REQUIREMENTS ENGINEERING PROCESS ASSESSMENT AND IMPROVEMENT APPROACH FOR MALAYSIAN SOFTWARE INDUSTRY

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Alhamdulillah

For Mak and Abah, my beloved children Fatin Batrisyia, Fatini Madihah and Ahmad Iyad Aqil, my life partner Abu Bakar, and the rest of Solemon's family members

whose love and support make life beautiful

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ABSTRACT

It is widely acknowledged that Requirements Engineering (RE) has an important implication on the overall success of software or system development projects. As more and more organisations consider RE as the principal problem area in projects, improving the RE process therefore becomes critical for future business success. Moreover, nowadays there are evidences highlighting that improvements in RE process maturity can contribute to improved business performance. There exist generic Software Process Improvement (SPI) standards and assessment methods, specialised RE process improvement models as well as guidance and advices on RE. However, they suffer from various issues that limit their adoption by organisations that are interested to assess and improve their RE process capabilities. This thesis proposes a new RE process assessment and improvement approach, which has two main components: a maturity model for RE process and an assessment method. To ease compliance to the Capability Maturity Model Integration for Development (CMMI-DEV), the approach was developed based on the de-facto SPI framework. Based on previous researches, the RE maturity model is the first completely and consistently developed model that is provided with detailed, explicit guidance on RE best-practices and targeted for Malaysian software industry. The RE practices were mainly identified through a survey on the state of RE problems and the practices among local practitioners, and a review of RE textbooks, maturity frameworks and assessment methods. The proposed approach was evaluated and refined twice before it was validated by two sets of local RE and CMMI expert panels. The two-plus-one round of development and validation phases was designed based on a typical three-round Delphi method. To allow higher adoption rate among local practitioners, the approach supports organisations of all sizes to establish RE process improvement initiatives, particularly the small and medium enterprises (SMEs) who comprises up to 99% of the total enterprises in the country.

ABSTRAK

Kejuruteraan Keperluan (RE) diakui secara meluas mempunyai implikasi penting terhadap kejayaan keseluruhan projek-projek pembangunan perisian atau sistem. Dengan pertambahan bilangan organisasi yang mempertimbangkan RE sebagai permasalahan utama dalam projek-projek, maka meningkatkan proses RE menjadi kritikal untuk kejayaan perniagaan masa hadapan. Selain itu, pada masa kini terdapat bukti yang menyokong usaha meningkatkan kematangan proses RE boleh menyumbang kepada pembaikan prestasi perniagaan. Sememangnya wujud standard dan kaedah penilaian Peningkatan Proses Perisian (SPI) umum, model khusus penambahbaikan proses RE serta bimbingan dan nasihat RE. Walau bagaimanapun, semua ini menghadapi pelbagai isu yang menghadkan penggunaannya oleh organisasi yang berminat untuk menilai dan meningkatkan keupayaan proses RE mereka. Penyelidikan yang telah dibentangkan di dalam tesis ini mencadangkan pendekatan penilaian dan peningkatan proses RE yang baru yang mempunyai dua komponen utama iaitu: model kematangan untuk proses RE dan kaedah penilaian. Untuk memudahkan pematuhan kepada Integrasi Model Keupayaan Kematangan untuk Pembangunan (CMMI-Dev), pendekatan ini telah dibangunkan berdasarkan rangka kerja SPI tersebut. Berdasarkan kajian terdahulu, model kematangan RE adalah model pertama yang dibangunkan secara penuh dan konsisten yang menyediakan panduan terperinci dan jelas tentang amalan RE terbaik dan disasarkan untuk industri perisian Malaysia. Amalan RE di dalam model ini kebanyakannya dikenal pasti daripada satu tinjauan tentang keadaan masalah RE dan amalan di kalangan pengamal tempatan, serta kajian terhadap buku teks, rangka kerja kematangan dan kaedah penilaian RE. Pendekatan yang dicadangkan telah dinilai dan diperhalusi dua kali dan ia telah disahkan oleh dua set panel pakar RE dan CMMI tempatan. Fasa pembangunan dan pengesahan dua tambah satu itu telah direkabentuk berdasarkan kaedah tiga pusingan Delphi yang tipikal. Untuk menggalakkan penggunaan kadar yang lebih tinggi di kalangan pengamal tempatan, pendekatan ini menyokong organisasi tanpa mengira saiz dalam mewujudkan inisiatif penambahbaikan proses RE, terutamanya perusahaan kecil dan sederhana (PKS) yang mewakili hampir 99% daripada perusahaan yang beroperasi di negara ini.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASEAN	-	Association of South East Asian Nations
BABOK	-	Business Analysis Body of Knowledge
CAR	-	Causal Analysis and Resolution (CMMI-DEV process area)
CASE	-	Computer-Aided Software Engineering
CCB	-	Change Control Board
CEO	-	Chief Executive Officer
CI	-	Confidence Interval
CM	-	configuration Management
CMM	-	Capability Maturity Model
CMMI	-	Capability Maturity Model Integration
CMMI-DEV	-	CMMI for Development
CPRE	-	Certified Professional for Requirements Engineering (IREB)
EPA	-	Express Process Appraisal
ERP	-	Enterprise Resource Planning
ESA	-	European Space Agency
EU	-	Educational Unit (IREB CPRE syllabus)
FAME	-	Fraunhofer Assessment Method
FI	-	fully implemented
FLA-RE	-	Flexible Lightweight Assessment Method for assessing RE Process
GP	-	generic practices (CMMI-DEV)
GQM	-	Goal Question Process Metric
ICT	-	Information and Communication Technology
IEEE	-	Institute of Electrical and Electronics Engineers
IIBA	-	International Institute of Business Analysis
IPD	-	Integrated Product Development (CMMI-DEV process area)
IPM	-	Integrated Project Management (CMMI-DEV process area)

IREB	-	International Requirement Engineering Board
IEC	-	International Electrotechnical Commission
ISO	-	International Organization for Standardization
KPA	-	Key Process Area (CMM)
LI	-	largely implemented
M	-	Mean total point scores
MA-MPS	-	MA-MPS Process Assessment Method
MDEC	-	Multimedia Development Corporation Sdn. Bhd.
MDREPM	-	Market-Driven Requirements Engineering Process Model
ML	-	maturity level
MMA	-	Modular Mini-Assessment
MPA	-	Main Process Area (REPM MPA)
MSC	-	Multimedia Super Coridor
NI	-	not implemented
NY	-	not yet
OID	-	Organizational Innovation and Deployment (CMMI-DEV process area)
OPD	-	Organizational Process Definition (CMMI-DEV process area)
PA	-	process area
PI	-	partially implemented
PMBOK	-	Project Management Body of Knowledge
PMC	-	Project Monitoring and Control (CMMI-DEV process area)
PMI	-	Project Management Institute
PMM-RE	-	Process Maturity Model for RE
PP	-	Project Planning (CMMI-DEV process area)
PPQA	-	Process and Product Quality Assurance (CMMI-DEV process area)
Q	-	Question
QA	-	quality assurance
QFD	-	Quality Function Deployment
QPM	-	Quantitative Project Management (CMMI-DEV process area)
RAPID	-	Rapid Assessment for Process Improvemnt for Software Development
RD	-	Requirements Development (CMMI-DEV process area)
RE	-	Requirements Engineering

REGPG	-	Requirements Engineering Good Practice Guide
REPAIM	-	RE Process Assessment and Improvement Model
REPM	-	Requirements Engineering Process Maturity Model
REQM	-	Requirements Management (CMMI-DEV process area)
RG	-	RE goal
RP	-	RE practice
RQ	-	Research question
R-CMM	-	Requirements Capability Maturity Model
SCAMPI	-	Standard CMMI Appraisal Method for Process Improvement
SD	-	Standard Deviation
SDL	-	Specifications Description Language
SEI	-	Software Engineering Institute
SME	-	Small-Medium Enterprise
SP	-	specific practices (CMMI-DEV)
SPA	-	Sub Process Area (REPM)
SPC	-	Statistical Process Control
SPI	-	Software Process Improvement
SPICE	-	alias for ISO/IEC 15504
SPM	-	Structured Process Matrix
SPSS	-	Statistical Package Software System
SSO	-	Shared Services and Outsourcing
SQA	-	Software Quality Assurance
SWEBOK	-	Software Engineering Body of Knowledge
SW_CMM	-	Software Capability Maturity Model
S&M	-	small and medium
TOPS	-	Toward Organized Process in SMEs
TQM	-	Total Quality Management
UK	-	United Kingdom
VER	-	Verification (CMMI-DEV process area)
VSE	-	Very Small Entity

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

This thesis describes a research conducted to develop, evaluate, refine, and validate a new Requirements Engineering (RE) process assessment and improvement approach for Malaysian software industry. This chapter introduces the thesis' setting by outlining the problem statements, research questions, objectives, significance, assumptions and scope of the research conducted. Description of how the thesis is organized is also provided. The detailed background necessary to appreciate and understand the problem that this thesis addresses is detailed in the review of existing literature on RE and process improvement in the next chapter.

1.2 Background to the Research Problem

Software is the product of a software development project. Software can be produced by a single person but most software is produced by a group of people working together. To create software several steps are required, which is known as a process – a software process. A term defined by Sommerville (2007) as *"…the set of activities and associated results that produce a software product.*" There are four fundamentals activities common to all software process: software specification, software development, software verification and validation, and software maintenance. The software specification activity is the one also known as RE, which

is defined by Wiegers (2003) as "*The domain that encompasses all project life cycle activities associated with understanding a product's necessary capabilities and attributes. Includes requirements development and requirements management. A subdiscipline of system engineering and software engineering.*"

RE problems are known to have profound effects on system development costs and functionality (Sommerville and Ransom, 2005). Ad hoc, undefined RE process and poorly defined requirements are known as nearly always end with an unsatisfactory product or a delayed or cancelled project (Beecham *et al.*, 2003c, 2005b). Consequently RE has become one of the central research topics in the field of software engineering. However, although progress in RE has been painfully slow with software development projects continue to experienced problems associated with RE (Young, 2001), research effort in the area continues to be done. These research are mainly motivated by the list of potential benefits expected to be brought about by the successful implementation of an improved RE process. It is widely acknowledged that RE process has an important implication for the overall success of the projects (Hofmann and Lehner, 2001; Martin *et al.*, 2002). Moreover, there is now empirical evidence, such as demonstrated in Chisan (2005) and Damian *et al.* (2004), that support the claimed benefits of RE in improving a software project by improving productivity (Lauesen and Vinter, 2001; Wohlwend and Rosenbaum, 1993), assuring quality (Herbsleb and Goldenson, 1996; Wohlwend and Rosenbaum, 1993), and reducing project risk (Brodman and Johnson, 1995).

Results of a survey performed in Beecham *et al.* (2005a) show that an expert panel consists of both practitioners and academics agreed that RE process remains the most problematic of all software engineering activities. Results of three other surveys involving software development companies in United Kingdom (Beecham *et al.*, 2003d; Hall *et al.*, 2002), and Australia (Niazi and Shastry, 2003) also indicated that organisations still considered RE problems very significant. Amongst the causes of project failures that are attributed to requirements cited by researchers (Beecham *et al.*, 2005b; Niazi and Shastry, 2003; Olson, 2001; Young, 2001) include incomplete requirements, lack of user involvement, unrealistic customer expectations, and changing requirements.

There exists RE standards that set out general principles and give detailed guidance for performing the RE process such as ESA PSS-05-03 Guide to the Software Requirements Definition Phase (Mazza *et al.*, 1996), IEEE Recommended Practice for Software Requirements Specifications (IEEE, 1998c) and IEEE Guide for Developing System Requirements Specifications (IEEE, 1998a). However, these standards offer no aid for selecting appropriate methods or for designing a RE process optimized for a particular organization (Sawyer, 2004). In another survey, Ibanez and Rempp (1996) clearly demonstrated that RE process improvement is an important issue. An improved RE process does not only provide clear benefits to the development and management of software requirements but also to the other activities of a software development project as shown in a case study in Damian *et al.* (2004). Consequently, many organizations seek to improve RE processes by adopting generic Software Process Improvement (SPI) models and standard frameworks (Napier *et al.*, 2005). These models and standards include ISO 9001 standard for Quality Management System (Persse, 2006; Weissfelner, 1999), Software Engineering Institute (SEI)'s Capability Maturity Model (CMM) for Software (Paulk *et al.*, 1993) and Capability Maturity Model Integration or CMMI (Chrissis *et al.*, 2007), ISO/IEC 29110 (ISO, 2011), BOOTSTRAP (Steinen, 1999), and ISO/IEC 15504 standard known as SPICE (Drouin, 1999; Mutafelija and Stromberg, 2003).

It was reported that SPI generally delivers substantial benefits (Humphrey *et al.*, 1991). However, a European survey of organizations engaged in SPI programs during the 1980s confirmed that the SPI models then available offered no cure for RE problems (Sawyer, 2004). These enthusiastic adopters of SPI programs found that while SPI brought them significant benefits, their problems in handling requirements remain hard to solve. This and several other problems related to the process have motivated the development of several specialised RE process improvement models. They include Requirements Engineering Good Practice Guide (REGPG) (Sommerville and Sawyer, 1997), Requirements Engineering Process Maturity Model (REPM) (Gorschek and Tejle, 2002), Requirements Capability Maturity Model (R-CMM) (Beecham *et al.*, 2003b, 2005b), and Market-Driven

Requirements Engineering Process Model (MDREPM) (Gomes and Pettersson, 2007). In addition to the existing standards and models (as mentioned earlier), there also exist recommendation on RE practices and improvement advice in the form of textbooks such in Wiegers (1999, 2003) and Young (2001), however they neither include a process maturity model nor an assessment method (Sawyer, 2004).

Although REGPG, REPM and R-CMM provide methods for assessing existing RE processes, they have presented their improvement advices within the obsolete and no longer supported framework of CMM or Software Capability Maturity Model (SW_CMM) since the SW_CMM (and other previous versions) were retired starting 1st January 2008 to force adherence of participants to the CMMI single model (SEI, 2006a, 2009a). In addition, each of these RE process improvement models has its own problems that could hinder software industry to experience the expected benefits in implementing the model. The classification of the good practices in the REGPG with eight-level of cost of introduction of guidelines was perceived as far too complex (Sommerville and Ransom, 2005), which could easily lead software organisations to be over-ambitious in the improvement programmes that they undertook. Furthermore, the model was originally developed for the safety-critical domain (Sawyer, 2004). Thus, adaptation to different domain is necessary but is currently lacking (Sommerville and Ransom, 2005). The REPM, which is targeted to the Small and Medium Enterprises (SMEs), is designed for project rather than organisational assessment and improvement. As for the R-CMM, at the time of writing, the model remains partially-completed with levels 3 to 5 only exist in draft form. Unlike the first three models, which are built for the use of broad audience, the MDREM's applicability is limited to define the market-driven RE process and the large model size, which has 76 practices, could pose an issue to its usability in the industry (Sawyer, 2004).

1.3 Statement of the Problem

Despite voluminous research on RE as discussed in Nuseibeh and Easterbrook (2000), and Cheng and Atlee (2007), for many years, RE is one of the biggest problems many software and system developers face (Quispe *et al.*, 2010), which are also demonstrated in two research that study the state of RE problems experienced by organizations in two parts of the world: 1) research involving twelve United Kingdom (UK) software companies (Beecham *et al.*, 2003d; Hall *et al.*, 2002); and 2) research that covers eleven Australian software companies (Niazi and Shastry, 2003). As more and more organizations consider RE as one of the principal problems in system or software development, improving the RE process therefore appears critical for future business success (Ning *et al.*, 2005). Consequently, to help practitioners improve their RE processes, many RE practices have been proposed in various research (Beecham *et al.*, 2005b; Gomes and Pettersson, 2007; Pettersson *et al.*, 2007; Sommerville and Sawyer, 1997).

In order to understand which RE practices are used by practitioners, researchers need to constantly aware of what is really going on in practice (Cox *et al.*, 2009). There exist several empirical research that study the state of RE practices in different parts of the world including a study of 60 (12 interviews and 48 document inspection) cases in Canada (Emam and Madhavji, 1995); a survey of 15 respondents in twelve SMEs in Finland (Nikula *et al.*, 2000); a survey of 194 practitioners who are also postgraduate students in the Penn State University, US (Neill and Laplante, 2003); a study within a single Australian company (Damian *et al.*, 2004); and another study involving 10 software development companies in Australia (Cox *et al.*, 2009). However, findings from most of this existing empirical research may not be appropriate to generalize from the small samples used. Moreover, there was not any research done to study the current state of the RE problems experienced and RE practices implemented by practitioners working in software companies in this country. Therefore it is abviously useful to perform similar research to verify the previous findings so that they could be generalised as well as to compare whether there is any major difference in the RE problems

experienced and RE practices implemented by practitioners in other countries particularly Malaysia.

There also exists empirical evidence that improving RE process maturity contributes to improved business performance (Chisan, 2005; Damian *et al.*, 2004; Sommerville and Ransom, 2005). Research in the recent years has shown that software organisations, in need to find ways to improve their RE processes, may either refer to improvement advices from RE textbooks or adopt process improvement models and standards. However, such textbooks do not map out route for incrementally adopting their recommended RE practices or provide a method for assessing weaknesses of the existing RE processes (Sawyer, 2004). That leaves organisations to adopt either any of the generic SPI approaches, and standards or existing specialised RE process improvement models. However, although adopting generic SPI approaches, and standards such as CMMI, ISO 9001/2000 for Software, Sig Sixma, and ISO/IEC 15504 offer promising benefits, they seem unable to solve problems in handling requirements. Similarly, the specialised RE process improvement models, such as REGPG, R-CMM, REPM and MDREPM, also suffer from problems and issues that could hinder organisations from adopting them. These models not only are integrated with the obsolete and unsupported CMM or SW_CMM since the release of the new maturity model CMMI, but they are also either too complex or applicable to only limited type of RE process and application domain or exist in draft form and yet to be completely developed and validated.

The current improvement advices from RE textbooks or generic SPI approaches and standards as well specialised RE process improvement models suffer from various issues, are not adopted and seem unable to help solve RE process problems. Thus, a new RE process improvement model is necessary to help solve RE process problem. But that RE process improvement model should be provided with a method for assessing existing RE processes too as has been suggested by Sawyer (2004). Although several assessment methods already exists, formal assessment methods are considered too expensive, cumbersome and require high resources (Coleman, 2005) while less formal methods may not be applicable in this research since they focus on specific models or standards-based assessment.

Therefore, there remains the need for a new RE process assessment and improvement approach that can help software organisations assess and improve their RE processes and eventually solve their problems in handling requirements.

1.4 Research Question

Based on the problem statement abovementioned, the primary research questions investigated in this research are as follows:

- RQ1: What kind of generic SE problems and RE problems are Malaysian software organisations experiencing and their implemented RE practices?
- RQ2: What are the relationships between RE problems and RE practices, process maturity as well as overall project performance of the software organisations?
- RQ3: What is the best approach in developing a new RE process assessment and improvement approach?
- RQ4: How to validate the completeness, consistency, practicality, usefulness, and verifiability of the new RE process assessment and improvement approach?

The approach to answer the first two questions was by performing literature review and survey amongst practitioners in the local software industry. Findings of the survey then provide input to the development of the new RE process assessment and improvement approach, which help answer the third research question. Lastly, the fourth research question has lead to the validation of the developed RE process assessment and improvement approach by expert panel from the software industry in the country.

1.5 Objectives of the Research

The research objectives therefore are as follows:

1. To investigate the state of RE problems and practices amongst software development companies in Malaysia.
2. To develop a new RE process assessment and improvement approach that can assist software organizations assess and improve their RE process capability.
3. To validate the new RE process assessment and improvement approach.

1.6 Significance of the Research

This research is important to the software engineering domain in general and to the RE domain and RE process improvement in specific. The research performed a survey to investigate the RE problems experienced by local software organizations and their implemented RE practices. The survey provides empirical evidence on the pattern of generic SE problems and RE problems experienced by the organizations. The survey also provides the state of RE practices in the local software industry as well as empirical evidence on the relationships between the company maturity and the project problems, RE problems and practices.

Also, this research enables the new RE process assessment and improvement approach to be completely developed and validated, which has meet certain selected development success criteria and hopefully could enable software organisations to experience the benefits of implementing the new RE process assessment and improvement approach. Software organisations could use the sufficient level of essential information provided in the proposed RE process improvement model and assessment method for initial guide to assess their RE processes, prioritise improvements and thus achieve improved development and management of software requirements. Also, generally, software development projects can expect to improve

their productivity, produce higher software quality, and deliver software product within budget and schedule as indirect results of applying the proposed RE process assessment and improvement approach. Last but not least, the proposed approach should provide insights into effects of SPI especially to organisations that are yet to be certified, in particular with the CMMI-DEV certification.

1.7 Scope and Assumptions of the Research

As mentioned earlier, a survey was conducted to investigate the current RE problems and practices amongst software development companies in the country. This survey was carried out based on the perspective of software development practitioners in Malaysian software companies. These people include requirements analysts, business analysts, project managers and anyone responsible in the RE process. The organisations have different settings such as organisation size and type, project domain, operating environment, software development project practices, and RE practices. Results from this survey were also compared with findings reported in other similar surveys as reported in Niazi and Shastry (2003), Hall *et al.* (2002), and Beecham *et al.* (2003d).

This research develops a new RE process improvement model based on the proven and familiar SPI approach of CMMI-DEV. The research also develops a new RE process assessment method that has been customized for the new RE process improvement model. In addition, the proposed RE process assessment and improvement approach has been twice evaluated by a set of five expert panel and validated by another panel of twenty seven CMMI and RE experts from the local software industry. The data collected indicate that all of the experts have sufficient experiences in handling the RE process or have received a formal training on the CMMI framework. Furthermore, the experts were provided with ample time to perform the validation to the proposed RE process assessment and improvement approach. Therefore, the accuracy of the information given is assumed to be reliable and the generalization to the results of the validation is possible to be made, at least

to represent the software development community in the country. Thus, Malaysian software organizations particularly may use the proposed RE process assessment and improvement approach independently to assess and improve RE process maturity and also to complements the CMMI-DEV SPI approach.

1.8 Organization of Thesis

This thesis is structured as follows:

- **Chapter 2** provides the background necessary to appreciate and understand the problem that this thesis addresses and to provide a context and requirements for the new model development. This chapter reviews several definitions of terminology related RE, roles of RE process to software development, practices and techniques used in RE activities, and why organizations seek to improve RE process. Also, this chapter generally reviews three software process improvement (SPI) standards namely ISO 9001:2000, CMMI-DEV, and Six Sigma. Then the chapter goes on to review CMMI-DEV in details by discussing several issues that surround the standard. After that, the four specialised RE process improvement models, REGPG, REPM, R-CMM, and MDREPM, are reviewed and compared in terms of their structure and components, process assessment implemented and validation methods used. Also, the chapter reviews and compares several existing CMMI-based assessment methods. Next, the chapter reviews five criteria that can be used to determine the success of the RE process assessment and improvement approach and compare the existing specialized RE process improvement model and the existing assessment methods against the success criteria The rationale for developing the new RE process assessment and improvement approach based on the existing maturity framework and assessment methods is described too.
- **Chapter 3** outlines the research methodology employed in this research. This chapter begins with an introduction of the overall research design and followed by a description of an initial data collection performed to

justify the motivation of the research. Detailed information pertaining to the initial data collection and data analysis instruments and procedures is presented too. Then, the chapter discusses on the procedures applied in the development, evaluation and refinement and validation of the proposed RE process assessment and improvement approach.

- **Chapter 4** provides detailed discussion on the survey performed to investigate the RE problems and practices amongst software companies in Malaysia, which is an initial data collection performed to justify the motivation of the research. The chapter focuses at presenting the results of the survey. The chapter also discusses the findings and the threats to the validity of the survey.
- **Chapter 5** provides insight into the key deliverable of this study, which is the new RE process improvement approach. There are two main components to the approach: the maturity (or reference) model; and the assessment method. This chapter begins with discussions on the requirements of the model and model components as derived from the literature reviews in **Chapter 2** and the preliminary study conducted as discussed in **Chapter 4**. Then the chapter defines both model components one by one in great details. The chapter also discusses the evaluation and refinement performed to the proposed RE process assessment and improvement approach before it was validated by the expert panel from the industry.
- **Chapter 6** focuses at presenting the results and findings of the validation performed to the new RE process assessment and improvement approach.
- **Chapter 7** concludes the research described in this thesis by summarising the research conducted. This is followed by discussions of the research contributions and limitations, and some recommendations for future work.

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