A Formally Assured Intelligent Ecosystem for Enhanced Ambient Assisted Living Support

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ABSTRACT

The increasing proportion of elderly adults across the world calls for Ambient Assisted Living (AAL) solutions that can support the elderly in their daily activities, ensure timely resolution of critical scenarios, and help them live independently and without social isolation. However, most of the existing AAL solutions deliver only certain functionalities, that, if used side by side, cannot resolve potentially critical scenarios in a timely manner. A safe mitigation of such situations is possible if all relevant AAL functions are seamlessly integrated, and supported by artificially intelligent decision-making solutions. Moreover, given the safety-critical nature of such systems, evidence of their correctness and quality of service needs to also be provided via formal analysis techniques. This paper addresses such issues by presenting the ongoing Ph.D. research work of the author, aiming at developing a formally assured ecosystem for AAL systems.

1 PROBLEM AND MOTIVATION

The world population is rapidly increasing, leading to new societal challenges, such as an increased number of diseases, increased health-care costs, shortage of caregivers etc.[4]. Such facts have motivated the research community to focus on the so-called "Ambient Assisted Living" (AAL) technologies, which aims to develop intelligent assisting solutions that help the elderly in their safe and independent living, while ensuring that they are not isolated.

A survey of the existing AAL systems uncovers a potential research gap in the design and development of user-tested solutions for AAL that integrate various relevant functionalities but also cater for the possible critical situations in a timely manner [1] [2]. Assuming that particular critical events might occur simultaneously, we have analyzed the behaviors of existing partially integrated solutions working side by side and concluded that they are not able to tackle certain critical, concurrent events in real-time. One example is the occurrence of fire and fall events simultaneously. In such scenarios, a safe resolution can be achieved only when the occurrences of both events are communicated to both caregivers and firefighters, who can then further communicate and prioritize their actions accordingly. If the firefighters are informed only of the fire event and not of the person's fall too, and assuming that answering a telephone call is the way to confirm that the event is veridical, they might deem the fire alarm false and decide not to take action, which can possibly result in loss of life. Moreover, most of the existing AAL solutions are not necessarily backed by user-acceptance studies, and there is no formal-analysis-based evidence of their functional and timing correctness, which given the connected and distributed nature of most AAL systems is far from trivial. Based on the above motivation and challenges, our overall thesis goal is to increase the quality of life and self-management of the elderly by user-centered, intelligent AAL solutions with ensured quality of service (QoS).

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2 BACKGROUND AND RELATED WORK

A study on existing AAL architectures shows that there are certain architecture types that address the construction of integrative AAL applications, like Multi-Agent Systems (MAS), Cloud-based and Internet-of- Things (IoT) centric [2]. Although none of the AAL architectures existing on the market are being formally assured, there has been some research that has progressed in this direction via applied methods for dependability and reliability analysis [5] [3]. However, the analyses presented in these related approaches address only simple scenarios and are not used to analyze complex behaviors of integrated AAL systems and their decision making capabilities by employing artificial intelligence (AI) techniques.

3 APPROACH AND UNIQUENESS

As part of the thesis, first we identify the main characteristics of existing AAL solutions by a vast literature survey of the state of the art and state of practice [1]. Given the distributed nature and the safety-critical aspects of a complex AAL solution, as well as the various user preferences, in terms of its functionalities and cost, one needs to find a versatile, modular architectural design of the AAL system that could be easily customized to different needs. To address this challenge, we develop two categories of integrated AAL solutions: a) An architecture with local and cloud-based processing with centralized Decision Support System (DSS) [2] b) A completely distributed solution with multiple agents and active database management systems. Once the AAL solutions are designed, it is crucial to ensure their functionality, QoS and timely response by using formal techniques. The success of any AAL solutions lies in its intelligent decision making supported by AI techniques, especially for critical scenarios. Therefore, any verification of such a solution should include the analysis of the AI-based DSS also. As a final step, we need to validate our proposed solutions on real-life scenarios with representative users.

The salient point of our contribution is in providing integrated solutions for AAL, with ensured QoS via formal analysis, customizability via their modular design, and applicability via their validation on scenarios involving users.

4 RESULTS AND CONTRIBUTION

In this section, we outline the main contributions of the ongoing Ph.D. work (achieved and expected).

(1) *A survey of existing academic and on-the-market AAL solutions to identify strengths, and possible research gaps:* As part of this survey, we have explored the characteristics of existing AAL solutions, in terms of supported services, their flexibility, guaranteed QoS, etc. The potential research gaps in the development of AAL solutions that point out to the following:(i) certain scenarios(like simultaneous occurrence of fire and fall events as cited before) can only be tackled by fully integrated AAL solutions and (ii) there is a need for providing some types of assurance at the design level, with respect to functionality and QoS [1].

(2) *An integrated cloud-based ecosystem architecture for AAL with centralized DSS:* We have proposed a cloud-based architecture that integrates all the selected functionalities as outlined by our survey, and endorsed by end users. The architecture is based on micro services, bearing a clear separation of concerns. The crux of the architecture lies in its modular integration, and its both local and cloud processing modules, such that critical decisions can be processed locally without additional time overheads [2]. We have designed an intelligent context-aware DSS architecture incorporating a combination of AI techniques - fuzzy logic, case-based reasoning and rule-based reasoning. A high level view of our DSS architecture is shown in Fig. 1.

(3) *An extensible agent-based distributed architecture for AAL, with enforced timeliness, adaptivity and consistency:* We propose a distributed architecture involving different agents and an active database management system (ADBMS). The communicating agents are autonomous, whereas the task of maintaining data consistency is performed by the ADBMS. In this way, the real-time overhead incurred by ensuring data consistency is reduced without compromising the distributed computations.

(4) *A formal approach for verification and statistical analysis of AAL systems' dependability:* We propose a pattern-based modeling of the proposed architectures within the Architecture Analysis and Design Language (AADL) including the DSS modules. To make the solution formally analyzable, we assign formal semantics to these patterns in terms of stochastic timed automata (we have already addressed this for our cloud-based architecture). Our method is generic and can be applied to conventional assisted living systems. The network of stochastic timed automata will be automatically obtained via a rule-based transformations. The formal model is then (statistically) model checked with the state-of-the-art UPPAAL tool and its statistical extension (UPPAAL SMC), in order to verify functional and timing properties and thereby perform an extensive comparison of architecture properties in the two cases.

(5) *A prototype implementation and validation of an AAL system with integrated health monitoring, home management and telepresence functionality:* In order to validate our results, we have started to implement a prototype solution based on our integrated centralized architecture, which we plan to validate on real-life scenarios by involving end users of different countries.

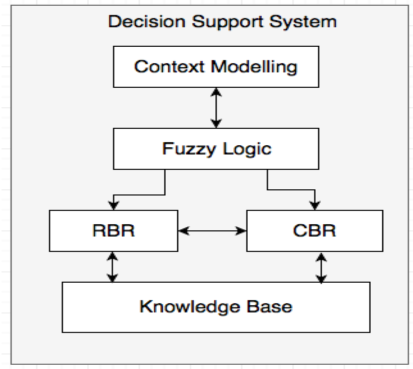

Figure 1: DSS architecture.

5 CONCLUSIONS

As part of this Ph.D. work, we develop integrated architecture solutions for AAL (centralized and distributed) that are formally assured, intended to enhance the quality of life of the elderly. At the present stage of work, we have developed integrated architectures (centralized and distributed agent-based architectures) with guaranteed timeliness. We have also proposed a DSS solution that relies on different AI techniques such as rule-based and case-based reasoning. We employ architecture modeling languages like AADL, and use formal verification tools like UPPAAL SMC to verify the functional and QoS properties of the proposed architectures and its DSS. The major challenges that we face in our research work are connected to: (i) designing integrated and configurable architectures with strict real-time constrains and (ii) formal modeling and analysis of the proposed AAL solutions, such that all modules and AI methods are adequately abstracted, to ensure analyzability while preserving essential information. We are currently developing a prototype to validate the proposed cloud-based solution.

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