providers in the construction industry to computerize the construction field data communication process. Examples of the early works include researches on pen tablets, barcode technologies, radio frequency identification (RFID) technology, wireless communication technologies (Coble et al 1998), and pocket PC's (Repass et al 2000). Examples of more recent work include personal digital assistant (PDA) and wireless web integrated system for quality inspection (Kim et al 2008), mobile computing integrated with telematics digital workbench for onsite defect management (Dong et al 2009), and on-site management system that integrated most mobile computing infrastructure components such as closed circuit television (CCTV), wireless technologies, GPS, and smartphones (Kim et al 2013).

Real-time communication with remote information server is no longer technical obstacle with the wireless wide area network (WWAN) from commercial cellular service providers or wireless local area network (WLAN) implemented on the jobsites. The form factors and functionalities of mobile computing devices for construction site use are also no longer a debatable issue as mobile computing devices nowadays generally are all equipped with touch sensitive screen, digital camera, GPS, gyroscope, accelerometer, and other kinds of sensors.

There have been proliferations of commercially developed project management mobile applications for construction site use in recent years. Examples of such include HCSS, e-Builder, Canvas, Dexter+Chaney, and Bentley Field Supervisor. However, many of these commercialized mobile application solutions are focused on information retrieval and presentation (viewing construction CAD drawings, installation details, etc.) part of the construction field communication process but not much on data input end. When information is entered through various forms on these mobile computing systems, it is usually done through typing with the "soft" (onscreen) keyboard or using hand writing recognition method. However, these data input methods are still not very efficient means for these tasks.

USABILITY THEORY

The usability concept was introduced in 1990's by Shackel (1990) and Nielsen (1994) in the human-computer interface/interaction (HCI) research field. In simple words, it defines how usable a product or system is when it is used by the targeted users to perform the intended activities or tasks. In other words, a product with high usability is easier to learn and use than one with low usability. Since then, usability theory is widely recognized as an important system quality besides the technical performance, functionality, internal consistency, and reliability. Most major information technology companies have usability engineering divisions to test their products and systems before market releases. To the end users, a system with good usability can help improve their productivities, reduce the magnitude and frequency of the user errors, decrease training effort, and provide higher user satisfactions. Generally, the usability of a system is typically measured by collecting and analyzing data on time required for using the system to complete a given task, number of errors and type of errors experienced by the users, time required to learn the system, retention quality of the knowledge learned to use the system, and the user's subjective assessments of the system.

In a retrospective view, the past research in the construction industry on computerizing field information communication has mainly focused on usability issues of the hardware and functionality aspects of the HCI. The approach adopted by most researchers consisted of integrating commercially available information technologies and evaluating their appropriateness and robustness in various types of field information documentation/communication tasks. While these research efforts provided many valuable insights and lessons as to the characteristics of the ideal mobile computing systems for construction field settings, the graphic user interface (GUI) aspect of the system usability unfortunately did not receive much attention. The characteristics of an effective GUI for field users were seldom considered in the past research efforts.

PICTOGRAMS vs. PRE-DETERMINED TEXT DATA INPUT MECHANISMS FOR FIELD DOCUMENTATION

Field documentation essentially consists of "what," "when," and "where" information. The "when" (date/time) information can be easily entered by using onboard calendar/time functions whereas the "where" information (geo-referenced location information) can be automated by using onboard sensors and project site and building plans loaded on the mobile computing devices. The "what" (activity) information though more complex can be automated as well. Many researchers believe a substantial portion of the information documented in the field is repetitive from project to project and can easily be standardized (Bowden et al. 2002, and Cox et al. 2002).

Experts in the construction research field have accepted that predefined drop-down menus and text lists in a GUI may be a more efficient and easy-to-implement method than typing or writing on the screen to automate the standardized information input process in the construction field. Using a pen/stylus to click and select items in a GUI is a relatively quick and effortless process therefore the user efforts in performing these tasks would be minimal.

Pictograms, also called pictographs or icons, are ideograms that convey their meanings through pictorial resemblance to a physical object, activity, or idea. Pictograms are widely used in the construction industry in forms of symbols to convey various safety messages. Since pictograms are more visually distinctive than abstract words, it is generally believed that it is easier to identify a pictogram than a word from a group of GUI objects. Pictograms can represent a considerable amount of information in very little space while space is a premium resource in GUI's. Both pictograms and pre-defined text have the potential to reduce the data input effort by construction field supervisors as the intended users. Therefore it would be interesting to know if there is a difference between these two mechanisms in terms of usability, and if so what the difference would be. This is important as the results would help validate or invalidate the concept of using pictograms as a key GUI component to automate the data entry process on the mobile computing systems designed for construction field supervisors. This is especially important to the IT industry sector serving the construction industry because it takes a great amount of time and effort to develop quality pictograms which often require many iterations and refinements before achieving something that would best convey the design intent.

RESEARCH METHODOLOGY

Research questions. From the usability point of view, there were several questions of primary interest and will be discussed in this paper:

- Do construction field supervisors perform computer tasks faster using pictograms than using predefined text lists or vice versa?
- Do construction field supervisors experience fewer errors using pictograms or pre-defined text lists?
- How do construction field supervisors perceive the pictogram-based GUI as effective means to automate the information input process on mobile computing devices?
- How do construction field supervisors perceive the order of importance among the usability factors of task completion time, errors and user satisfactions?

As visual search tasks generally take up a great amount of time in the human interactions with a GUI, the study specifically focused on this domain.

Pilot/preliminary studies. Several preliminary studies were conducted before the actual research study and these included: pictogram design and recognition quality testing; sample size preliminary estimation for hypothesis testing; visual search game initial testing; test platform effect study; and pictogram learning curve analysis. Test subjects were selected for the pilot/preliminary studies and they were not part of the sample for the full study.

Test apparatus. The apparatus used in the visual searching task experiment was a custom developed icon/text matching JAVA computer game (see Figure 1). The computer game was tested in the pilot study phase and underwent several iterations and refinements to incorporate the findings from the pilot study phase. In this visual search game, each subject was required to complete three icon-training sessions before the two visual search test sessions. Three training sessions were given to each subject as the pilot study showed this was required for the majority of subjects to master the icon-text associations. The sequence of the text→icon visual search session and the icon→text visual search session in each game was randomized. The reciprocal search scheme of the computer game was intended to eliminate any bias that may exist due to possible visual appeal factor associated with iconic interface.

Pictograms/icons included in this study were designed in Axialis® AX-Icons 4.5 program. A total of thirty-five (35) 64-pixel by 64-pixel pictograms were developed to represent various sitework construction activities. These pictograms were first evaluated by a university professor in the construction management program and went through several iterations before a recognition quality testing was done by 18 construction industry users (foremen, equip operators, etc.) who were familiar with sitework construction activities. 15 pictograms with a minimum recognition rating of 90% were selected for the computer visual search game.

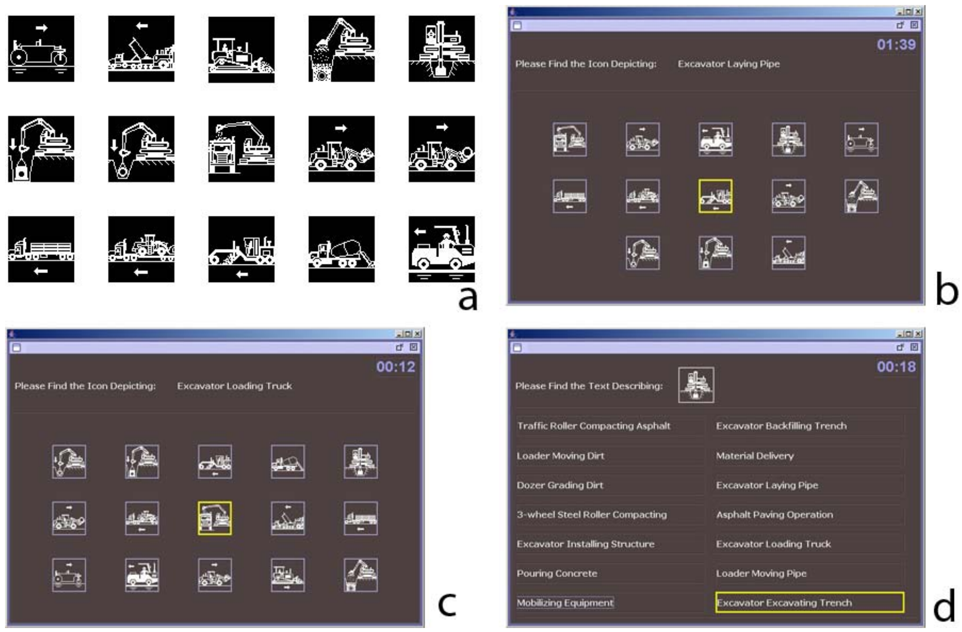

Figure 1. (a) 15 Pictograms used for the final study, (b) Sample pictogram recognition training screen, (c) Sample text->icon visual search screen, (d) Sample icon->text visual search screen

Data collection methods. The data for the two research questions (visual search task time and errors) were collected using the visual search game. The visual search game captured and recorded the system time stamps at the following user interface events: screen displayed/elapsed time meter started, search instruction displayed, mouse cursor enters the search object panel, and screen object selected. It also recorded information such as the target object names and the name of each screen object selected. Figure 2 shows the graphic illustration of the algorithm used to compute these variables.

Study Samples. The samples used in this paper included two samples. The first sample was used in a Ph.D. dissertation study (Qu 2006) and included thirty-five foremen who were selected from eight sitework construction companies. A total of twelve companies were contacted but eight actually participated in the final study. These eight companies were not the same ones that participated in the pilot study phase. The second sample was more recent (2013) and included forty-one students enrolled in the construction and engineering technology program at a local college in central Florida. These students were selected because they would likely be in various construction supervision/management positions when they graduate from the program and the data from this group would be relevant as well.

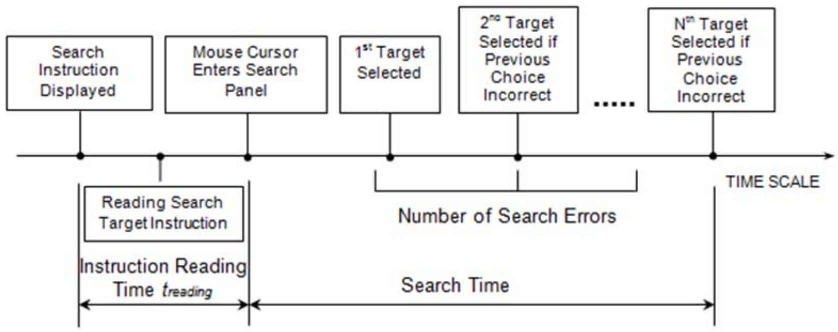

Figure 2. Visual search response variable definitions

RESULTS AND DISCUSSIONS

Sample demographics. The foremen sample had an average age of 40.8 years and an average construction experience of 19.6 years. Over 85% of the foremen had experience of using touch sensitive screen devices (ATM's, store self-checkout, etc.) but only 32.4% had used PDA either for work or personal business. In comparison, the student sample had an average age of 36.1 years and an average construction experience of 6.57 years. Over 85.4% of the student sample used a PDA for either work or personal business.

Average visual search task time. The mean values of the average task time observed in the icon visual search session and the text visual search session for the foremen were 5,952 milliseconds and 7,344 milliseconds. The mean values of the average task times observed in the icon visual search session and the text visual search session for the construction students were 6,476 milliseconds and 7,925 milliseconds. For the purpose of this study, a meaningful difference between the task completion time for pictogram-based user interface and text-based user interface on the per-task level was defined as 1,000 milliseconds (or one second). This number was selected by basing on the theories in the physiology and psychology of eye movements. During a typical visual search process, when the target appears in the peripheral vision, the eyes make sudden movements (called saccades, typically 30-120 milliseconds) to make the target appear in the fovea vision range and then a fixation (a period of relative stability during which an object can be viewed) follows. Fixations typically last between 200 and 600 milliseconds. There is also a 100 to 300 milliseconds delay before the saccade occurs. It is estimated that a complete fixation process could take 330 to 1,020 milliseconds. Therefore 1,000 milliseconds (translated to one to three fixation periods) could be used as a meaningful difference.

The results from the paired differences t-test showed the differences were statistically significant for the foremen ($p<0.01$) and the construction students

($p<0.01$). In addition, the means of the paired differences by foremen (1,391.7 milliseconds) and construction students (1,449.5 milliseconds) were greater than the meaningful difference (1,000 milliseconds).

Task errors. The means of the task errors observed during the icon visual search game and the text visual search game for the foremen were 0.58 and 0.85, respectively. The means of the task errors observed during the icon visual search game and the text visual search game for the student sample were 1.90 and 1.70, respectively. The results from the paired differences t-test showed that the differences in the number of errors were not statistically significant (foremen $p=0.24$ and students $p=0.483$). This indicated there was insufficient evidence to support the hypothesis that the number of task errors differed between the icon visual search game and the text visual search game. This is primarily due to the small sample size used for this study and the ratio of meaningful detectable error (1) over the much lower actual observed errors (less than 2). A much larger sample size would be required to test the hypothesis. However, the Pearson bivariate correlation analyses showed there was a significant and fairly strong negative correlation between the construction experience and task errors in the icon visual search game and text visual search game. In other words, the more construction experience a subject has the fewer visual search errors are likely to be made. This explains well that the student sample had more visual search task errors as some were not familiar with some of the sitework construction activities that pictograms were designed to depict. This further suggests that for users who already have the specialized domain knowledge (experienced field supervisors), pictograms can be an effective component in a GUI.

Perceptions of pictogram-based GUI. When asked of their opinions if the pictogram-based GUI would help them do their field documentation, 84.85% of the foremen responded favorably. In comparison, 89% of the student sample agreed that pictogram-based GUI can help construction field supervisors with their documentation responsibilities.

Order of importance of the usability factors. Foremen gave an average importance rating of 7.767 to shorter task time, 7.900 to fewer task errors, and 8.200 to higher user satisfaction. In comparison, the students gave an average importance rating of 8.25 to shorter task time, 9.06 to fewer task errors, and 8.0 to higher user satisfaction. Paired samples t-tests with a significance level of 0.05 ($\alpha = 0.05$) did not indicate there is a statistical difference between these importance ratings.

CONCLUSIONS

This paper discussed the important role of the field supervisors in the construction site information flow process. It provided an overview of the past research efforts on computerizing the construction site information communication process from a usability perspective. The usability concept was introduced as pertaining to the graphic user interface on mobile computing systems designed for construction field use. Through a customized computer visual search game, the study compared usability properties of pictograms and pre-defined text lists as mechanisms for automated information entry on touch sensitive screen based GUI's. The results showed that the foremen and construction students performed computer visual search tasks faster on the icon interface than on the text interface and had positive perceptions of pictogram-based interface. The extensive field experience and knowledge of the graphic nature of the construction activities give construction field supervisors a unique advantage of using pictograms as an automated data input mechanism. Pictogram-based data input components in GUI's for mobile computing devices can make foremen more productive and reduce the errors associated redundant data input in the information flow process on construction sites therefore would lead to better decisions on project management and cost control and makes the overall construction process more productive and profitable.

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