On Internet-of-things Devices in Ambient Assisted Living Solutions

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Abstract

In this paper, we present the results of a Rapid Review (RR) of Internet-of-Things (IoT) devices that have been using in AAL solutions for elderly people. In that respect, our literature review is born from the need of delivering evidence to the stakeholders that are involved in the project in which this RR has been conducted. Nevertheless, the obtained results can be of interest to software engineers who want to know which IoT devices have been using in AAL solutions for elderly people to support decision-making in the development of these solutions. The findings of our RR emerge from 61 papers and can be summarized as follows: *(i)* a number of IoT devices are used in AAL solutions for elderly people; *(ii)* most IoT devices do not explicitly focus on specific diseases; and *(iii)* IoT devices support several needs.

Keywords: Rapid review, Ambient assisted living, Internet of things.

1. Introduction

Based on the latest available data, released by Eurostat in 2019, there are 90.5 millions of elderly people—*i.e.,* people aged 65 years or more—in the European Union (EU), accounting for 20.3% of the whole EU population [7]. The proportion of elderly people in the EU is projected to increase from 20.3% to 31.3% by 2100 [8]. The positive trend of longevity in the EU, as well as in other countries, has led to the birth of Ambient Assisted Living (AAL), which aims to let elderly people age in their preferred environment (*i.e.,* at home) as long as possible, managing their physical and mental health, staying connected, and being supported when necessary.

To foster the development of AAL solutions, the EU has funded the AAL program since 2007—specifically, the EU renamed the "Ambient Assisted Living" program as "Active and Assisted Living" in 2014. Other organizations have funded programs to foster the development of AAL solutions too. For example, the research presented in this paper is part of a three-year project, in the AAL field, funded by the Apulia Region through the REsearch For INnovation (REFIN) program. In particular, our project focuses on the definition of a modular and customiz-

able architecture for AAL solutions, which leverages Software Product Line (SPL) engineering. In broad terms, this architecture will consist of: *(i)* a core component providing base functionality; and *(ii)* a series of extensions, which joined the core component, will allow creating different AAL solutions, each of which will be tailored to the needs of a specific class of users.

In this paper, we present the starting point of our three-year project, namely a literature review of Internet-of-Things (IoT) devices that have been using in AAL solutions for elderly people. The project, including its agenda that envisages a literature review as a first research step, underwent a peer-review process and then received funding by the Apulia Region, which also monitors the progress of the project. To review the literature about the use of IoT devices in AAL solutions for elderly people, we conducted a Rapid Review (RR) [4]. We opted for a RR, rather than another kind of secondary study like a Systematic Literature Review (SLR), because it better fitted our needs. First, RRs aim to deliver evidence in a timely manner with limited resources [4]. To do so, RRs can, for instance, restrict themselves to survey the literature from a single database or employ a single researcher when scrutinizing papers [4]. Consequently, while SLRs can last several months, RRs can be completed in a few months or even weeks [4]. Due to the agenda of our project, we had a close time constraint to deliver evidence about the use of IoT devices in AAL solutions. Also, we had limited resources—*i.e.,* just one researcher could be allocated to the execution phase of the literature review. That is, as is the case of RRs, we needed to deliver evidence in a timely manner with limited resources. Second, RRs are practice-oriented secondary studies [3]. In that respect, our literature review is born from the need of delivering evidence to the stakeholders (*e.g.,* physicians or the Apulia Region) that are involved in our project. Third, the results from RRs are shown by using media (*e.g.,* evidence briefing [5]) appealing to stakeholders, rather than researchers [3]. Since we need to mainly show our results to the project stakeholders (including the Apulia Region), the use of media more appealing to the project stakeholders is advisable. Nevertheless, our results can be of interest to any software engineer who wants to know which IoT devices have been using in AAL solutions for elderly people in order to support decision-making in the development of AAL solutions.

2. Rapid Review

In this section, we report the planning and execution of our RR, as well as the obtained results.

2.1. Planning and Execution

Research Questions

To drive our RR, we formulated the following Research Questions (RQs).

RQ1. *What are the IoT devices that have been using in AAL solutions for elderly people?*

This RQ aims to take a census on the IoT devices (*e.g.,* wearable devices) that have been using in AAL solutions. These devices could be used when we will define, in the next steps of our project, a modular and customizable architecture for AAL solutions based on SPL engineering.

RQ2. *What are the diseases (including old age) that IoT devices, used in AAL solutions for elderly people, have been explicitly focusing on?*

With RQ2 we want to understand which diseases (*e.g.,* cardiovascular diseases or, simply, old age) IoT devices have been explicitly focusing on, in the context of AAL solutions for elderly people. That is to say that we linked a device with a disease if the paper's authors explicitly mentioned that such a device is intended for elderly people with such a disease. If no specific disease is mentioned, we consider such a device intended for old age. Knowing these diseases and the supporting IoT devices could help us to define, in the next steps of our project, specific

classes of users for AAL solutions. Also, the answer to RQ2 can help us understanding if researchers in the AAL field have been considering specific diseases of elderly people.

RQ3. *What are the needs that IoT devices, used in AAL solutions for elderly people, have been supporting?*

With RQ3 we want to deepen the study of RQ1 by understanding which specific needs (*e.g.,* detecting when older adults fall) the IoT devices have been supporting, in the context of AAL solutions for elderly people. The answer to this RQ will help us to define our modular and customizable architecture for AAL solutions based on SPL engineering.

Search Strategy

As suggested by Cartaxo *et al.* [4], we searched on a single database, *Scopus*, to keep the execution time of our RR as short as possible. We opted for Scopus because it is the largest database of peer-reviewed literature [10]. To built the query string, we first identified the concepts of interest, namely: "Ambient Assisted Living", "Elderly", and "IoT Device." We identified these three concepts because we were interested in IoT devices used in AAL solutions for elderly people. Afterward, we identified terms/phrases related to each concept (*e.g.,* "Ambient Assisted Living" and "AAL" are terms/phrases related to the "Ambient Assisted Living" concept). Finally, we combined the terms/phrases related to the same concept by using the `OR` operator, while we combined different concepts by using the `AND` operator. Accordingly, the query string we used to search on Scopus is:

```
(TITLE-ABS-KEY ("Ambient Assisted Living") OR TITLE-ABS-KEY(AAL) OR TITLE-ABS-KEY
("Active and Assisted Living") OR TITLE-ABS-KEY ("Active Assisted Living"))
AND (TITLE-ABS-KEY(Elderly) OR TITLE-ABS-KEY(Elder) OR TITLE-ABS-KEY(Aged)
OR TITLE-ABS-KEY(Older) OR TITLE-ABS-KEY(Old) OR TITLE-ABS-KEY(Senior)) AND
(TITLE-ABS-KEY ("IoT Device") OR TITLE-ABS-KEY ("Internet of Things Device")
OR TITLE-ABS-KEY ("Intelligent Device") OR TITLE-ABS-KEY ("Smart Device")
OR TITLE-ABS-KEY ("Wearable Device") OR TITLE-ABS-KEY ("IoT Technology") OR
TITLE-ABS-KEY ("Internet of Things Technology") OR TITLE-ABS-KEY ("Intelligent
Technology") OR TITLE-ABS-KEY ("Smart Technology") OR TITLE-ABS-KEY ("Wearable
Technology") OR TITLE-ABS-KEY (Wearable))
```

where `TITLE-ABS-KEY` is the Scopus operator to search a given term (*e.g.,* "AAL") or phrase (*e.g.,* "Ambient Assisted Living") on titles, abstracts, or keywords. It is worth mentioning that our query string included plurals and spelling variants (*e.g.,* `TITLE-ABS-KEY(Wearable)` allowed searching "wearable" and "wearables").

Selection and Analysis Procedures

Alter searching on Scopus by using the above-mentioned query string, we applied the following filtering options (of Scopus) to limit the search results to papers published from 2007 (*i.e.,* when the EU launched the AAL program) in conference proceedings or journals (*e.g.,* chapters in books were not considered) and written in English. The application of these filtering options (which can be seen as inclusion criteria applied in an automatic fashion) resulted in 209 papers—before that, the papers were 258. Given this set of papers, a solo researcher (*i.e.,* the fourth author) applied, in a manual fashion, the inclusion/exclusion criteria we had defined. In particular, the solo researcher included those papers that *(i)* presented AAL solutions, using IoT devices, that contributed to answer the RQs (*e.g.,* papers reporting secondary studies like SLRs or discussion papers were not included). On the other hand, the solo researcher excluded those papers that: *(ii)* presented AAL solutions that were not aimed to elderly people (*e.g.,* solutions aimed to children); *(iii)* presented AAL solutions for environments different from elderly people's home (*e.g.,* solutions for environments like rehabilitation facilities); *(iv)* presented solutions for purposes different from AAL (*e.g.,* home automation); *(v)* were duplicated or extended

by another paper (*i.e.,* in this case, we considered the extended paper); or *(vi)* we could not found. The inclusion/exclusion criteria from *(i)* to *(vi)* were checked by the solo researcher in two rounds. In the first one, this researcher screened the title and abstract of the papers to determine if they met the inclusion/exclusion criteria—at the end of this round, the selected papers were 171. In the second round, the solo researcher checked the inclusion/exclusion criteria by analyzing the full text of the papers—at the end, 61 papers were selected. It is worth recalling that the use of just one researcher to screen papers is frequent in RRs [4]. Also, checking the inclusion/exclusion criteria in two rounds is frequent in literature reviews (*e.g.,* [1]).

To analyzed the selected papers and then answer our RQs, we conducted a thematic analysis [2]. As so often in RRs, we did not conduct a quality appraisal of the selected papers [4].

Threats to Validity

The main threats of our RR follow: *(i)* we used only one database of peer-reviewed literature, which might limit the number of papers to be selected; *(ii)* the paper screening was executed by a solo researcher and the initial screening was executed by considering papers' title and abstract only, which might introduce a selection bias; and *(iii)* we did not conduct a quality appraisal of the selected papers so possibly limiting the reliability of the gathered evidence.

2.2. Results

To make the RR results more appealing to the stakeholders of our projects, as well as any other software engineer interested in those results, we used an evidence briefing [5]—a one-page document presenting only the main findings of a study—to report the findings of our RR. In Figure 1, we show the evidence briefing we created to present our findings.

3. Related Work

Some literature reviews have been conducted in the AAL field (*e.g.,* [6], [9]). For example, Maskeliunas *et al.* [9] conducted an SLR about IoT-based AAL systems (*e.g.,* on how artificial intelligence is used in IoT-based AAL systems) by scrutinizing papers published from 2011 to 2019. The obtained results were then used to define an acceptance model for IoT-based AAL systems. Another example is Cedillo *et al.*'s SLR [6], which reviewed papers published from 2007 to 2017, related to AAL but not focusing on IoT devices used AAL solutions for elderly people (*e.g.,* the authors considered solutions for children and pregnant women). Despite these literature reviews are related to our RR, none of them fitted for our research objectives—*i.e.,* these reviews did not address our RQs. Also, we consider a longer time span of published papers (from 2007 to mid-2021) and more recent papers. Other differences concern the research method as well as the medium to report the obtained results (*i.e.,* our paper is the first one at presenting a RR in the AAL field and reporting the results by using an evidence briefing).

4. Final Remarks

In this paper, we present the results of a RR about the IoT devices that have been using in AAL solutions for elderly people. These results, extracted from 61 papers, are summarized in Figure 1 through an evidence briefing. From this briefing, we can observe that: *(i)* a number of IoT devices are used in AAL solutions (*e.g.,* wearable sensors, built-in wearable devices, *etc.*); *(ii)* most IoT devices do not explicitly focus on specific diseases; and *(iii)* IoT devices support multiple needs (*e.g.,* affective-state monitoring, and physical-activity monitoring, *etc.*). The results of this RR represent the starting point to define, in the next steps of our project, a modular and customizable architecture for AAL solutions based on SPL engineering.

ON INTERNET-OF-THINGS DEVICES IN AMBIENT ASSISTED LIVING SOLUTIONS

This briefing reports scientific evidence from a rapid review of the Internet-of-Things (IoT) devices that have been using in Ambient Assisted Living (AAL) solutions for elderly people.

FINDINGS

WHAT ARE THE IOT DEVICES THAT HAVE BEEN USING IN AAL SOLUTIONS FOR ELDERLY PEOPLE?

Several IoT devices have been using in AAL solutions for elderly people. We can group these devices into the following categories: wearable sensors, built-in wearable devices, home devices, mobile devices, medical devices, and robots.

Wearable sensors (wrist-, waist-, or chest-worn):
(1) Accelerometers or Inertial Measurement Units (IMUs);
(2) GPS sensors;
(3) Body temperature sensors;
(4) Galvanic skin response sensors;
(5) Electromyography sensors;
(6) Electrocardiography sensors;
(7) Photoplethysmography sensors.

Built-in wearable devices:
(8) Smart bracelets or watches – these devices can be equipped with accelerometers or IMUs, photoplethysmography sensors, video cameras, and/or body temperature sensors;
(9) Smart garments – these devices can be equipped with accelerometers or IMUs, electrocardiography sensors, and/or body temperature sensors;
(10) Smart insole or shoes – these devices can be equipped with accelerometers or IMUs, force sensors, body temperature sensors, and GPS sensors;
(11) Wearable emergency buttons – these devices can be equipped with GPS sensors.

Mobile devices:
(12) Smart phones or tablets – they can include accelerometers or IMUs, and/or GPS sensors.

Medical devices:
(13) Smart glucometers;
(14) Smart blood pressure monitors;
(15) Smart pulse oximeters;
(16) Smart scales;
(17) Smart electroencephalographs;
(18) Smart pill dispensers;
(19) Smart rolling walkers;
(20) Smart medical thermometers;
(21) Smart health bags;
(22) Smart sarcopenia monitors;
(23) Smart sleep tracking mats;
(24) Smart electrocardiographs.

Home devices:
(25) Smart voice assistants or speakers;
(26) Smart home controllers or light switches or plugs;
(27) Monitors or smart TVs or wall panels;
(28) Microphones;
(29) Fixed emergency buttons;
(30) Smart armchairs;
(31) Smart seat cushions;
(32) Depth or video or infrared cameras;
(33) Passive infrared sensors;
(34) Optical sensors;
(35) Asynchronous temporal contrast vision sensors;
(36) Magnetic contact sensors;
(37) Bed or seat occupancy sensors;
(38) Toilet usage sensors;
(39) Smart stickers or beacons;
(40) Ambient light sensors;
(41) Water flow sensors;
(42) Air quality sensors (including gas, smoke, air temperature, and air humidity sensors);
(43) Noise sensors;
(44) Flooding sensors;
(45) Flame sensors.

Robots:
(46) Humanoid or non-humanoid robots.

WHAT ARE THE DISEASES (INCLUDING OLD AGE) THAT IOT DEVICES, USED IN AAL SOLUTIONS FOR ELDERLY PEOPLE, HAVE BEEN EXPLICITLY FOCUSING ON?

Most of the identified devices have not been explicitly focusing on specific diseases. That is, these devices are intended for elderly people in general.

Few devices have been explicitly focusing on specific diseases. These diseases (and the corresponding devices) are:
- Sarcopenia (22);
- Dementia and cognitive impairment (8, 23, 25, 26, 32, 39).

WHAT ARE THE NEEDS THAT IOT DEVICES, USED IN AAL SOLUTIONS FOR ELDERLY PEOPLE, HAVE BEEN SUPPORTING?

IoT devices have been supporting several needs. These needs (and the corresponding devices) are:
- Health-status monitoring – more than one device can be used to get a wider picture of the health status of older adults (3, 4, 5, 6, 7, 8, 9, 13, 14, 15, 16, 17, 20, 21, 23, 24, 31);
- Sarcopenia monitoring for older adults suffering from sarcopenia (22);
- Physical-activity monitoring – while some devices are alone enough to monitor the physical activity of older adults (1, 8, 9, 10, 12), others are used jointly with those devices, namely the data from more devices are used to support that need (2, 3, 6, 7, 32);
- Affective-state monitoring – devices are used alone to monitor the affective states of older adults (8, 17);
- Pill administration to older adults (18);
- Interaction of older adults with caregivers or physicians (e.g., to get help) – devices can be used together or alternately (8, 11, 12, 25, 27, 28, 29, 46);
- Familiar people recognition – devices are used jointly to help older adults, suffering from dementia or cognitive impairment, in recognizing familiar people through sounds (8, 25);
- Activities-of-Daily-Living (ADL) monitoring – while some devices are alone enough to monitor the ADL (e.g., sleeping or cooking) of older adults (1, 8, 10, 32), others are used jointly with those devices, namely the data from more devices are used to support that need (12, 14, 15, 23, 26, 33, 36, 37, 38, 39, 40, 41, 42, 45). Devices are also used when older adults suffer from dementia and cognitive impairment;
- Abnormal-behavior detection – the data from more devices are used to detect anomalies in the behaviors of older adults (1, 8, 12, 26, 33, 37, 38, 39, 40, 42, 45) and also of those suffering from dementia and cognitive impairment;
- Fall detection – while some devices are alone enough to detect when older adults fall (1, 8, 9, 10, 32, 35), others are used jointly with those devices, namely the data from more devices are used to support that need (6, 33, 34, 36, 37);
- Outdoor-location monitoring of older adults – devices are used alternately (8, 10, 12).
- Posture or gait monitoring of older adults – devices can be used jointly or alternately (10, 19, 30);
- Home environment monitoring – more than one device can be used to get a wider picture of older adults' home (40, 42, 43, 44);
- Walking assistance of older adults (19).

Who is this briefing for?

Stakeholders of the Apulia Region and any software engineer who wants to know which IoT devices have been using in AAL solutions for elderly people in order to support decision-making in the development of AAL solutions.

Where the findings come from?

All findings of this briefing were extracted, through a rapid review, from 61 papers about IoT devices that have been using in AAL solutions for elderly people.

Where can I find the papers included in the rapid review?

At the link on the bottom of this briefing.

REFERENCES TO THE INCLUDED PAPERS: https://drive.google.com/file/d/1jmhIk101mjkSnMNWlyuGeVfdnG9DWeAl/view?usp=sharing

Fig. 1. Evidence briefing reporting the results of our RR. This briefing is also available online at: tinyurl.com/ybrnx62w.

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