Intelligent Situation Awareness Support System for Safety-Critical Environments

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Ph.D. Thesis
This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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March 2015

CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student: Production Note: Signature removed prior to publication.

Date: 27.03.2015

DEDICATION

To my darling wife for her passion and patience and to my beloved parents for their encouragement, that let my dreams came true.

ACKNOWLEDGEMENT

I would like to express my appreciation to Professor Jie Lu, who supervised this Ph.D. program, for all of her knowledgeable comments, precious support, right guidance at hard times, and great suggestions along the way. I want to thank Jie for her willingness that let my research follow my interests. I am also grateful to Associate Professor Guangquan Zhang, my co-supervisor, for his knowledgeable suggestions and valuable advice through my PhD study.

Looking back at my Ph.D., I see my wife, Fahimeh, truly shoulder to my shoulder during this journey. Thank you very much for being so supportive in all circumstances throughout the four years of this Ph.D., for understanding the stress I was subject to, for having sacrificed your time for me while you were doing your Ph.D., and for giving me the freedom to follow my scientific interests unconditionally. I could not have accomplished this without your constant love and support.

I would like to thank my parents, the first ones who taught me, for their encouragement and support despite the geographical distance. Pursuing my PhD was not possible without their love and assistance. I express my gratitude to all my friends and colleagues in the Decision Systems & e-Service Intelligence (DeSI) Laboratory for their help and valuable comments during my study.

I also appreciate the Faculty of Engineering and Information Technology and the Centre for Quantum Computation and Intelligent Systems (QCIS) at the University of Technology Sydney for conference registration and travel funds provided during this research. This research was also supported by the International Postgraduate Research Scholarship (IPRS) funded by the Australian government.

Last, but absolutely not least, a special thank you goes to Ms. Sue Felix and Ms. Barbara Munday for helping me to identify and correct grammar and syntax problems in my publications.

ABSTRACT

In today's safety-critical systems such as process and manufacturing plants, operators are often moved to a control room far away from the physical environment, and increasing amounts of information are passed to them via automated systems, they therefore need a greater level of support to control and maintain the facilities in a safe condition. This is especially important when operators confront abnormal situations in which the information flow is quite high and poor decisions may lead to serious consequences. Therefore, they need to be supported from a cognitive perspective to reduce their workload, stress, and consequent error rate. Of the various cognitive activities, a correct understanding of the situation, that is situation awareness (SA), has been found to be a crucial factor in improving performance and reducing error. However, existing system safety researches focus mainly on technical issues and often neglect SA.

This research reviews the role of SA in accidents of safety-critical environments and introduces a clear definition for abnormal situations based on risk indicators. It then relies on mental models that embody stored long-term knowledge about the systems, and develops an abnormal situations modelling (ASM) method, that exploits the specific capabilities of Bayesian networks (BNs). In this sense, it is assumed that the operator's mental model can be modelled using BNs as a representation of static cause–effect relationships between objects in the situation. Following this, the research presents an innovative cognition-driven decision support system called the situation awareness support system (SASS) to manage abnormal situations in safety-critical environments in which the effect of situational complexity on human decision-makers is a concern. The SASS consists of five major components: (1) a knowledge–base that contains the abnormal situation models of the intended environment developed by the ASM method, (2) a situation data collection component that provides the current state of the observable variables based on online conditions and monitoring systems, (3) a situation assessment component that uses risk indicators and a fuzzy logic system to generate the assessment result, (4) a situation

recovery component that provides a basis for decision-making to reduce the risk level of situations to an acceptable level, and (5) a human-computer interface. The performance of the SASS is demonstrated by three cases investigated by the US Chemical Safety Board in which poor operators' SA has created industrial disasters in recent US history. The results of performance demonstrate that the SASS provides a useful graphical, mathematically consistent system for dealing with incomplete and uncertain information to help operators maintain the risk of dynamic situations at an acceptable level.

The SASS is partially evaluated by a sensitivity analysis, which is carried out to validate the BN-based situation models, and a multi-perspective evaluation approach is proposed based on SA measures to determine the degree to which the SASS improves not degrades the operator's SA. The approach consists of three SA metrics: the Situation Awareness Global Assessment Technique, the Situation Awareness Rating Technique, and the NASA Task Load Index. The first two metrics are used for direct objective and subjective measurement of SA, while the third is used to estimate the workload of operators. The approach is applied in a safety-critical environment, and ten operators participate in two 40-minute simulation trials using a virtual plant user interface, both with and without the support of the SASS. The results indicate that the SASS improves operators' SA, and specifically has benefits for SA levels 2 and 3. No significant correlations between the participants' SA scores have been found. In addition, it is concluded that the SASS reduces the workload of operators, although further investigations in different environments with a larger number of participants have been suggested.

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