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A multi-agent fuzzy consensus model in a Situation Awareness framework

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ABSTRACT

In order to define systems enabling the automatic identification of occurring situations, numerous approaches employing intelligent software agents to analyse data coming from deployed sensors have been proposed. Thus, it is possible that more agents are committed to monitor the same phenomenon in the same environment. Redundancy of sensors and agents is needed, for instance, in real world applications in order to mitigate the risk of faults and threats. One of the possible side effects produced by redundancy is that agents, observing the same phenomenon, could provide discordant opinions. Indeed, solid mechanisms for reaching an agreement among these agents and produce a shared consensus on the same observations are needed. This paper proposes an approach to integrate a fuzzy-based consensus model into a Situation Awareness framework. The main idea is to consider intelligent agents as experts claiming their opinions (preferences) on a phenomenon of interest.

1. Introduction and motivation

The emerging paradigm of Internet of Things (IoT) [1] provides an infrastructure that connects things anytime and anywhere, with anything and anyone, by using any network and service. The IoT emergence fosters the continuous improvement of sensors which become smaller, cheaper and more intelligent [2]. This trend has led to a widespread adoption of sensors deployed to monitor the environments in which we live. Moreover, personal devices, like smart-phones and tablets, are equipped with several sensing capabilities which could be used to monitor users' activities or environmental phenomena.

The exploitation of heterogeneous data collected by different sensors allows applications to provide users with context-aware behaviours and support decision-making processes in a wide range of domains like, for instance, Emergency Management, Energy Savings, e-Health, Physical and Cyber Security. In this scenario, Situation Awareness represents a powerful paradigm enabling the aforementioned capabilities. Situation Awareness has been defined by Endsley as "the perception of the elements in an environment within a volume of time and space, the comprehension of their meaning, and a projection of their status in the near future" [3]. Typically, main models for Situation Awareness foresee the execution of a challenging task, namely situation identification [4] that can be synthesized in a generic workflow composed by three activities: (i) gathering data from a sensor network, (ii) deriving more abstract elements from sensor data and (iii) identifying occurring situations by considering the abstract elements provided by the second step.

The complexity of situation identification is due to several factors like, for instance, the variety of admissible situations, the uncertainty and inaccuracy of data, the dynamic nature of the observed environments and so on. Often, redundant sets of sensors (i.e., sensors which can support the observation of the same phenomenon) are deployed in the environment (to be monitored) in order to handle cases in which it is important to enable resilience that is the capability of a system to absorb and mitigate unexpected faults and risks [5]. Redundancy provides the capability of using a specific sensor instead of another one in cases where an anomaly has been detected in the data gathered by the latter. Moreover, it provides end-users with the capability to select, among several sensors, the most appropriate one, with respect to its characteristics and to the application scenario. This case can be scaled at a more abstract layer where software agents operate (employing different analysis techniques). In this scenario, it is plausible to

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consider cases in which sensors (or agents), observing the same phenomenon, provide different (also discordant) opinions on what is happened in the environment. The choice of the most suitable opinion represents a crucial task that impacts on the quality of the situation identification.

Existing approaches to select the most suitable sensor, among a set of sensors observing the same phenomenon, are recognizable in scientific literature. CA4IOT [6] supports users to formally define their requirements in order to automatize the task of understanding which sensors can provide relevant information to satisfy the users needs with respect to the situation identification. Linked Sensor Middleware (LSM) [7] provides facilities for selecting and searching sensors. However LSM limits queries to sensor locations and sensor types. Furthermore, CASSARAM [8] provides context-aware sensor search, selection, and ranking model for IoT. CASSARAM allows searching and selecting sensors with respect to users priorities and numerous characteristics of sensors (e.g., reliability, accuracy, battery life). Search-based approaches to face redundancy-related problems in sensor networks are also proposed by Elahi et al. [9] and Truong et al. [10].

With respect to the aforementioned works, the research described in this paper defines a different approach that focuses on: (i) working with agents rather than sensors in order to consider perceptions[1] which are more easily processable than raw data and (ii) building the consensus rather than searching, selecting and ranking sensors in order to take advantages from several sources and do not exclude a-priori potentially interesting data.

In order to explain the two main aforementioned focuses, the paper is divided into two parts. The first part (Section 2) describes a perception-based approach for situation identification (that is part of a whole framework for Situation Awareness). The main idea underlying the proposed approach is that human perception strongly relies on cognitive processes. Human cognitive processes support perception by considering and integrating additional knowledge about context and previous experiences together with data coming from the sensing phase. These aspects allow humans reacting also when they have incomplete information. Human perception is defined as "the interpretations of sensation, giving them meaning and organization" [12]. As a result, the activity of perception is not rigorous and well-defined: despite the fact that it depends on the elaboration of information acquired by sensing, the results of the perception are not the same for different individuals or even for the same individual at different times. This is because the human perception is affected by external factors that are not related to sensing activities. In the second part (Section 3), the definition of a multi-agents fuzzy consensus building model to solve redundancy-related problems for situation identification is provided. More in details, a group decision making approach is contextualized and integrated in an existing architecture to allow building consensus among discordant opinions provided by different agents on the same phenomenon. Lastly, Section 4 describes the application of the group decision making approach in a sample scenario and Section 5 provides final remarks and anticipates future works.

2. A perception-based approach for Situation Awareness

The whole framework for Situation Awareness originally introduced in [13,14], sketched in Fig. 1, aims at supporting decision-making processes in heterogeneous application domains. Roughly speaking, the architecture of the proposed framework is composed by four main modules:

- **Situation identification** that is committed to recognize the occurring situations in a given environment.
- **Situation exploitation** that is committed to reason on the identified situations and make forecasting on future situations.
- **Adaptation engine** that is committed to adapt the situation identification process by performing modifications on the ontologies (modelling environment, sensors, goals, etc.) and on the physical environment (for sake of simplicity this relation is not shown in Fig. 1).
- **Application layer** that contains all the elements belonging to domain- and problem-specific scenarios.

In particular, the focus is on the situation identification module that implements a human-oriented perception approach by means of a multi-layered (Fig. 1) multi-agents (Fig. 2) architecture. The main idea is to borrow the methods for analysis and measurements similar to those of humans in which *sensing* (i.e., capturing external stimuli with senses), *perception* (i.e., interpreting the perceived stimuli, giving them meaning and organization) and *cognition* (i.e., retrieving and using the interpreted information) are not clearly separated processes, but they strongly depend from one another. In the proposed approach, perceptions are generated through two levels of abstractions (low-level and high-level) both sustained by ontologies which are used, in synergy with other mechanisms, to assign meanings to the observations and, consequently, to the sensor data.

The sensing phase is achieved by means of several sensors, deployed in the environment [15], which are responsible for gathering data related to different environmental phenomena (φ_1, φ_2, ..., φ_l).

In the low-level perception phase: (i) more than one agent can be deployed to observe the same phenomenon (for redundancy purpose) by using raw data coming from one or more sensors and (ii) the same agent can observe more than one phenomenon. Moreover, the same sensor can be exploited by several agents. More in details, the goal of each agent is establishing and communicating a *preference degree* for each admissible observation of a given phenomenon.

In the high-level perception phase, the preference degrees are exploited for identifying the current situation (see Fig. 1). The identified situation supports decision-making processes by providing a concise, yet exhaustive, goal-related picture of the current environmental status. In complex environments and, in general, in scenarios that require high reliability, more sensors able to perceive the same environmental phenomenon (e.g., room temperature, number of people, etc.) are deployed to improve the accuracy of the gathered data and, consequently, reducing potential errors. In such cases, several agents are committed to provide opinions on the plausible observations of the same phenomenon (e.g., observing agents 2 and 3 in Fig. 2 monitor the same phenomenon φ_b). These opinions could be discordant, this may be due to sensors faults, malicious attacks, noises, etc. Indeed, mechanisms for coming to an agreement among these agents and producing a shared consensus are needed.

2.1. Sensing and low-level perception

Given a specific environment Γ, the *sensing* phase is realized by means of a set of sensors S belonging to different types. All sensors in S are connected and virtualized by means of Global Sensor Networks (GSN) [16]. GSN is a software platform that provides a middleware abstracting from the complexity of heterogeneous sensor technologies, supporting the dynamic deployment of

[1] *[..] perceptions are the primary basis of human intelligence and experience and represent the semantics of observations and measurements [..]* [11].