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Uncertainty handling in semantic reasoning for accurate context understanding

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ABSTRACT

Context aware systems are using various sensing technologies in order to recognize end-users situations; however these technologies are vulnerable to hardware failures, energy depletion, communication problems and multiple other issues. This generates an uncertainty about the events received from the sensors, which is translated into a confidence given to these events. This confidence is used in the context-aware reasoning through a fusion of sensor data to make more accurate decisions. In this paper, we focus on handling uncertainty in sensor-based context aware applications and we propose a method for the measurement of uncertainty based on both physical and operational behaviors of the sensors. We describe how the level of uncertainty is incorporated into different layers of a semantically driven context aware system and how it is transferred to a decision engine in order to perform more accurate decisions in ambiguous observations.

1. Introduction

Context aware systems have been used in different domains in order to guarantee end-users' safety and quality of life [1,2]. In some cases, it involves a remote monitoring and prompt intervention in dangerous and critical situations [3]. Therefore, the decisions made by context-aware systems have a very crucial and vital impact. This brings several constraints on the accuracy of these decisions and their conformity to real situations.

Sensory contextual information are not always accurate in the real world [4]. They are prone to hardware failure, energy depletion, communication problems and so on. Therefore, a context-aware system should be sensitive to their lack of accuracy in order to take the correct decisions. To account for this, uncertainty measurement and representation appears as a crucial need to perform a reasonable and logical reasoning. This becomes particularly important if the system using the contextual information intends to perform data fusion and higher-ordered reasoning.

A large scale and immersive use of context aware systems may require to limit the variety and complexity of sensing technologies used, in order to make their deployment simple and straightforward [5]. This makes the failures inherent to sensing technologies even more challenging for context awareness, as the imprecision of sensors is even more critical and the reasoning is more uncertain due to the lack of data.

In this paper, we present the different steps we went through to integrate the notion of uncertainty in a context aware system; starting from the uncertainty measurement and pursuing to the semantic modeling, semantic reasoning and decision making under uncertainty. In each section, we describe the related work and provide our approach to deal with the requirements. Finally, we provide a validation of our uncertainty handling approach based on data gathered from a real world deployment.

2. Background and motivation

Context awareness is nowadays used in different domains in order to ensure end users' well-being and security. A predominant use case for context aware systems is ambient assisted living. The goal is to help the growing dependent population with chronic diseases and age-related pathologies by providing personalized and continuous care and assistance, dynamically adapted to their individual needs. It also allows the remote care of dependent people by providing information to the caregivers about their patients'

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situations and sending alerts when they are at risk. In a recent survey that we have conducted with 123 dependent people [6], 49% asserted that they are living alone and 27% confirm that their caregivers (professional or family member) are living more than 10 km away. In addition, 21% of the investigated people claim that their accommodations are not adapted to their needs. The precision and accuracy of sensing technologies and reasoning systems used to provide contextual information in such case is very crucial. An inaccurate inferred information, a wrong decision or a missing alert, provided by an ambient assistive living system deployed in such situations, can have a significant impact on the security and safety of the assisted patients. The review made by McNaull et al. [7] specifies the impact of data and information quality on ambient assistive living systems and presents various factors that can affect the quality of sensors' events.

With this mindset, we have conducted a study to measure the accuracy of the decisions taken by an assistive solution and the possible sources of errors. We have deployed an ambient assistive solution in a nursing home in Singapore during 14 months [8]. This solution monitored 8 patients' activities and provided alerts to caregivers when assistance was needed. With the help of caregivers, we have evaluated the performance of the deployed system. A comparison between the system decisions about the patients' context and the caregivers' observations revealed 29% of incoherence.

The results of an investigation on the origins of these incoherences are given in Fig. 1. We observe that most of them are related to the sensors, mainly the battery level and communication failure. The same conclusion was also discussed in another paper [9]. Other problems were related to the reasoning failure due to the lack of knowledge or imprecise reasoning rules.

Our ambition is to deploy our platform for ambient assistive living [8] in the house of around 200 dependent people. This strengthens our need for a precise contextual information and an accurate decision in order to follow a large number of patients with a limited amount of false alerts being produced. The perspective of this large scale deployment implies the need to reduce the hardware complexity of the system with a restricted variety of sensors in order to simplify the deployment and maintenance tasks. Such situation increases the importance of the reasoning as each individual sensor can have a significant impact on the quality of decisions made by our system.

The results and ambitions stated above have motivated our work on reasoning under uncertainty in order to handle inaccuracy in context aware decisions. Although it is highly possible that such kind of inaccuracy could emerge from the lack of knowledge and the limitation in variety and number of the sensing technologies used, our current scope, based on our test case experimentation's results, focuses primarily on the question of sensors hardware performance.

3. Towards a proposal for uncertainty measurement

A very important requirement for reasoning with contextual information, which has emerged from our real world deployment, is to deal with uncertainty. Context reasoning in ambient environments is very complex due to the dynamic, imprecise, imperfect and ambiguous nature of contextual data that may derive from technological failures, sensing imperfection or incomplete knowledge. Uncertainty has been classified into two types [10]:

Aleatory uncertainty results from the fact that the system behaves in random ways. In context awareness it can result from sensors' hardware failure, energy depletion or communication problems. This type of uncertainty is also known as stochastic uncertainty or type A uncertainty.
Epistemic uncertainty results from the lack of context knowledge. This can be related to the limitation in number and type of sensing technologies used or the incapability of the reasoning system in some cases to classify the human behavior. This uncertainty is also known as subjective uncertainty or type B uncertainty.

To deal with these problems, a formal representation of uncertainty must be introduced in the context understanding reasoning model.

3.1. Related work

Quantitative measurement and numerical representation of uncertain phenomena are complex. Some work has already contributed to the identification of uncertainty in context information. The concept of Quality of Context (QoC) is introduced in [11,12] as "any information that describes the quality of information that is used as context information" with different parameters characterizing it. The main parameters are the precision defined as the "granularity with which context information describes a real world situation", the probability of correctness presented as "the probability that an instance of context accurately represents the corresponding real world situation, as assessed by the context source, at the time it was determined" and the up-to-dateness describing the age of the context information and defining "how

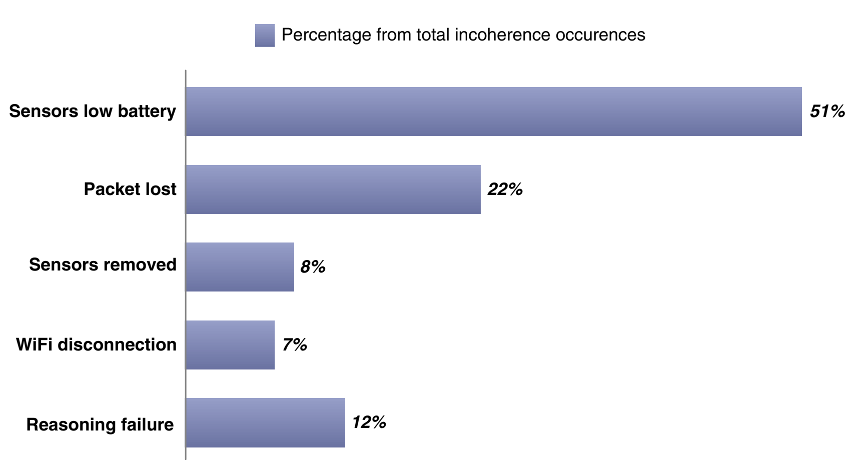

Fig. 1. System incoherence reasons in a nursing home.