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Improving the usability of mobile applications through context-awareness

CAPSTONE REPORT

Donald J. Davies

University of Oregon
Applied Information Management
Program

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722 SW Second Avenue
Suite 230
Portland, OR 97204
(800) 824-2714

Approved by

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Dr. Linda Ettinger
Academic Director, AIM Program

Abstract

for

Improving the usability of mobile applications through context-awareness

The usability of mobile applications is threatened by limited input/output capabilities and varied access situations (Bertini et. al., 2005). Through context-awareness, applications are programmed to respond to contextual information as an input source (Schmidt et al., 1999). Based on analysis of literature published between 1998 and 2006, techniques to both interpret and apply contextual input to improve mobile application usability are identified among four primary context types: location, identity, time, and activity.

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CHAPTER I – PURPOSE OF STUDY

Brief Purpose

Usability shortcomings are noted as one inhibitor to ready adoption of mobile commerce (Buranatrived & Vickers, 2002; Lee & Benbasat, 2004; Venkatesh, Ramesh & Massey, 2003). According to Dunlop & Brewster (2002), mobile application designers need to create applications that are not only valuable to end users, but are easy to use despite the limited input/output capabilities of mobile devices. Barnard, Yi, Jacko & Sears (2006) explain that mobile applications are used in a wide variety of environments, often while a user is engaged in other tasks. The purpose of this study is to provide designers with practical ideas for ways context, i.e., "information that can be used to characterize the situation of an entity" (Dey & Abowd, 1999, section 2.2) can be used as an input source to improve the problematic usability of mobile software applications (Ryan & Gonsalves, 2005).

In a process known as context-awareness (Aaltonen & Lehikoinen, 2005), measurable features of user context are interpreted by a computing device and used as an implicit source of input (Schmidt, 2000). An application then acts upon the interpreted contextual input to "provide relevant information and/or services to the user" (Dey & Abowd, 1999, section 3.2). Under this model, the way context is interpreted and acted upon is pre-determined by the application designer (Schmidt, 2000). If an application is programmed to assess and respond to context appropriately, it "can engage in more efficient user interaction and proactivity" (Anagnostopoulos, Mpougiouris & Hadjiefthymiades, 2005, p. 137). The assumption underlying this study is that an examination of ways in which context-awareness has been previously employed to make mobile applications more usable could inform future development efforts.

This study is designed as a literature review (Leedy & Ormrod, 2001). Peer-reviewed literature is collected from academic journals that describe mobile applications that respond to implicitly gathered contextual information (Dey & Abowd, 1999, section 2.2) in an effort to increase usability. For the purposes of the present research, usability is defined by Jakob Nielsen as "a quality attribute that assesses how easy user interfaces are to use" (2003).

Conceptual analysis (Palmquist et al., 2007) is applied to the collected literature to identify instances of contextual information, as these correlate to the following general definition: **"** . . any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves." (Dey & Abowd, 1999, section 2.2) Then, a pre-defined set of four factors is collected for each instance of the use of contextual information as input: (1) the instance(s) of contextual information, (2) the context that is interpreted, (3) the response of the application, and (4) a description of the related user interface improvement(s). Results from the content analysis process are reported in a table, designed with five columns – one per factor and an additional column for the source.

The results of the conceptual analysis are further reviewed in order to develop the final outcome of the study, presented in two tables designed to help application designers implement context-awareness in mobile applications. The outcome is intended to provide application designers with some basic approaches that have been used to both interpret and apply contextual information to boost mobile application usability. This is also intended to reveal gaps in the existing research concerning the use of context-awareness to improve mobile application usability.

One outcome table focuses on the interpretation of context and classifies the contextual information instances identified in the conceptual analysis into one of Dey & Abowd's four, "primary context types for characterizing the situation of an entity" (1999, section 2.3, para. 4), location, identity, time and activity. The organized contextual information is presented with corresponding contextual interpretations. A second table focuses on the exploitation of contextual input to improve mobile application usability. This table identifies the user interface improvements described in the literature with corresponding contextual interpretations and application responses.

Full Purpose

Mobile commerce (m-commerce) has been defined as "any transaction with a monetary value that is conducted via a mobile telecommunication network" (Durlacher, 1999, as cited by Okazaki, 2005). A more recent definition (Sadeh, 2002) removes the 'monetary value' distinction and focuses on m-commerce as a general set of applications and services that are accessible through a portable telecommunications device, such as a modern cellular telephone or personal digital assistant (Chan, Fang, Brzezinski, Yanzan, Xu & Lam, 2002). Mobile devices run mobile applications, which host mobile services (m-services) that are offered through mobile telecommunication networks (Chen, Zhang & Zhou, 2005).

Jakob Nielsen (2003) defines usability as "a quality attribute that assesses how easy user interfaces are to use." According to Nielsen:

> The five main usability characteristics are learnability, efficiency of use once the system has been learned, ability of infrequent users to return to the system without having to learn it all over again, frequency and seriousness of errors and subjective user satisfaction. (1993, p. 15)

The importance of each of the five characteristics varies among different designs, however "getting good results on all of them is a normally a reasonable goal" (Nielsen, 1993, p. 15). In this sense, usability benefits are achieved by improving the user interface, which describes the ways in which human beings and computers communicate (Marcus, 2002).

Usability is an especially significant concern in mobile applications, since mobile device users have a wider range of skill, support and training than desktop computers (Dunlop & Brewster, 2002). Mobile application users "expect a wireless terminal to operate as it were a telephone or pager, not a computer" (Rischpater, 2002, p. 30). Tarasewich (2003) observes that difficulty using mobile applications can translate into wasted time, errors and frustration. Thus this researcher agrees with Jarvenpaa et al (2003) that improving the usability of mobile applications is a critical issue for application designers, because the success of their efforts depends on it.

Lee & Benbasat (2004) maintain that, in mobile applications, usability is affected by device constraints and mobile setting. Device constraints refer to the physical limitations inherent to mobile devices (Bertini, et al., 2005) and reflect the tradeoff between mobility and input/output capabilities (Schmidt, 2000). Examples of mobile device constraints that affect usability include slow connections (West, Hafner & Faust, 2006), small displays (Chae & Kim, 2004) and tedious, error-prone user input (O'Riordan, Curran, Woods, 2005). While technological developments have resulted in increased connection speeds and improved methods of user input (Sadeh, 2002), it is expected that screen size limitations will continue to present usability challenges well into the future (Chae & Kim, 2004).

Mobile setting refers to the context surrounding the use of a mobile device (Lee & Benbasat, 2004). Context is defined as "any information that can be used to characterize the situation of . . . a person, place or object that is considered relevant to the interaction between a user and an application, including the user and the application themselves" (Dey & Abowd, 1999, section 2.2). The context of mobile computing is more varied (Lee & Benbasat, 2004) and more dynamic (Schmidt, 2000) than that of desktop-based computers. A user's experience with a mobile application can be influenced by diverse, interrelated factors such as movement and lighting conditions (Barnard, Yi, Jacko & Sears, 2006), screen size (Chae & Kim, 2004), application type (Liang & Wei, 2004), the mode of user input (O'Riordan, Curran & Woods, 2005) and social considerations (Lumsden & Brewster, 2005). In addition, "a m-commerce application may not be the focal point of the user's current activity" (Tarasewich, 2003, p. 58). These complexities associated with mobile setting make it impossible to take a full range of use cases into account during usability testing (Zhang & Adipat, 2005), creating additional challenges for the mobile application developer.

Dey & Abowd (1999) contend that all specific types of context information can be aligned with one of four primary categories: location, identity, time and activity. The authors claim that this classification is reasonable because:

> It should be evident that the primary pieces of context for one entity can be used as indices to find secondary context (e.g. the email address) for that same entity as well as primary context for other related entities (e.g. other people in the same location). (section 2.3, para. 4)

A study by Bristow et al. (2004) produces a list of 15 context identifiers, each of which could be readily separated into one of the four categories from Dey & Abowd (1999).

Schmidt et al. (1999) proposes a model in which context is composed of a set of measurable features, each of which has a range of possible values. Under the model, applications perceive contextual information features such as physical location, ambient temperature or the type of information recently accessed by a user (Aaltonen, Huuskonen &

Lehikoinen, 2005). A specific context is interpreted through the presence or magnitude of certain features, according to how the application has been programmed (Schmidt et al., 1999).

In a process known as context-awareness (Aaltonen & Lehikoinen, 2005), applications are programmed to respond to implicit, contextual input (Schmidt et al., 1999). When implemented on mobile devices, context-aware mobile applications have been shown to improve the user interface by reducing the need for user input (Kurkovsky, 2005), maximizing the amount of useful information presented on a small screen (Aaltonen, Huuskonen & Lehikoinen, 2005) and moderating the level of detail in the output presented to a user (Chalmers, Dulay & Sloman, 2004). In addition, it is believed that context-awareness can reduce the complexity of interactive systems (Cheverst, Davies, Mitchell & Efstratiou, 2001). In this respect, the implementation of context-awareness has the potential to improve the usability of mobile applications (Aaltonen & Lehikoinen, 2005).

Under a context-awareness model called The Context Toolkit (Dey, 2001), middleware referred to as “context widgets” take “low-level sensor information and aggregate it into higher-level information” (Julien, Roman & Payton, 2004, section 2, para. 3). Working with high-level, pre-interpreted contextual input allows application designers to “concentrate on the heart of the design process: determining what context-aware features their application should support and when they should be enacted” (Dey, 2001, p. 7). Thus, the Context Toolkit model separates the collection and interpretation of context from its use as input by an application (Julien, Roman & Payton, 2004).

This study, which intends to show ways in which context has been interpreted and used as a source of implicit input to improve mobile applications, is designed as a literature review (Leedy & Ormrod, 2005). Literature review is selected as an appropriate method because it “previews methods that others have used” (Leedy & Ormrod, 2005) -- in this case, for applying context-awareness to increase the usability of mobile applications. The literature collected are primarily case examples published in academic journals from 1998 to present. Each piece of collected literature describes, at least in part, the implementation of context-awareness specifically in mobile applications to improve usability, based on Nielsen’s (2003) definition, “a quality attribute that assesses how easy user interfaces are to use.” The notion of contextual information, for identification purposes, is framed by Dey & Abowd (1999, section 2.2).

Conceptual analysis, as defined by Palmquist et al. (2007), is used to extract data from the texts identified in the literature review. This approach to data analysis is valuable because it supports identification of both implicit and explicit concepts among the collected literature that are relevant to the present study (Palmquist et al., 2007). First, instances of contextual information are identified in the selected literature, as these correlate to the following general definition: **“** . . any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves” (Dey & Abowd, 1999, section 2.2). This definition is used to guide identification because it encompasses all possible types of contextual information that might be available to mobile applications. Then, each time contextual information is identified as a source of implicit input, the following pre-defined dataset is gathered:

- *the contextual information* that is perceived (ie: the intensity of ambient light);
- *the context that is interpreted* through the evaluation of the feature and used as input (ie: brightness above a certain level is interpreted to be an indication that a user is in direct sunlight);

- *the way in which the application is designed to respond* to this contextual input (ie: the screen brightness and the text size are increased if a user is in direct sunlight); and
- a description, as this is reported in the literature, of the *related user interface improvement* (ie: the screen adapts to changes in environmental conditions to make it easier for a user to read).

The results of the conceptual analysis are provided in Table 2. In this table, each instance of contextual information is identified along with its corresponding dataset of three related factors and the source. By organizing the summarized coding results by source, this table makes it easy for application designers to consult the relevant literature to learn more about how contextual information is interpreted and applied in an effort to achieve specific usability improvements. The results of the conceptual analysis are also used to create two more tables that are the final parts of the outcome of this study (see Tables 3 and 4).

Table 3, intended primarily for mobile application designers concerned with finding ways to translate context into an input source, focuses on contextual information and its interpretation. The results of the conceptual analysis are further reviewed in order to classify the instances of contextual information identified in the conceptual analysis into one of Dey & Abowd’s four, “primary context types for characterizing the situation of an entity” (1999, section 2.3, para. 4), location, identity, time and activity. Each specific instance of contextual information is paired with a primary context type, along with the corresponding interpretation of context. In addition to presenting an organized list of the contextual information that have been used to contribute to the usability of mobile applications, this table indicates the contextual information that may contribute to different interpretations. This information could guide future development efforts.

Table 4 is intended primarily for designers concerned with improving the usability of the mobile applications that they create by employing contextual input. This table pairs the user interface improvements identified during conceptual analysis with the corresponding interpreted contextual input and application responses to that input. This outcome is intended to provide designers with some specific ways in which context has been employed to improve mobile application user interfaces.

Significance

Mobile applications must be easy to use in order to be successful (Jarvenpaa et al., 2003). However, few specific usability guidelines exist for the development of mobile applications (Zhang & Adipat, 2005) and usability guidelines designed for traditional, desktop-based computing do not translate well to a mobile environment (Chae & Kim 2003). This is unfortunate, since mobile applications are more likely to be used by people who lack skills and training (Dunlop & Brewster, 2002) and who expect applications to be as easy to use as a telephone (Rischpater, 2002). By highlighting some usability improvements that have been made to mobile applications and introducing the ways in which other researchers have attempted to realize them, this study could contribute to the construction of a larger set of usability practices for mobile applications.

Sadeh refers to context-awareness as “the Holy Grail of m-commerce” (2002, p. 197) because of its vast potential to make mobile applications more usable. Given such a bold statement, the lack of a single source of practical information for incorporating user context into mobile applications is surprising. Barnard et al. (2006) suggests a need to find ways to apply, as opposed to merely gather, context information to benefit usability. By examining ways in which context has been both interpreted and applied to make mobile applications more usable, this study attempts to fill in some of these gaps.

Limitations

This study only considers applications that are used on handheld mobile devices, such as mobile phones and personal digital assistants. Notebook computers and car-based navigation systems, while technically mobile devices and included in some m-commerce research, are excluded from this study. In addition, because this study focuses on m-commerce as defined by Sadeh (2002), applications that run on mobile devices, but do not communicate through mobile communication networks, are also excluded.

As an operational strategy, identification of instances of the primary concept sought during conceptual analysis – contextual information -- is guided by the definition provided by Dey & Abowd, which states: **“** . . any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves” (Dey & Abowd, 1999, section 2.2). While this definition has been criticized for being overly broad (Greenberg, 2001), it is used in this study because it captures the full range of contextual information that is potentially available to the mobile application designer.

In accordance with Dey’s (2001) model of context-awareness, this study separates the perception of context from both its interpretation and its use as an input source. The perception of contextual information is not addressed by this study – sources of contextual information are assumed to be available, reliable and accurate. This assumption avoids the complexities of working with inaccurate or ambiguous context information (Dey & Mankoff, 2005).

The context-awareness model used in this study, put forth by Dey & Abowd's (1999), has been criticized as falling short of true context-awareness (Erickson, 2002). Greenberg (2001) maintains that, in practice, it is impossible to pre-define context, much less pre-define the response of a software application that is appropriate in all situations. Greenberg continues that, without true artificial intelligence, Dey and Abowd's (1999) model only applies to "simple and highly routine contextual situations" (Greenburg, 2001, p. 263). However, artificial intelligence sufficient to recognize and respond to context is not yet practical (Greenburg, 2001). Further, Dey (2001) maintains by focusing on high-level context as input, his model allows applications to adapt to technological advances in context detection and interpretation. Thus the model is selected for use in this study.

This study approaches context-awareness as a process in which context is interpreted and used as a source of input (Schmidt, 2000). Therefore, this literature review only includes sources that discuss both an interpretation of context from contextual information and a response to contextual input. Further, Nielsen's (2003) definition of usability (see Definitions) is used as criteria to refine the collection of context-awareness literature selected for data analysis. As such, context-aware mobile applications that do not include:

- an interpretation of contextual information;
- a response to interpreted contextual input; or,
- a direct benefit to the ease of use of the mobile user interface

are not reflected in this study.

This study does not attempt to evaluate the efficacy of any specific context-awareness technique. Additional research is necessary to determine the optimal ways to interpret and apply different types of contextual information. Further research is also needed to determine suitable contextual input for achieving specific usability goals.

The literature review presented in this study only includes material published between 1998 and present. The date range is selected because Wireless Application Protocol (WAP) was first deployed in 1998 and mobile devices were not widely used for data services until this time (Goleniewski, 2003). The limited literature published prior to 1998 largely concerns fixed location computing or non-networked mobile devices. As a result, this study only takes into account techniques for using context that have been identified for use in modern, connected mobile devices.

As a literature review, this study only examines “previous research findings regarding the problem at hand” (Leedy & Ormrod, 2005, p. 64). The literature collected for use in this study includes only sources published in peer-reviewed academic journals that are available through the University of Oregon library. Additional, peer-reviewed literature exists, but is absent from this study. There are likely many other relevant case studies and whitepapers available on the World Wide Web, but tracking the validity of this information is more difficult. More significantly, while other research techniques, such as surveys or experiments, might expose other ways in which context-awareness may improve the usability of mobile applications, these are not used in this study.

Conceptual analysis, a data analysis technique that identifies “the occurrence of select terms within a text or texts, although the terms may be implicit as well as explicit” (Palmquist et al., 2005), is used in this study. Since this study uses a collection of literature as its data source, this method is an appropriate choice. In addition, the fact that conceptual analysis provides rules for identifying and coding implicit terms within the literature is conducive to this study, since some of the concepts presented in the collected literature are not explicitly identified.

Problem Area

"Human-computer interaction [HCI] is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" (Hewitt et al., 1996, section 2.1). In the present study, the term 'interactive computing systems' represents m-commerce applications, or applications that run on mobile devices (Sadeh, 2002). To facilitate interaction, HCI involves the development of interfaces between human users and computers that are "in line with the users requirements" (Bertini et al. 2005, p. 1). In this respect, human-computer interaction is fundamentally concerned with usability, or "how easy user interfaces are to use" (Nielsen, 2003).

Schmidt et al. (1999) maintain that "context is a key issue in the interaction between human and computer, describing the surrounding facts that add meaning" (p. 1). Mobile context is shaped by the input/output limitations inherent to mobile devices (West, Hafner & Faust, 2006) and the fact that ". . . location, environment, connectivity and other important factors are commonly unpredictable and dynamic" (Barnard, Yi, Jacko & Sears, 2005, section 1.1). Therefore, the field of human-computer interaction must account for the complex and variable context surrounding the use of mobile applications (Bertini et al., 2005) . As a result, it has been suggested that "the greatest challenge for various m-commerce applications is their usability" (Chan et al., 2002). In fact, "user interface design has been identified as second only to security as a barrier to user acceptance of m-commerce" (Buranatrived & Vickers, 2002).

The implementation of context-awareness, “an approach where context information is being applied to benefit the users” (Aaltonen & Lehikoinen, 2005, p. 381) has the potential to resolve some of the usability challenges inherent to the variable context surrounding the use of mobile applications. This is accomplished by using contextual information as an input source (Schmidt, 2000). “By improving the computer’s access to context, we increase the richness of communication in human-computer interaction” (Dey & Abowd, 1999, paragraph 1). Therefore, “the automated adaptation to context makes it possible to present more usable services and information” (Skov & Hoegh, 2006, p. 205) to the mobile application user.

In order to successfully implement context-awareness, relevant context must be sensed, interpreted and applied as an input source by an application (Schmidt, 2000; Dey & Abowd, 1999). This study offers application designers a source to consult to identify ways in which context has been both interpreted and applied to benefit the usability of mobile applications presented in literature. While a survey of context-aware mobile applications has been conducted (Korkea-aho, 2000), no research has been identified that examines various implementations of context-awareness intended to benefit usability across a range of modern mobile applications. It is hoped that the current research will not only provide practical information to designers that will assist in the development of improved mobile applications, but will also contribute to the larger field of human-computer interaction.

CHAPTER II – REVIEW OF REFERENCES

Ten sources are identified that provide the foundation for this research. This literature is organized into three general categories:

1. Literature that describes usability;
2. Literature that describes context-awareness, and;
3. Literature that describes research methodologies.

Literature that Describes Usability

Barnard, L., Yi, J., Jacko, J. & Sears, A. (2006). Capturing the effects of context on human performance in mobile computing systems. Personal and Ubiquitous Computing. Retrieved November 3, 2006 from ACM Portal.

This article details an experiment designed to investigate the effects of the variable context surrounding the use of mobile applications. The authors evaluate users on a mobile application while altering contextual elements (specifically, motion, lighting and task) and conclude that context can have a significant influence on performance. The authors maintain that, because mobile devices can be used in a wide variety of situations, context of use is a significant usability concern for mobile applications. A case is therefore made for the need to test mobile applications under realistic conditions, since the authors contend that laboratory testing cannot reproduce the complete range of situations under which mobile devices are actually used.

The article is cited in the present study in the Purpose and Problem Area sections. Barnard et al.’s work is cited to show that it is important for designers to consider the dynamic and variable context surrounding the use of mobile applications. Context-awareness is then framed as a technique for assessing and reacting to context in a way that benefits the mobile application user.

The authors of this article have all published several works in the fields of mobile computing and human-computer interaction and are frequently cited in other research. Andrew Sears currently chairs the Interactive Systems Research center at University of Maryland and is on the editorial board of several relevant journals. *Personal and Ubiquitous Computing*, as previously mentioned, is peer-reviewed and has been continuously published since 1997.

Lee, Y., & Benbasat, I. (2004). A Framework for the Study of Customer Interface Design for Mobile Commerce. *International Journal of Electronic Commerce, 8*(3), 79-102. Retrieved Tuesday, October 31, 2006 from the Business Source Premier database.

This article examines published research concerning user interface design in mobile applications. The authors identify device constraints and “mobile setting” (the dynamic context inherent to the various situations in which mobile devices are used) as important considerations for the design and evaluation of mobile application interfaces. Therefore, the authors maintain that proven design standards used to develop traditional, desktop-based e-commerce interfaces cannot be applied directly to m-commerce interfaces. Instead, the authors propose a framework for the analysis of m-commerce interfaces that involves observing existing, e-commerce interface design guidelines while considering the impacts of device constraints and mobile setting.

The present study builds from Lee & Benbasat's assertion that usability problems inhibit the adoption of mobile commerce. This work is also used in the present study to establish the perspective that device constraints and dynamic use context are significant challenges to the usability of mobile applications. Context-awareness is then introduced as a potential solution to both challenges.

This article is cited in other research that concerns user interface design in mobile applications. Dr. Izak Benbasat is a professor of Management Information Systems at the Sauder School of Business of the University of British Columbia. He has authored or co-authored over 50 peer-reviewed papers in the field of human-computer interaction that have been cited extensively. The *International Journal of Electronic Commerce* is peer-reviewed and has been published since 1996.

Nielsen, J. (2003). Usability 101: introduction to usability. Retrieved January 21, 2007 from http://www.useit.com/alertbox/20030825.html.

This article is published in a newsletter called Alertbox, described as "a column on web usability." The newsletter is written and published by usability consultant Jakob Nielsen and is available through his website, useit.com. Usability 101 presents a broad overview of the concept of usability that is in line with the author's previous work (Nielsen, 1993). Nielsen's definition of usability, ". . . a quality attribute that assesses how easy user interfaces are to use" (2003) is employed by the present research to select the literature that is subjected to conceptual analysis.

By tying the concept of usability to the user interface, Nielsen's definition provides a concrete way to identify usability within the literature.

Jakob Nielsen has published over 80 articles on human-computer interaction since 1985, 30 of which appear in peer-reviewed journals. Nielsen has also written several textbooks on usability engineering and user interface design and is on the editorial board of seven scholarly journals in the field of human-computer interaction. Currently, he is a usability consultant for the Nielsen Normal Group. The newsletter in which this article appears, Alertbox, has been published 2-3 times a month since 1995. Google Scholar reveals that Nielsen's work has been cited in several thousands of publications.

Sadeh, N. (2003). M-commerce: Technologies, services, and business models. Wiley, New York.

This book provides a broad overview of mobile commerce (m-commerce). In addition, the author discusses usability issues related to mobile computing and introduces context-awareness as an emerging technology that has the potential to improve future mobile applications. The present study uses this work to define m-commerce for the purposes of literature selection, since Sadeh's broad definition encompasses any application that runs on a mobile device connected to a data network. Sadeh's assertion that context-awareness is an important emerging technology in mobile applications is also cited in the Significance section of this study.

Norman Sadeh is a professor of Computer Science at Carnegie Mellon University who has authored over 150 journal articles. For the past two years, the author has lead a research project that examines context-awareness in a mobile application. Google Scholar shows that this book has been cited 79 times in other research, making it a recognized reference in the field.

Literature that Describes Context-Awareness

Aaltonen, A. & Lehikoinen, J. (2005). Refining visualization reference model for context information. *Personal and Ubiquitous Computing, 9*, 381-394. Retrieved December 1, 2006 from ACM Portal.

This article illustrates and discusses methods of presenting different types of contextual information on mobile devices. Context is portrayed as a potentially valuable information source. The authors maintain that contextual information, such as location or distance, can be especially helpful to a user when displayed visually among related content. The article goes on to describe a technique for the visual display of contextual information.

Aaltonen & Lehikoinen provide a definition for context-awareness – an "approach where the context information is being applied to benefit the users" (2005, p. 381). This aligns well with the present research, because both characterize context-awareness as having the potential to make mobile applications more usable. As such, the present study employs Aaltonen & Lehikoinen's definition of context-awareness as a criteria to select the literature used to form the data set for coding in conceptual analysis.

At the time of publication, Antti Aaltonen and Juha Lehikoinen are researchers with the Nokia Research Center, a lab run by the largest manufacturer of mobile phones worldwide. Each author has written several articles on various aspects of mobile computing and have been cited in other articles that are used in this research. The journal in which this article is published, *Personal and Ubiquitous Computing*, is peer-reviewed and has been continuously published since 1997.

Dey, A. & Abowd, G. (1999). Toward a better understanding of context and context-awareness. GVU Technical Report GIT-GVU-99-22, College of Computing, Georgia Institute of Technology. Retrieved November 3, 2006 from ftp://ftp.cc.gatech.edu/pub/gvu/tr/1999/99-22.pdf.

This article surveys existing context-awareness research and puts forth definitions of context and context-awareness that are relevant to application designers. Contextual information is organized into four, primary categories and implementations of context-awareness are classified into three categories. In addition, the article introduces the Context Toolkit, a model of context-awareness. Under this model, "context widgets" gather and interpret contextual information and provide input to an application. The Context Toolkit model therefore allows application designers to focus on developing ways for applications to respond to contextual input, regardless of the source of contextual information. The authors maintain that applications can become more useful if they are programmed to use contextual information as input.

Dey & Abowd's definition of context-awareness and the context-awareness model these authors introduce is used throughout the present research. In addition, the Dey & Abowd's definition of contextual information is used to identify relevant content within the literature selected for conceptual analysis. The four, primary context categories introduced by the authors (*location, identity, time* and *activity*) are also used in the present research to organize one of two final outcome tables.

Anid Dey and Gregory Abowd's research is widely used. Google Scholar shows that this particular article has been cited 523 times, thus making is a well-used source. The authors definitions of context and context-awareness, as well as their Context Toolkit model, continue to be frequently employed by other researchers. Anid Dey is a professor at the Human-Computer Interation institute at Carnegie Mellon University, has published numerous peer-reviewed articles that concern context-awareness and continues to conduct similar research. Gregory Abowd is a professor at Georgia Technical Institute, has authored several publications in the fields of human-computer interaction and context-awareness and continues to research in these areas.

Schmidt, A. (2000). Implicit human computer interaction through context. *Personal Technologies, 4*(2). Retrieved November 10, 2006 from http://www.comp.lancs.ac.uk/~albrecht/pubs/pdf/schmidt_pete_3-2000-implicit-interaction.pdf.

This article demonstrates how contextual information can be used as an input source for mobile applications. The article introduces the notion of implicit human-computer interaction, or the ability of an application to automatically respond to contextual input that is sensed, as opposed being explicitly provided by a user. Implicit human-computer interaction is presented as a specific implementation of the larger concept of context-awareness. The author maintains that implicit interaction in mobile applications can benefit a user by helping to overcome challenges related to the dynamic context in which mobile devices are used. In addition to reviewing other published examples of implicit interaction, the author discusses a mobile application that gathers contextual information through sensors, and uses this information to change its behavior in a way that benefits the user.

The present study uses Schmidt's notion of implicit interaction to separate context-awareness into three, distinct components; the perception of contextual information, the interpretation of a context and the response by an application to interpreted context. By separating context-awareness into these three components, the factors that are identified in the present conceptual analysis are defined. This breakdown of context-awareness aligns well with Dey & Abowd's context-awareness model. Schmidt's definition of implicit interaction is also employed by the present study to select the literature that is subjected to conceptual analysis.

Albrecht Schmidt is extremely active in the fields of human-computer interaction, having published over 100 peer-reviewed articles and conference papers on the subject since 1998. Many of these publications involve mobile technology and context-awareness. In addition, Schmidt has presented many lectures and workshops on these topics to universities and corporation research centers. The peer-reviewed journal *Personal Technologies*, first published in 1997, changed its name to *Personal and Ubiquitous Computing* in 2001 and continues to be published under that name. Google Scholar reports that this article has been cited in 139 other studies.

Schmidt, A., Beigl, M. & Gellersen, H.W. (1999). There is more to context than location. *Computer & Graphics, 23*(6). Retrieved November 17, 2006 from http://www.teco.uni-karlsruhe.de/~albrecht/publication/draft_docs/context-is-more-than-location.pdf.

This article is similar to Schmidt's later work annotated above, however, it substitutes the term context-awareness for implicit interaction. The article goes into detail about the different types of contextual information that can be used as input sources, the various types of sensors that can be used to gather contextual information and how different types of sensors can work together to facilitate the interpretation of context. The authors present an example of a context-aware mobile application that can respond to changes in both the ambient lighting and the physical orientation of a mobile device.

The present study cites this research in its purpose section to help illustrate context-awareness and provide examples of how the technique is implemented in mobile applications. The example presented in Schmidt et al.'s article is also used as a data source in the coding process in the present study's conceptual analysis.

As previously discussed, Albrecht Schmidt is an extensively published, active researcher in the field of human-computer interaction. *Computer & Graphics* is a peer-reviewed journal that has been published since 1975. Google Scholar shows that this article has been cited 271 times in other research.

Literature that Describes Research Methodologies

Leedy, P. & Ormrod, J. (2005). ***Practical research*** **(8th ed.). Upper Saddle River: Pearson Education, Inc.**

This book provides an overview of a wide range of research methodologies. The present research draws from the authors description of qualitative research, specifically literature review, as a technique to gather, evaluate and organize material surrounding a research question. The book, authored by two university professors, is in its eighth edition. It has also been credited as being a valuable source of information by instructors in several courses in the University of Oregon Applied Information Management (AIM) Master's Degree Program.

Palmquist. M. et al., (2006). ***Content analysis.*** **Writing@CSU. Colorado State University Department of English. Retrieved November 6, 2006 from http://writing.colostate.edu/guides/research/content/.**

This section of web content, available through the Colorado State University Writing Lab, provides practical techniques for gathering data from text. The present study draws upon the authors' description of conceptual analysis, the process of identifying concepts as they appear within a body of literature. Eight steps for the coding of concepts that address a research question are provided. This research study follows these steps to identify five factors that exist implicitly in each piece of the selected literature.

This source is selected because its techniques satisfy the requirements of the present research question and research design. Content analysis, as a research strategy, has a long and respected history within qualitative research circles.

CHAPTER III - METHOD

Primary Research Method

This study uses literature review (Leedy & Ormrod, 2005) as its primary research method. Using published literature as a data source is appropriate, because this study attempts to identify "previous research findings related to the problem at hand" (Leedy & Ormrod, 2005, p. 64), specifically how other researchers have both interpreted and applied contextual input in an effort to improve the usability of mobile applications.

Literature Collection

The literature used in this study focuses on the use of contextual information as input in mobile applications, a process referred to as context-awareness (Dey & Abowd, 1999). To support the intent of this study, the literature selected is limited to sources that specifically discuss the application of context-awareness to improve usability. For the purposes of literature collection, usability is defined by Nielsen (2003) "a quality attribute that assesses how easy user interfaces are to use."

Literature included in the review is exclusively collected from peer-reviewed, academic journals to address validity concerns. A publication date range from 1998 to present is established as a selection criteria to help ensure that sources to present-day technology consistent with the current research question. Finally, only literature that is freely available to the general public or students of the University of Oregon is included.

Literature is identified and collected through the following sources that are accessed through the University of Oregon library:

- The Business Source Premiere Database
- The Computer Source Database
- The ACM (Association for Computing Machinery) Digital Library
- The IEEE Computer Society Digital Library

In addition, relevant, peer-reviewed literature from the Google Search Engine and Google Scholar are also included.

Initial searches use a combination of search terms to first identify literature that discuss mobile applications. Results of initial searches vary, depending on the database used. Overall, several thousand potential sources are identified through the initial searches.

In order to get closer to purpose of the study, additional search terms are added to create advanced searches intended to identify literature that specifically discusses the use of context as an implicit source of input for a mobile application (Schmidt, 2000). A summary of the search terms used in literature collection is presented in Figure 1.

Initial Search Terms (Mobile Applications)	Secondary Search Terms (Use of Contextual Input)
Mobile Applications M-Commerce Applications Mobile Commerce Applications Mobile Web Mobile Internet	Context Contextual Input Implicit Input Context-Awareness Context-Aware Implicit Interaction

Figure 1 – Search Terms Used in Literature Collection Process

Approximately 30 journal articles are identified from the advanced search queries that discuss applications that both interpret and respond to contextual input. These articles are then read by the researcher to identify sources in which contextual input is used in an effort to benefit usability, based on Nielsen's (2003) general definition.

Nine articles, all published between 1999 and present, meet the purposes of this research study. Three of these articles present multiple context-aware mobile applications intended to benefit usability. Each relevant, independent application presented in these studies are coded separately. In total, the nine articles identified represent 13 data sources.

The literature selected for content analysis, along with the number of relevant data sources contained in each, are presented in Table 1.

Literature selected for content analysis	Number of data sources
Cheverst, K. Mitchell, K. & Davies, N. (2002). Exploring context-aware information push. *Personal and Ubiquitous Computing, 6*, 276-281. Retrieved December 29, 2006 from the ACM Portal.	1
Cheverst, K., Mitchell, K. & Davies, N. (2002b). The role of adaptive hypermedia in a context-aware tourist guide. *Communications of the ACM, 45*, 47-51. Retrieved January 3, 2007 from the ACM Portal.	1
Hammond, K., Shamma, D. & Sood, S. (2003). Context-aware keyless computing. In *Proceedings of Ubiquitous Computing Workshop on Location-Aware Computing*. Retrieved December 29, 2006 from http://infolab.northwestern.edu/infolab/downloads/papers/paper10128.pdf.	3
Hinckley, K., Pierce, J., Sinclair, M. & Horvitz, E. (2000). Sensing techniques for mobile interaction. In *Proceedings of the 13th Annual ACM Symposium on User Interface Software and Technology*. Retrieved December 29, 2006 from the ACM Portal.	2

Table 1 – Literature Selected for Content Analysis (continued on the following page)

Literature selected for content analysis	Number of data sources
Kurkovsky, S. (2005). Using principals of pervasive computing to design m-commerce applications. *Proceedings of the International Conference on Information Technology: Coding and Computing*. Retrieved November 8, 2006 from the IEEE Computer Society.	1
Ludford, P., Frankowski, D., Reily, K., Wilms, K. & Terveen, L. (2006). Because I carry my cell phone anyway: Functional location-based reminder applications. *CHI '06: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 889-898. Retrieved January 4, 2007 from the ACM Portal.	1
Schmidt, A., Beigl, M. & Gellersen, H.W. (1999). There is more to context than location. *Computer & Graphics, 23*(6). Retrieved November 17, 2006 from http://www.teco.uni-karlsruhe.de/~albrecht/publication/draft_docs/context-is-more-than-location.pdf.	2
Skov, M., Hoegh, R. (2006). Supporting information access in a hospital ward by a context-aware mobile electronic patient record. *Personal and Ubiquitous Computing, 10*, 205-214. Retrieved December 3, 2006 from ACM Portal.	1
Smith, D., Ma, L. & Ryan, N. (2005). Acoustic environment as an indicator of social and physical context. *Personal and Ubiquitous Computing, 10*, 241-254. Retrieved December 12, 2006 from ACM Portal.	1

Table 1 – Literature Selected for Content Analysis (continued from the preceding page)

Data Collection and Analysis

Conceptual analysis, described by Palmquist et al. (2007), is the approach used to structure the analysis of the selected literature. In this approach, "a concept is chosen for examination, and the analysis involves quantifying and tallying its presence." Coding is accomplished by following the eight category coding steps presented by Palmquist et al. (2007).

Step One: Level of Analysis

Level of analysis is chosen by determining which word or set of words or phrases constitute a concept. In this study, concepts are identified as they emerge in relation to the phrase 'contextual information', which is defined as **"** . . any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves." (Dey & Abowd, 1999, section 2.2)

Step Two: Decide How Many Concepts to Code For

Conceptual analysis is first used to identify instances of the primary concept which is the focus of the study -- contextual information -- as these correlate to the following general definition: **"** . . any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves." (Dey & Abowd, 1999, section 2.2) Then four, pre-defined factors are coded:

- *the instance(s) of contextual information* that is evaluated (ie: the intensity of ambient light);

- *the context that is interpreted* through the evaluation of the feature(s) and used as input (ie: brightness above a certain level is interpreted to be an indication that a user is in direct sunlight);
- *the way in which the application is designed to respond* to this contextual input (ie: the screen brightness and the text size are increased if a user is in direct sunlight); and
- a description, as this is reported in the literature, of how the response to contextual input *improves the user interface*, (ie: the screen adapts to changes in environmental conditions to make it easier for a user to read).

Each of these four concepts must be present in order for a potential data source to be used.

Step Three: Decide Whether to Code for Existence or Frequency of a Concept

This study codes for the existence of the emergent and pre-defined concepts presented above.

Step Four: Decide on How You Will Distinguish Among Concepts

The concepts presented in the text come in a variety of forms and are often implicitly defined. As a result, this study uses a high level of implication to "generalize their meaning" (Palmquist et al., 2007). Implication is tied to rules for coding, described in Step Five.

Step Five: Develop Rules for Coding

The following definitions are used to guide the identification of each concept in the text:

- *contextual information* -- **"** . . any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves" (Dey & Abowd, 1999, section 2.2)

- *interpreted contextual input* - "action, performed by the user that is not primarily aimed to interact with a computerized system but which such a system understands as input" (Schmidt, 2000, section 2.1)
- *application response* – describes how the behavior of a mobile application changes as a result of contextual input; examples from literature include the increasing of font size when motion is detected (Schmidt, 2000) and changing a list of available choices when a user's location changes (Kurkovsky, 2005)
- *user interface improvement* – describes the stated improvement to the ease of use of "computer-mediated means to facilitate communication between . . . a human being an artifact" (Marcus, 2002) as a result of the application response to interpreted contextual input

Step Six: Decide What to Do with "Irrelevant Information"

Information that does not fit into one of the guiding definitions listed in Step Five is discarded. Further, information that is outside of the relevant scope of the selected section of text within a particular piece of literature under analysis is not included.

Step Seven: Code the Texts

In each text analyzed, relevant text describing each concept is manually underlined and labeled with a letter that corresponds to that specific concept. This text is then transcribed into the appropriate cells of a table that includes the instance of contextual information and the four, pre-defined factors as columns and the literature sources as rows.

Step Eight: Analyze Your Results

This step of the data analysis process pertains to Data Presentation. See a full discussion in the section below.

Data Presentation

The summarized results from the first round of conceptual analysis are presented in a single table (see Table 2) that includes the specific instance of contextual information identified, the four relevant, pre-defined factors and the source. A template of this table is presented in Figure 2.

Source	Contextual Information Instance(s)	Interpreted Contextual Input	Application Response	User Interface Improvement

Figure 2 – Template of Table 2 (Summary of the results from the conceptual analysis)

These results are then re-examined in light of the needs of mobile application designers who could benefit exploring some approaches for both interpreting and applying a range of contextual information to improve the usability of the applications that they create. This is represented by two additional tables that comprise the final outcome of the study (see Tables 3 and 4).

A modified form of the conceptual analysis process (Palmquist et al., 2007) is used to develop the first outcome table (see Table 3). This table, derived from the re-examination of Table 2, classifies contextual information instances identified in the conceptual analysis into one of Dey & Abowd's (1999) primary context types:

- *location* – answers the question "**where**"
- *identity* – answers the question "**who**"
- *time* – answers the question "**when**"
- *activity* – answers the question "**what**"

The contextual information instances and corresponding interpreted contextual input are sorted by primary context type. The goal at this stage of the analysis is to organize the various contextual information instances described in the literature into logical categories. This provides mobile application developers with the types of contextual information that have contributed to contextual interpretations in previous research.

Categories are created from the results of the content analysis to make the table easier to reference and to better expose the prevalence of various specific ways to interpret context for use as input. Similar contextual information instances within a primary context type are combined into a single descriptive category. Corresponding contextual interpretations, also summarized into single descriptive categories where applicable, are paired with cooresponding contextual information instances. In cases in which descriptive categories are used to represent both multiple contextual information instances and multiple interpreted contextual input, the number of sources represented by these categories is presented in the table.

Contextual interpretations can be made through a combination of different types of contextual information (Dey & Abowd, 1999). When different types of contextual information contribute to the interpretation of a single contextual input, the additional contextual information that contribute to the interpretation are presented with each interpreted contextual input. The goal of this approach is to expose ways in which different types of contextual information are combined.

Primary Context Type	Contextual Information Instance	Interpreted Contextual Input	# Sources

Figure 3 – Template of Table 3 (Outcome 1)

Table 4, the second outcome of this study, is designed for mobile application designers interested in ways to enhance the usability of mobile applications by using contextual input to improve the user interface. The user interface improvements identified in the initial conceptual analysis are presented, along with the corresponding interpreted contextual input and the response of the mobile applications to that input. Similar user interface improvements, interpretations of context and application responses are combined into descriptive categories. In cases in which categories are used to represent multiple user interface improvements, interpreted contextual input and application responses, the number of sources represented by the three category types is presented in the table. Organizing the table in this way allows application designers to identify specific ways in which contextual input has been applied to address various aspects of usability.

User Interface Improvement	Interpreted Contextual Input	Application Response	# Sources

Figure 4 – Template of Table 4 (Outcome 2)

CHAPTER IV – ANALYSIS OF DATA

The conceptual analysis process described in the Method section is applied to each of the 13 data sources selected for analysis. Four factors, identified in Step 2 of the data analysis process, are coded for each source and are summarized in Table 2 (see Appendix B - Interpretation and Application of Contextual Information to Improve Usability).

The results of the conceptual analysis reveal the ways in which the 13 data sources interpret and apply contextual information to improve usability. Nineteen instances of contextual information are identified – two sources include three instances of contextual information, two include two instances and the remaining nine sources each include a single instance. Eleven sources are shown to interpret a single interpreted contextual input, while two sources include multiple interpretations, resulting in a total of 16 contextual interpretations identified in the data. Sixteen application responses are identified across the 13 sources, with three studies exhibiting three sources each. Finally, each source exhibits one of four types of the usability improvements identified.

Results from the coding process are further analyzed to create Table 3 (see Appendix C – Classification of Contextual Information According to Four Types), which is the first part of the final outcome of this study. In this table the instances of contextual information identified above are classified into one of Dey & Abowd's (1999) four primary categories of contextual information (location, identity, time, and activity) and are presented with the corresponding interpreted contextual input. The goal of this stage of analysis is to reveal the different types of contextual information that are used to interpret context.

Three of the four primary context categories are exhibited in this outcome. Of the 13 sources analyzed, nine of the 19 instances of contextual information identified are classified into the "Location" primary context category, eight are classified as "Activity" and two are classified as "Time." The "Identity" primary context category is not represented among the contextual information instances identified.

Similar contextual information instances are combined into two descriptive categories: *"electronic signals from an external source"* describes eight instances, while *"device movement"* describes three instances. The remaining eight contextual information instances are identified and presented independently. Two descriptive categories are also created to represent ten similar interpreted contextual inputs – *"physical location of the user"* describes eight contextual interpretations and *"orientation of the device relative to the user"* describes two.

One of the identified interpreted contextual inputs (*"User intention to record a voice memo"*) is associated with three instances of contextual information, and another (*"Type of user activity"*) is associated with two instances of contextual information. The remaining contextual interpretations are associated with a single instance of contextual information.

Results from the coding process are also manipulated to create Table 4: Contextual Input Aligned with User Interface Improvements (see Conclusions chapter), which is the second part of the final outcome of this study. In this table the user interface improvements identified in the content analysis are combined into four categories and presented with the corresponding interpreted contextual input and the application responses to that input. The goal of this stage of analysis is to reveal the different ways in which contextual interpretations have been applied to improve various aspects of usability in mobile applications.

Sixteen application responses to 16 interpreted contextual inputs are represented among the 13 data sources. In one source, a single response is associated with three instances of interpreted contextual input. In another source, a single response is associated with two instances of interpreted contextual input. In three sources, two application responses are associated with a single interpreted contextual input. Four categories of user interface improvements are identified:

- *"Reduces user input to required to find relevant information"* is identified in six sources,
- *"Automatic adaptation of the user interface for optimal display"* is identified in three sources,
- *"Reduces user input required to find and format relevant information"* is identified in three sources, and
- *"Simplifies a task"* is identified in one source.

CHAPTER V – CONCLUSIONS

This study is intended to provide application designers with ways in which context can be used as an input source to improve the usability of mobile software applications. To accomplish this goal, this study examines selected literature in an effort to reveal how context has been both interpreted and applied in previous research in an effort to improve mobile application user interfaces.

Interpretation of Context

Table 3: Classification of Contextual Information According to Four Types (see Appendix C) provides mobile application designers with some of the contextual information that is available to mobile applications. In addition, the table identifies the interpretations that have been made from this information.

The present research classifies each instance of contextual information identified in the conceptual analysis into one of Dey & Abowd's four "primary context types for characterizing the situation of an entity" (1999, section 2.3, para. 4), location, identity, time and activity. According to Dey & Abowd (1999), the four primary context types are important, because they answer the following basic questions: *"Who?"* (identity), *"What?"* (activity), *"When?"* (time) and *"Where?"* (location). Application designers are able to interpret context that can be used as an input source by collecting contextual information that answers these basic questions (Dey & Abowd, 1999). Therefore, Table 3 presents the contextual information identified in the conceptual analysis by these four primary context types.

An examination of Table 3 reveals that there is a wide range of contextual information available to mobile applications. Most contemporary mobile devices, such as wireless phones, are capable of gathering this contextual information. Mobile application designers can benefit from examining ways in which this readily available contextual information can be interpreted to create input for context-aware applications.

The majority of the instances of contextual information identified in this research are classified into the **"location"** primary context type. In eight out of nine sources, the *"physical location of the user"* is interpreted from the contextual information *"electronic signals received by a mobile device."* This finding aligns with literature that suggests that a user's physical location, interpreted through electronic signals such as a global positioning system, is the most common context interpreted by mobile applications (Schmidt, Beigl & Gellersen, 1999; Lee & Benbasat, 2004). However, this study also demonstrates that "location" contextual information can also describe the *"proximity of device to an object"* which, in one source, is associated with an interpretation of user intent. It is likely that other sources and interpretations of "location" contextual information are possible.

The **"activity"** primary context type is also well represented among the instances of contextual information in the literature. Six unique categories of this type of contextual information are identified:

- Amount of ambient light
- Device capacitance
- Device movement
- Device speed
- Previous user locations
- Type of environmental noise

These categories of contextual information are diverse, as they describe either the user, the mobile device or the environment. Since several sources of this activity-related contextual information are available, this type of contextual information could potentially be used to support a wide range of interpretations. This is demonstrated here, as the following six interpretations are associated with activity-related contextual information:

- Orientation of the device relative to the user
- Range of user from current physical location
- Surrounding lighting conditions
- Type of user activity
- User intention to record a voice memo
- User interests

In this respect, contextual information describing the activity surrounding the use of a mobile application could be especially valuable to a designer.

The **"time"** primary context type is represented by only two instances of contextual information identified in the literature, *"time of day"* and *"duration of environmental noise."* The fact that *"time of day,"* contextual information that is readily available to mobile devices, is identified as contextual information in only one source is surprising. This research suggests that time-related contextual information by itself is not sufficiently valuable to form contextual interpretations. Of the two sources that exhibit contextual information associated with time, one uses *"duration of environmental noise"* together with *"type of environmental noise"* to interpret *"type of user activity."* The other uses *"time of day"* as one of three contextual interpretations. In this sense, time-related contextual information might be best used by mobile application designers to supplement to other types of contextual information.

No instances of contextual information associated with the **"identity"** primary context type are identified in the conceptual analysis. The use of contextual information associated with user identity might be described as personalization in the literature. Studies may exist that use contextual information associated with identity to improve the usability of mobile applications, but such is not described as context in the material selected for coding in this study and therefore cannot be reported.

Only two contextual interpretations identified in the literature, *"user intention to record a voice memo"* and *"type of user activity"* are derived from multiple instances of contextual information. The contextual information associated with both interpretations represents multiple primary context types. In one source, the interpretation *"user intention to record a voice memo"* is associated with the contextual information *"device movement"* (activity), *"device capitance"* (activity) and *"proximity of device to an object"* (location). In the second source, *"type of user activity"* is interpreted from the contextual information *"type of environmental noise"* (activity) and *"duration of environmental noise"* (time). Since each primary context type provides answers different questions, the use of multiple, diverse instances of contextual information might help application designers derive more sophisticated contextual interpretations.

Application of Context

Table 4 (Contextual Input Aligned with User Interface Improvements) presents four types of user interface improvements that are associated with the use of context as an input source in mobile applications. For each user interface improvement identified in the literature, the associated contextual input and application response are listed. This information is intended to provide designers with some specific approaches to context-awareness that may be used to improve the usability of mobile applications.

User Interface Improvement	Interpreted Contextual Input	Response of the Application	# Sources
Automatically adapts the user interface for optimal display	Orientation of the mobile device relative to the user	Mobile device display is re-orientated to face the user	2
	Surrounding lighting conditions	Adjusts the backlight of the mobile device's display	1
Reduces user input required to find relevant information	Physical location of user	Displays content relevant to user location	4
	1. Physical location of user 2. Range of the user from current physical location	Delivers content relevant to user location and range	1
	1. Physical location of user 2. User interests 3. Time of day	Displays content relevant to user location, interests and time of day	1
Reduces user input required to find and format relevant information	Type of user activity	1. Delivers content relevant to user activity 2. Selects output format to best suit user activity	1
	Physical location of user	1. Displays a map indicating user location 2. Provides directions to user location through a mobile website	1
		1. Displays a map indicating user location 2. Displays content relevant to user location	1
Simplifies a task	User intention to use mobile device to record a voice memo	Voice recording application starts	1

Table 4 – Contextual Input Aligned with User Interface Improvements

The reduction of required user input to both find and find/format information are shown to be the most common user interface improvements associated with the use of contextual input. As an example, four sources describe applications that use the interpreted contextual input *"physical location of the user"* to *"deliver content relevant to the physical location."* Users of such applications do not need to know their current physical location, much less have to manually input a location on a cumbersome mobile device, to find the information they are looking for. This is significant, considering the limited input/output capabilities of mobile devices (Dunlop & Brewster, 2002) and the fact that users are often engaged in other tasks while using mobile applications (Barnard et al., 2006). By reducing required user input, designers have an opportunity to use context-awareness to improve mobile applications by alleviating some of the cognitive and physical burden normally placed on the user.

One identified application response is associated with the user interface improvement *"simplifies a task."* In this particular source, the interpreted context *"user intention to record a voice memo"* is associated with a response in which a voice memo application starts automatically. As noted above, this application response improves usability by reducing the need for user input. However, this example suggests that application designers can apply contextual input in a way that makes it easier for users to perform a variety of tasks in addition to finding/formatting relevant information.

Contextual input is also shown to be associated with the user interface improvement *"automatic adaptation of the user interface for optimal display."* In one example of this approach, two sources present applications that respond to the interpreted contextual input *"orientation of the mobile device relative to the user"* by automatically adjusting the display of the mobile device. Similarly, a third study describes an application that responds to the contextual input *"surrounding lighting conditions"* by automatically adjusting the backlight of the mobile device. Such responses eliminate the need for the mobile application user to either adapt to a static display or make manual adjustments to it, situations that are problematic given the dynamic context associated with the use of mobile devices (Barnard et al., 2006). In this sense, the application of contextual input to automatically adapt a mobile device's display gives designers an opportunity to improve the user interface.

APPENDIX A – DEFINITION OF TERMS

Context-Awareness – "... approach in which the context information is being applied to benefit the users. . ." (Aaltonen & Lehikoinen, 2005, p. 381); "A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on a user's task" (Dey & Abowd, 1999, section 3.2).

Context-Awareness Model – "A mathematical representation of [the concept of context-awareness] used for analysis and planning" (TechEncyclopedia: Model, n.d.).

Contextual Information -- ". . . any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves" (Dey & Abowd, 1999, section 2.2).

Efficiency – an assessment of "how quickly [users] can perform tasks . . . once they have learned the design" (Nielsen, 2003).

Entity – ". . . a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves" (Dey & Abowd, 1999, section 2.2).

Implicit Input – ". . . action, performed by the user that is not primarily aimed to interact with a computerized system but which such a system understands as input" (Schmidt, 2000, section 2.1).

Learnability – an assessment of "how easy is it for users to accomplish basic tasks the first time they encounter the design" (Nielsen, 2003).

Mediation – “. . . the dialog that occurs between a user and a computer that resolves ambiguity” (Dey & Mankoff, 2005, p. 57).

Memorability – an assessment of the “ability of infrequent users to return to the system without having to learn it all over” (Nielsen, 1993, p. 15).

Middleware – “Software that functions as a conversion or translation layer” (TechEncyclopedia: Middleware, n.d.).

Mobile Application -- Mobile devices run mobile applications, which host mobile services (m-services) that are offered through mobile telecommunication networks (Chen, Zhang & Zhou, 2005).

Mobile Commerce (M-Commerce) – “. . . an emerging set of applications and services people can access from their Web-enabled mobile devices” (Sadeh, 2002, p. 5).

Mobile Services (M-Services) – “. . . extends the concept of a web service to the wireless environment. . . requesting and running web services on wireless devices” (Chen, Zhang & Zhou, 2005, p. 2).

Pervasive Computing – “. . . describes a concept of unobtrusively embedding computing devices and technologies into an environment that is conducive for users to perform their everyday tasks” (Kurkovsky, 2005, section 2, para. 1).

Physical Sensors – “. . . electronic hardware components that measure physical parameters in an environment” (Schmidt et al., 1999, p. 5).

Proactive – [in the context of computer applications] “. . . anticipating user action . . .” (Anagnostopoulos, Mpougiouris & Hadjiefthymiades, 2005)

Satisfaction – An assessment of “how pleasant it is to use the design” (Nielsen, 2003).

Ultra-Mobile Computing – "... computing devices that are operational and operated while on the move" (Schmidt et al., 1999, p. 1).

Usability – "... a quality attribute that assesses how easy user interfaces are to use" (Nielsen, 2003) or "methods for improving ease-of-use during the design process" (Nielsen, 2003).

Usability Testing – "... an evaluation method used to measure how well users can use a specific software system" (Zhang & Adipat, 2005).

User Interface – "A computer-mediated means to facilitate communication between human beings or between a human being and an artifact" (Marcus, 2002)

APPENDIX B - INTERPRETATION AND APPLICATION OF CONTEXTUAL INFORMATION TO IMPROVE USABILITY (TABLE 2)

Source	Contextual Information Instance(s)	Interpreted Contextual Input	Application Response	User Interface Improvement
Cheverst, Mitchell & Davies (2002)	Electronic signal sent from nearby laptop computer	Physical location of the user	Displays content relevant to user location	Reduces user input required to find relevant information
Cheverst, Mitchell & Davies (2002b)	1.Electronic signal sent from a nearby base station 2. Previous user locations 3. Time of day	1. Physical location of the user 2. User interests 3. Time of day	Displays content relevant to user location, interests and time of day	Reduces user input required to find relevant information
Hammond, Shamma & Sood (2003) – 1	Electronic signals from cellular towers	Physical location of the user	1. Displays a map that indicates user location 2. Displays content relevant to user location	Reduces user input required to find and format relevant information
Hammond, Shamma & Sood (2003) – 2	Electronic signals from cellular towers	Physical location of the user	1. Displays a map that indicates user location 2. Provides directions to user location through a mobile website	Reduces user input required to find and format relevant information
Hammond, Shamma & Sood (2003) – 3	Electronic signals from cellular towers	Physical location of the user	Displays content relevant to user location	Reduces user input required to find relevant information
Hinckley, Pierce, Sinclair & Horvitz (2000) – 1	1. Device capitance 2. Device movement 3. Proximity of device to an object	User intention to use mobile device to record a voice memo	Voice recording application starts	Simplifies a task

Source	Contextual Information Instance(s)	Interpreted Contextual Input	Application Response	User Interface Improvement
Hinckley, Pierce, Sinclair & Horvitz (2002) – 2	Device movement	Orientation of the mobile device relative to the user	Mobile device display is re-orientated to face the user	Automatic adaptation of the user interface for optimal display
Kurkovsky (2005)	Electronic signal from nearby wireless access point	Physical location of user	Delivers content relevant to user location	Reduces user input required to find relevant information
Ludford, Frankowski, Reily, Wilms & Terveen (2006)	1. Electronic signal from global positioning system 2. Speed	1. Physical location of user 2. Range of the user from current physical location	Delivers content relevant to user location	Reduces user input required to find relevant information
Schmidt et al. (2000) – 1	Amount of ambient light	Surrounding lighting conditions	Adjusts the backlight of the mobile device's display	Automatic adaptation of the user interface for optimal display
Schmidt et al. (2000) – 2	Device movement	Orientation of the mobile device relative to the user	Mobile device display is re-orientated to face the user	Automatic adaptation of the user interface for optimal display
Skov & Høegh (2005)	Electronic signal from a control center	Physical location of user	Deliver content relevant to user location	Reduces user input required to find relevant information
Smith, Ma & Ryan (2006)	1. Environmental noise 2. Duration of environmental noise	Type of user activity	1. Delivers content relevant to user activity 2. Selects output format to best suit user activity	Reduces user input required to find and format relevant information

APPENDIX C – CLASSIFICATION OF CONTEXTUAL INFORMATION ACCORDING TO FOUR TYPES (TABLE 3)

Primary Context Type (per Dey & Abowd, 1999)	**Contextual Information Instance**	**Interpreted Contextual Input**	**# Sources**
Location	Electronic signal from an external source	Physical location of the user	8
	Proximity of device to an object	User intention to record a voice memo (with device movement and device capitance)	1
Time	Time of day	Time of day	1
	Duration of environmental noise	Type of user activity (with type of environmental noise)	1
Activity	Previous user locations	User interests	1
	Device capacitance	User intention to record a voice memo (with proximity of device to an object and device movement)	1
	Device movement	User intention to record a voice memo (with proximity of device to an object and device capitance)	1
		Orientation of the device relative to the user	2
	Amount of ambient light	Surrounding lighting conditions	1
	Type of environmental noise	Type of user activity (with duration of environmental noise)	1
	Device speed	Range of user from current physical location	1

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