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ONTOLOGY-DRIVEN AND TEMPLATE-BASED APPROACH FOR USABILITY REQUIREMENTS ELICITATION AND SPECIFICATION

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ONTOLOGY-DRIVEN AND TEMPLATE-BASED APPROACH FOR USABILITY REQUIREMENTS ELICITATION AND SPECIFICATION

By

TOO CHIAN WEN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

October 2018

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This thesis work is dedicated



My mother who has devoted her life to her children,

My husband who has been giving me support along my research journey,

My lovely daughter, our gift from God

And

To all people who live with peace and wisdom.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

ONTOLOGY-DRIVEN AND TEMPLATE-BASED APPROACH FOR USABILITY REQUIREMENTS ELICITATION AND SPECIFICATION

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October 2018

Chair: Sa'adah Hassan, PhDFaculty: Computer Science and Information Technology

Nowadays, due to the high demand for quality software, the challenges facing by developers to meet the user expectations are increased from time to time. Usability, a quality attribute related to efficiency, effectiveness and satisfaction of the end users to a system has been recognized as one of the significant factors that can influence user preferences and acceptance of software products. However, due to its abstract in characteristic and most of the software developers are lack of sufficient knowledge or expertise about usability issues, usability requirements are always being neglected especially from the early stage of software development. Typically, usability requirements are being specified at the later stage, such as during design, implementation or evaluation. The improper treatment of usability issues always cause the poor quality in software products and can contribute largely to software failure. As a result, it increases the efforts and costs of resolving usability problems after the software implementation and deployment. Therefore, an essential approach for considering and incorporating usability requirements start from the early stage of software development especially during the requirements elicitation became tremendously important. This study attempts to address the issues in improper treatment of usability by proposing a conceptual framework known as Usability Requirements Elicitation and Specification (UReS). The UReS is an ontologydriven and template-based approach mainly used for usability requirements elicitation and specification during the requirements engineering (RE) activities. UReS aims to provide semantic guidance to facilitate the requirement engineer in eliciting the relevant usability features of a domain's function and specifying the usability requirements. To ensure the sufficient knowledge on usability is provided, a domain ontology which encodes the knowledge about usability features that are relevant to a domain context is designed and acts as the knowledge model in UReS framework during the requirements elicitation activity. Meanwhile, to foster the consistency and clarity of requirements specification, UReS uses a set of predefined boilerplate template to support the process of usability requirements specification. Apart from that, an UReS prototype tool has been developed to support the automation of UReS conceptual framework for facilitating the requirement engineer in performing the requirements elicitation and specification tasks. Furthermore, UReS conceptual framework and the prototype tool are validated using controlled experiment and usability study. The results achieved from the controlled experiment shows that the treatment approach, UReS framework performed well compared to control approach, the manual usability guidelines in terms of the accuracy which measured by correctness and completeness and the number of consistent and unambiguous usability requirements specification generated. In addition, the usability study used to evaluate the user perceptions in terms of the usefulness and usability of UReS prototype tool has received positive feedbacks from the targeted respondents.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENDEKATAN PERPANDUKAN ONTOLOGI DAN BERASASKAN TEMPLAT UNTUK ELISITASI DAN SPESIFIKASI KEPERLUAN KEBOLEHGUNAAN

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Pada masa kini, disebabkan oleh permintaan yang tinggi terhadap kualiti perisian, cabaran yang dihadapi oleh pemaju perisian untuk memenuhi permintaan kebolehgunaan adalah semakin tinggi. Kebolehgunaan, salah satu atribut kualiti yang berkaitan dengan kecekapan, keberkesanaan dan kepuasan pengguna terhadap sistem telah diiktirafkan sebagai salah satu faktor penting yang boleh mempengaruhi pilihan pengguna dan penerimaan terhadap produk perisian. Walau bagaimanapun, disebabkan ciri-ciri kebolehgunaan yang abstrak dan kebanyakan pemaju perisian yang kekurangan pengetahuan atau kepakaran yang mencukupi mengenai isu kebolehgunaan, keperluan kebolehgunaan sentiasa diabaikan semasa proses pembangunan perisian terutamanya dari peringkat awal pembangunan. Lazimnya, keperluan kebolehgunaan dinyatakan pada peringkat akhir umpamanya semasa reka bentuk, perlaksanaan atau penilaian. Pengolahan yang kurang tepat mengenai isu kebolehgunaan sentiasa menjejaskan kualiti produk perisian dan banyak menyumbangkan kegagalan perisian. Akibatnya, ia meningkatkan usaha dan kos untuk menyelesaikan masalah kebolehgunaan selepas pelaksanaan dan penggunaan perisian. Oleh sebab itu, satu pendekatan penting untuk mempertimbangkan dan melingkungi keperluan kebolehgunaan bermula dari peringkat awal pembangunaan perisian terutamanya semasa elisitasi keperluan adalah amat diperlukan. Kajian in bertujuan untuk menangani isu mengenai pengolahan yang kurang tepat dalam kebolehgunaan dengan mencadangkan satu rangka kerja konseptual yang dikenali sebagai Elisitasi dan Spesifikasi Keperluan Kebolehgunaan (UReS). UReS merupakan satu pendekatan berasaskan ontologi dan templat yang digunakan terutamanya untuk elisitasi dan spesifikasi keperluan kebolehgunaan dalam aktiviti keperluan kejuruteraan (RE). UReS bertujuan untuk menyediakan panduan semantik untuk memudahkan jurutera keperluan menggumpulkan ciri-ciri kebolehgunaan yang berkaitan dengan fungsi sesuatu domain dan

menyatakan keperluan kebolehgunaannya. Demi memastikan pengetahuan tentang kebolehgunaan yang mencukupi disediakan, ontologi domain yang mengekodkan pengetahuan tentang ciri-ciri kebolehgunaan yang berkaitan dengan konteks domain telah direka dan digunakan sebagai model pengetahuan dalam rangka kerja UReS semasa aktiviti elisitasi keperluan. Sementara itu, untuk memupuk konsistensi dan kejelasan spesifikasi keperluan, UReS menggunakan templat plat dandang yang telah ditetapkan bagi menyokong proses spesifikasi keperluan kebolehgunaan. Selain itu, satu aplikasi prototaip UReS telah dibangunkan untuk menyokong automasi rangka kerja UReS dalam memudahkan kerja jurutera keperluan dalam melaksanakan tugas elisitasi dan spesifikasi keperluan semasa aktiviti RE. Seterusnya, rangka kerja konseptual UReS dan aplikasi prototaipnya disahkan dengan menggunakan eksperimen terkawal dan kajian kebolehgunaan. Keputusan vang diperolehi daripada eksperimen terkawal menunjukkan bahawa pendekatan pengolahan iaitu rangka kerja UReS dilaksanakan dengan lebih baik berbanding dengan pendekatan terkawal iaitu garis panduan kebolehgunaan manual dari segi kejituan yang diukur dengan ketepatan dan kesempurnaan dan juga bilangan spesifikasi keperluan kebolehgunaan konsisten dan jelas yang dapat dihasilkan. Tambahan lagi, kajian kebolehgunaan yang digunakan untuk menilai persepsi pengguna terhadap aplikasi prototaip UReS dari segi kegunaan dan kebolehgunaan telah menerima maklum balas yang positif daripada responden yang disasarkan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

RE	Requirements Engineering
HCI	Human Computer Interaction
SE	Software Engineering
QAW	Quality Attribute Workshop
UML	Unified Modeling Language
UReS	Usability Requirements Elicitation and
	Specification Framework
FR	Functional Requirement
NFR	Non-Functional Requirement
FUF	Functional Usability Feature
UI	User Interface
UEG	Usability Elicitation Guideline
UEC	Usability Elicitation Cluster
UQAW	Usability-Driven Quality Attribute Workshop
MDD	Model-Driven Development
RDF	Resource Description Framework
W3C	World Wide Web Consortium
OWL	Web Ontology Language
DL	Description Logic
KR	Knowledge Representation
KB	Knowledge Base
FSE	Fixed Syntax Element
DO	Domain Ontology
SUS	System Usability Scale
GUI	Graphical User Interface
IDE	Integrated Development Environment
IR	Information Retrieval

CHAPTER 1

INTRODUCTION

This chapter presents an introduction to this research on the inclusion of usability at the early stage of software development process which started from requirements engineering (RE) activities. The first section provides the research background and problem statements, followed by the research objectives and scope. The chapter also discussed about the significance of the research and the associated terms used. Finally, a brief description on the thesis organization is presented at the last section of this chapter.

1.1 Research Background

The core of a successful software product is the clear understanding of its requirements (L M Cysneiros & Leite, 2004). Consequently, the way how requirements are treated during software development process is important to determine the success of a system. Nowadays, the challenges in software engineering discipline have been increased with the highly and sophisticated user demand for quality software products. Thus, software developers have to make sure their products are excellent in both functionality and quality in order to meet their users expectations and as well as able to compete with their competitors. Poor in quality becomes a major barrier to the success of a commercial software product as users are becoming more critical in quality aspects. The increasing of software complexity and competition in software industry has highlighted the importance of software quality issue to be considered in development process.

Usability is one of the most important quality attributes which have been widely recognized as a potentially critical factor that can affect the performance of a software product especially those highly interactive systems. It is defined by the standard ISO 9241-11 as the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO, 1998). Usability requirements specify how easy the system must be used in helping users to perform their task effectively and increase the productivity and acceptability of the system. The deactivation of the London Ambulance Service Software is one of the best classical example to illustrate how important the role of usability (Finkelstein & Dowell, 1996). The proper consideration of usability at early stage can save many efforts and costs to resolve usability issues after the software being implemented and deployed.

Both in Human Computer Interaction (HCI) and software engineering (SE) disciplines have classified usability as a kind of non-functional requirements (NFR). In HCI, usability had been treated as an essential feature when define

and develop a usable software system. While, one of the common views in SE field is that usability is mainly related to the user interface but not the core of a system. Varieties of techniques and approaches to enhance usability in software have been proposed in the past decades due to the awareness of the importance of usability. However, the characteristics of usability, abstract and intangible in nature make it hard to quantity or specify precisely (L.M. Cysneiros, Werneck, & Kushniruk, 2005). Dealing with usability in the shape of NFR causes it hardly to satisfy such requirements as there is lack of detail information to reflect the users need and expectations in usability. In consequences, usability issues are always being dealt at the later stage of software development process such as during implementation or evaluation (Natalia Juristo, 2009; Ormeno, Panach, Condori-Fernandez, & Pastor, 2013; Rafla, Robillard, & Desmarais, 2007). Moreover, studies had found that usability should not be treated as NFR since it has major implications with the FR.

Since past years, number of findings from the studies indicate that the drawbacks of late integration of usability as it often implies significant constraints and requirements on the system architecture and design (Bass & John, 2000; Folmer, Van Gurp, & Bosch, 2003; Natalia Juristo, Moreno, & Sanchez-Segura, 2007a). It affects the core functionality of a system, resulted in additional reworks need to be implemented and tested (John, Bass, Golden, & Stoll, 2009). These findings were proven by the empirical evidence showing that certain usability factors have major relationship with the underlying software architecture by evaluating their impact using real application case studies (Natalia Juristo et al., 2007a). As such, it must be carefully regarded during software development process especially from the early stage of RE activities.

For this reason, many research have proposed to address usability at the early stage of software development process. Some authors suggested to start from architectural design stage (Bass & John, 2000; Folmer & Bosch, 2004; Natalia Juristo et al., 2007a). Meanwhile, another group of authors proposed should deal it prior to the architectural design stage which is from the requirement stage (Cysneiros, Werneck, & Kushniruk, 2005; N Juristo, Moreno, & Sanchez-Segura, 2007b; Rafla, Robillard, & Desmarais, 2007; Rivero, Marczak, & Conte, 2013; Roder, 2012). According to the Quality Attribute Workshop (QAW) technical report, it is beneficial to identify quality attributes early as the essential quality attributes will be built into the system and more cost-effective to reason about their trade-off earlier where corrections are always difficult or impossible when come to the later stage (Barbacci et al., 2003).

Knowing the benefits of guaranteeing the usability of software as early as possible has led to emergence of some approaches aimed to address usability starting from requirements elicitation activity albeit the common practices mainly focused on specifying functional requirements. Common techniques used to elicit usability requirements are conventional requirements engineering gathering techniques like checklist, interviews, questionnaires, brainstorming and workshops. However, those techniques are insufficient to capture usability requirements specifically. Besides methods, guidelines like ISO standards, HCI heuristics and principles, representation for example using catalogues, patterns, scenarios and models are being proposed to elicit usability requirements in different contexts. Most of these representations are reusable and updateable. Studies also found that some representations adopted graphical notations in depicting usability requirements besides using textual-based specification (L M Cysneiros & Leite, 2004; L.M. Cysneiros et al., 2005).

However, most of the methods proposed are still mainly focused on capturing usability together with other quality attributes at the same time or eliciting usability using general NFR methods (Doerr, Kerkow, Koenig, Olsson, & Suzuki, 2005; Jokela, Koivumaa, Pirkola, Salminen, & Kantola, 2006). Commonly used standard guidelines like ISO 9126, ISO 9241-11 or ISO 25010 are too generic and neither practical nor detail enough to support the effort in usability elicitation based on their definitions in the models. It is a challenging task which involves complex activities and hardly to identify or capture the usability requirements completely (Grosse-Wentrup, Stier, & Hoelscher, 2009; Jokela, 2005). Figure 1.1 shows an example of usability attribute representations in ISO 9126 quality model. Usability is defined with the characteristics of understandability, learnability, operability, attractiveness and usability compliance.



Figure 1.1: Representation of Usability in ISO 9126 Quality Model [Adapted from (International Organization For Standardization ISO, 2001)]

Furthermore, certain proposed guidelines are too domain specific and difficult to apply other than in the context being defined (Cronholm & Bruno, 2008; L.M. Cysneiros et al., 2005). Extra efforts or modifications are needed in order to reuse and adapt them into different contexts. Graphical notations like UML or notations supported by certain representations used to elicit usability

requirements hardly get the involvement of end user as it is not easy to understand the meaning of the notations used. Some approaches suggested to extend the notations from their original version, thus it becoming more complex and could not clearly represent the requirements. Anyway, although textualbased representation is easier to understand and facilitating in user participation compare to graphical notations, but the common problems of ambiguous and incomplete requirements might be generated when used.

From all the issues highlighted, obviously it shows that there is still room for improvement from the existing proposed approaches. Thus, the inclusion of usability into early stage of development process approach acquires few refinements in terms of isolation of usability with other NFR attributes during capturing process, a systematic way to reason and explicitly model the usability features related aspects and consistent structure to standardize the requirements specification. Furthermore, there is a need of a tool to provide guidance and help developers to perform their task faster, thus make its application more efficient (Laura Carvajal, 2012). So, this research aimed towards in improving the usability elicitation and specification at the requirement stage in order to fill the gap.

1.2 Problem Statement

In general, the main reason that caused the failure of software product is the improper treatment of quality attributes during software development process. Among them, usability is one of the most critical factors that determine user acceptance to the product. The late identification of usability issues and not taken usability into consideration systematically during the requirements engineering process are the main problems in the existing practices. Most of the proposed approaches did not clearly address on how to perform the elicitation and specification process to explicitly consider usability requirements (Marques et al., 2018; Rodríguez & Acuña, 2013). Besides that, many software developers do not have the sufficient knowledge or expertise in usability (Natalia Juristo, 2009; Ormeño & Panach, 2013). The information presented in the existing solutions is limited with proper guidelines used to identify or specify the details of usability features related to certain system functionality.

In addition, the problem of ambiguity and poor understanding between stakeholders is another issue contributed to the problem in existing elicitation and specification methods. Due to lack of common vocabulary used, different stakeholders interpreted and expressed their needs in different ways (Dermeval et al., 2016). Moreover, the common used of unstructured textually specification in natural language always cause the generated requirements are inconsistent and ambiguous (Nguyen, Grundy, & Almorsy, 2016). Lastly, lack of supporting tool to in the existing methods to assist the stakeholders in usability requirements elicitation and specification is also another issues to be concerned (Laura Carvajal, 2012; Ormeño & Panach, 2013).

1.3 Research Objectives

The main goal of this research is to propose a conceptual framework for usability requirements elicitation and specification. The proposed conceptual framework is aimed for specifically supporting the incorporation of usability along with functional requirements in a systematic way from the early stage of RE activities. In order to meet the research purposes, the followings are the objectives to achieve the research goal:

- 1. To construct a domain ontology to represent the knowledge relating to the concepts of usability features and their relevant elicitation guidelines in order to provide semantic guidance to the software developers in identifying the important usability requirements of a domain context.
- 2. To use ontology as a reusable knowledge model to represent a common set of usability features relevant terms to promote a shared vocabulary and fostering a common understanding among the stakeholders.
- 3. To apply boilerplate together with ontology by defining a consistent structure and enforce a uniform way of terms with semantic relationships among the terms in order to reduce the variability of representations thus improve the correctness, completeness and consistency in specification.
- 4. To develop a prototype tool to assist stakeholders especially the requirement engineer in performing the usability requirements elicitation and specification tasks.

1.4 Scope of Study

This section discussed about the boundaries of this study in order to limit the research elements into manageable context. Generally, the scope of this study is mainly dealing with usability at the elicitation and specification stage during the requirements engineering activities. Notably, the usability requirements discussed in this study are not targeted on User Interface widgets or design concepts. It is mainly referring to the usability features that have major implications on the software functionality.

1.5 Significance of Study

This work has been set out to propose a conceptual framework for usability inclusion during requirement stage that focused at elicitation and specification process. The framework is aimed to design a reusable usability ontology that encodes the knowledge relating to the concepts of usability features and their elicitation guidelines. The domain ontology generated from merging the usability ontology with functional ontology is expected to serve as knowledge model to enable the assertions between functionality of an application domain with their relevant usability features. Consequently provide a semantic guidance to facilitate the requirement engineer in identifying and analyzing complete set usability requirements of an application during the interview or discussion with stakeholders correctly.

Besides that, the proposed framework is also expected to help the requirement engineer to specify their selected usability features in a more structure way based on the boilerplates template given and attributes values suggested from the domain ontology. It promoted a shared vocabulary for standardization and avoided ambiguities arising among different requirement engineers or stakeholders. Eventually, it is expected that the prototype tool developed based on the proposed framework can speed up the elicitation and specification tasks, and produce a set of correct, complete, consistent and unambiguous usability requirements specification that meet users need.

1.6 Glossary

This section explains the terms that have been used throughout this study. Each term listed here is come with brief descriptions. A detailed explanation for each of these terms will be presented in Chapter 2.

- a) **Non-Functional Requirements (NFR)** constraints on services or functions provided by system, inclusive of timing constraint, development constraint and constraints imposed by standards.
- b) **Functional Usability Feature (FUF)** a list of usability features grounded on solid HCI principles used for identifying usability requirements together with system functionality
- c) Usability Property the heuristic and design principles that researchers in HCI field have identified to have a direct influence on system usability
- d) **Requirements Engineering (RE)** process of discovering that purpose by identifying stakeholders and their needs, documenting them for future analysis, communication and subsequent implementation
- e) **Ontology** a formal explicit specification of a shared conceptualization.
- f) **Description Logic (DL)** represent the knowledge of an application domain and reasoning about it.
- g) Reasoner collection of software with inference rules used to check the consistency of the ontology to ensure that the object or data properties are linked correctly with the concepts or classes based on the defined axioms.
- h) **Boilerplates** a pre-defined structural textual template for requirements statements writing.

1.7 Thesis Organization

This thesis is divided into six chapters. The first chapter is the introduction of the thesis. A brief background of the research is included in this chapter. Besides that, the problem statement, research objectives and scope of study also covered in this introduction chapter.

The second chapter is the literature review concerning on the definitions of terms used in usability and usability related work. It presents also the requirements engineering, ontology and boilerplates backgrounds. Apart from that, the existing works focused on usability elicitation and specification also discussed in this chapter

The third chapter is the research methodology. This chapter describes the research methods and activities that been applied in the process of creating conceptual framework. It also discusses the research instruments and the evaluation criteria used during the research.

The fourth chapter explained the formalization of the proposed conceptual framework, called UReS, with an overview is discussed. This is followed by a detailed discussion on the required components in the proposed elicitation and specification approach presented. Lastly, the steps involved in the designing of UReS conceptual framework also discussed.

The fifth chapter discussed about the controlled experiment and usability study conducted during evaluation and validation. Both evaluation methods were explained in details and followed by the results analysis and discussions.

The sixth chapter covered the conclusion and future work. It presented a general conclusion and gives some suggestions on the research path that can be further explored in future.

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