Smartphone Devices in Smart Environments: Ambient Assisted Living Approach for Elderly People

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***Abstract*—One of the motivations for smart environment and Ambient Assisted Living (AAL) research works is the significant increase in the elderly population. In that sense, it is important to address the problems associated with aging and to provide solutions to support the elderly in their daily life. This paper aims to present an AAL approach able to identify ongoing elderly activities and their context through embedded smartphone sensors in a mobile smart environment. Based on the learned context of elderly people, the proposed approach addresses the elderly's needs and triggers the most appropriate service based on ontological reasoning so that it could interact with the elderly and, more importantly, seamlessly ensure their assistance. Finally, we validate the proposal through a questionnaire exploring elderly's views about service satisfaction. We found that our proposed approach has the potential to assist the elderly in their daily life, with the majority of elderly people being mostly satisfied with the provided services.**

Keywords-context-awareness; smart environment for elders; AAL; activity recongnition; ontology.

I. INTRODUCTION

The number of elderly people keeps on growing in today's societies. According to the World Health Organization (WHO), the elderly population will quickly increase in the upcoming years [1] and may reach about 2 billion in 2050 [2]. Since age-related declines and chronic diseases can severely impair elderly's ability to remember and adequately perform everyday activities, the fulfillment of their needs with relevant assistance with daily activities and with continuous caregiving is essential to promote healthy aging. Therefore, the rapid population aging, the importance of independent living and the fulfillment of elderly's needs, together motivate the development of smart environments for elders, which open up novel opportunities for enhancing their independence and their quality of life. The concept of smart environments that interact with the elderly has emerged to provide them support and assistance with their needs, preferences and surrounding context, in addition to helping elderly who are experiencing a disability or a decline in their health and their ability to remember and undertake activities of daily living. Assisting elderly's needs and reducing caregiver's burden without compromising safety and the sense of self-control could, therefore, be regarded as one of the main purposes of smart environments for elders. In this regard, such environment shall detect emergency situations or deviations in the elderly's routine, which can indicate a decline in their abilities. To cope with this, AAL has emerged to represent a promising approach where the aging issues are further addressed [3]. Owing to the fact that AAL systems represent support for aging in place and offer great potential to carry out tailored services to suit elderly's needs, they are able to guarantee the monitoring of the daily living activities performed by the elderly through data captured from heterogeneous sensors and context.

Moreover, context-awareness and recent advancements in mobile and wearable sensors help the vision of AAL to become reality. With AAL, context-awareness highlights a crucial feature that facilitates the decision-making in real-time according to elderly's circumstances and gain in accuracy. In order to support context-awareness and justify its effectiveness, another key feature in AAL is human activity recognition to detect the elderly-relevant activities. Activity recognition plays an important role in bridging the gap between sensor data and interpretation of necessary services that the elderly need.

Within this context, we propose, in this paper, an AAL approach that meets the requirement related to continuously monitoring, motivating and assisting elderly in different daily life situations and locations. The presented AAL approach acts as a mobile smart environment for elders to help them to be more integrated within their societies while being monitored and assisted indoors and outdoors. This mobile smart environment is illustrated with merging sensor data provided by different sensors embedded in smartphone devices to dynamically find out what services should be promoting for helping the elderly to continue to live an independent life.

The rest of this paper is structured as follows: Section II provides some background knowledge. In Section III, we review some related works that deal with support for the

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elderly in smart environments. Section IV presents an overview of the proposed AAL approach. We describe the implementation details and the potential scenarios and then, we present the main evaluation findings in Section V. Finally, conclusions are drawn in Section VI.

II. BACKGROUND

Aging is associated with progressive problems and needs in different domains, such as psychology, physiology and societal environment. Preparing for a further aging society, it is essential to deeply explore these heterogeneous elderly's needs and problems. In this regard, we put forward Maslow's hierarchy of needs [4] to provide more effective solutions for the elderly. Tamang et al. [5] argue that Maslow's hierarchy provides a solid footing to understand the needs faced by elderly people seeing that each Maslow's level of need has relevance for elderly assistive technologies [6]. The hierarchy of needs proposed by Maslow categorizes human needs into 5 distinct levels, namely, physiological needs, safety needs, love and belonging needs, esteem needs and self-actualization needs.

III. RELATED WORK

Many non-trivial issues should be addressed when monitoring elderly activities and providing assistive services. Within that context, recognizing daily activities, deploying sensors and providing tailored support services for the elderly in smart environments are well-researched problems. With this purpose, numerous solutions have been proposed in the literature for supporting the elderly in smart environments. For instance, Fahim et al. [7] proposed a daily life activity tracking solution for an aging society. The system monitors elderly activities through different kinds of sensors, such as Radio-Frequency Identification (RFID) Tags and cameras that are located in their homes. Then, it can generate reminders for scheduled tasks and for overlooked medicines. Alternatively, Mainetti et al. [8] described an AAL system to assist the elderly by tracking them during indoor and outdoor activities. In particular, the proposed system focuses on capturing elderly data for recognizing their behavioral changes, both in their home and city environment. When abnormal behavioral changes occur, the system triggers health care notifications. More recently, Huang et al. [9] explored context awareness, an ontology-based and a rule-based reasoning approach for risk recognition and assistance. They proposed a framework for smart home management based on numerous sensors located in the home, such as device, contact, position and camera sensors. The proposed framework offers safety assistance services according to the current user activity inferred through the reasoning process based on the Semantic Web Rule Language (SWRL) rules. Moreover, Jung et al. [10] presented a hybrid-aware model for elderly wellness service in a smart home. This model detects elderly health risk based on monitoring their activities and locations in the smart home. Elderly activity is monitored using biosensors in each location. After detecting elderly health status, appropriate treatment (e.g., music therapy, exercise and hospital checkup) is recommended for the elderly using an Expectation Maximization (EM) algorithm. Lately, Patel et al. [11] introduced a hybrid framework for human behavior modeling in AAL. The proposal employs machine learning and deep learning approaches to discover the user's activity in a smart home. For that, the authors employed different types of sensors, i.e., body, object, camera and environmental sensors. This proposed solution recognized user's actions to offer essential services like medical assistance or emergency response.

Following the aforementioned works, we observe that most of them have not taken into consideration the mobility of the elderly. For that reason, a common problem associated with these works discussed so far [7][9][10][11] is that they detect daily activities performed by the elderly in a single smart environment that is usually a smart home. They target a single smart environment since sensors, which are integrated with everyday objects and connected through networks, are exploited in elderly's smart home. In addition, they apply an activity recognition approach based on dense object sensors that are attached to such indoor objects. So, elderly activities are inferred by monitoring elderly-object interactions. On the other hand, the work of Mainetti et al. [8] supported elderly people in their indoor and outdoor activities by gathering ambient parameters through sensors included in wearable devices. Moreover, all these works are based on healthcare and medical services. They do not take into account more interesting services that fulfill current elderly needs to allow them to live safely and independently in their environments. Furthermore, none of the mentioned solutions really uncover the different needs of the elderly. There is a lack of research works that propose elderly need-related services within smart environment based on a good reference for elderly needs interpretation and services development.

In the context of an aging society, we present an AAL system to enhance and provide support for daily life of the elderly by sensing the surrounding environment and the elderly activity, and interpret these data to identify their situations and to infer services accordingly. Unlike the main solutions investigated in the literature, the gap of elderly mobility has been addressed by conducting a mobile smart environment in our work. As a consequence, our proposed solution encompasses heterogeneous smart environments through which an elderly can move, by using a mobile device and by applying sensor-based activity recognition. In other words, the exploitation of sensors embedded in mobile devices with the abandonment of object-attached sensors provides a mobile smart environment where the elderly mobility is supported. In this regard, our solution transparently collects and processes information about the elderly and the environment around them from the multitude of sensors built in their smartphones. In this way, the adopted sensor-based activity recognition does not require environment object sensors and ensures elderly mobility. And then, our solution identifies needed service with respect to the current elderly's situation that falls under a specific category of needs. These elderly's needs are put forward based on Maslow's hierarchy of needs already presented in the background section. Although services offered for the

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elderly in main AAL works cover only the healthcare and medical areas, our solution can improve the elderly relief and promotes more elderly-friendly care services by figuring out different needs addressed in the two lowest levels of Maslow's hierarchy. Apart from the need for health care that is fulfilled as a safety need, we focus on physiological needs, such as food, sleep, housing, transportation, etc.

IV. PROPOSED APPROACH

A. *Architecture Overview*

The main focus behind our proposed approach aims to assist the elderly users in a mobile smart environment and provide them with an appropriate service at the right time considering their preferences, current activity and surrounding environment. In that sense, this approach should allow a continuous monitoring of all incoming sensor data and an immediate prediction to detect a certain elderly's emergency or anomalous situation over a short period of time. Further, it necessitates to perceive any significant changes in elderly's context and manage the current elderly's needs to meet their context changes.

As a solution to this, we present a layered architecture overview as depicted in Figure 1 that summarizes the above discussed facts.

1) Context manager layer: Is responsible for continuously managing both static and dynamic elderly's context information. This lowest layer includes the following components:

a) Context collector: Refers to the process of gathering the sensed data in real-time to deal with the dynamic aspects involving contextual elements, such as elderly's activity, location and time.

b) Context pre-processor: Is in charge of analyzing the incoming sensor data. For both location and time sensor data, a high-level information is produced from a set of low-level information. And with respect to built-in accelerometer sensor data, the analysis process is to choose the better window size.

c) Constraint analyser: Interprets the elderly's profile that reveals their different preferences, requirements and health status.

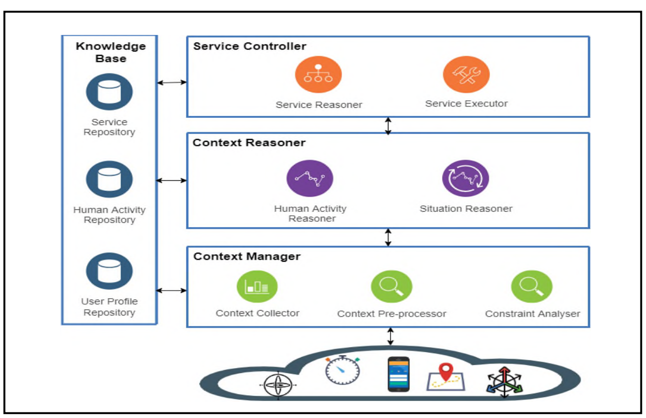

Figure 1. Architecture Overview.

2) Context reasoner layer: Supports reasoning mechanisms for activity recognition and then for situation identification regarding elderly's current context. This layer comprises two components as follows:

a) Activity reasoner: Is responsible for identifying the current activity of elderly using ontology reasoning and machine learning.

b) Situation reasoner: Is based on inference engine and uses rules on the available context information of an elderly to infer their current situation.

3) Service controller layer: Sustains the provision of personalized and adapted services to go with different elderly's needs and requirements. This layer includes the following components:

a) Service reasoner: Is responsible for determining which appropriate service should be executed through ontological inferences that are based on the current situation and elderly's profile.

b) Service executor: Is responsible for executing services that are earlier selected by "Service Reasoner" on the elderly's mobile device.

B. *Elderly service identification*

To support the proposed architecture, we focus on elderly service identification. To this end, we address the underlying needs of the elderly people based on Maslow's hierarchy previously discussed to offer certain assistive services for elders. Considering the most fundamental Maslow's levels in the view of prior study results [5], these services are fully provided to fulfill both Maslow's need levels that concern elderly physiological and safety needs. Thus, we can arrange our assistive services into two main categories to reach optimal elderly's satisfaction. The first category is elderly's physiological needs-related services and the second is elderly's safety needs-related services. In fact, both categories are often easily conflated, we investigate each of them in turn, as follows:

1) Elderly's physiological needs-related services: In addition to the basic human physiological needs, such as food, sleep, housing, transportation, etc., the eldely's physiological needs target also the daily care due to age-related problems. To moderate the side effect of unfulffiled physiological needs, a variety of elderly's physiological need-related services are developed to get over their physiological barriers.

a) Food recommendation service: Many elderly people cannot eat and drink unaided and need a special assistance. In this regard, we offer service that reminds elderly about eating at the right time. This service creates numerous reminders as notifications based on sensing and analyzing the current situation of elderly.

b) Exercise recommendation service: Elderly can carry out some physical activities that require moderate efforts, such as walking, biking, aerobics, etc. to maintain and improve their physical well-being. Hence, the increase of the efectiveness of well-being and falls-prevention needs further interventions for elderly into the behavioral patterns. To tackle that concern, we propose an exercise recommendation service that provides a reminder notification to encourage elderly to perform selected physical activity or exercise suggested by their doctors.

c) Entertainment recommendation service: While few studies, such as [12] along these lines have revealed that the entertainment needs of the elderly people is equally important for their well-being and joyful living, we provide entertainment recommendation service that selects the relevant entertainment media and delivers notification with the proposed media content, such as music, movie and so forth.

2) Elderly's safety needs-related services: Once physiological requirements are met, the safety needs, such as healthcare, emergency prevention, etc., arise. Elderly's safety needs-related services look forward to cover the demand of elderly people for life safety that refers to halth, emrgency and medical services.

a) Health recommendation service: Ensuring safe circumstances and protections for elderly, we aim to move when there are some anomalous events occurred as elderly's fall or inactivity and assure rapid and efficient help. To accomplish this aim, a health recommendation service raises alerts to an emergency contact, such as doctor, caregiver or family member when elderly is falling to the ground or has not arisen from bed for a long period in order to repond to an emergency event in a fast way.

b) Medication recommendation service: With age-related decline of memory and cognitive functionalities [13], elderly may forget to take the relevant medications at the appropriate times. For this attend, a medication recommendation service is offered to provide basic medical attention for people in old age. It yields an alert to remind them about their medicines at a pre-scheduled time to experience a healthy aging.

C. Elderly activity recognition

Tracking ongoing elderly's activity is regarded as a basis context information to better recognize their current situation in real-time and then providing the most relevant service from the aforementioned elderly's services. In this respect, we present a sensor-based activity recognition method based on mobile device using tri-axial accelerometer. We perform an online activity recognition on different activities, such as sitting, standing, walking, running, walking up/downstairs and falling, from the Heterogeneity Human Activity Recognition (HHAR) dataset [14]. The published HHAR dataset was employed as input to train a model. For inferring accurately, the actual elderly's activity, we enclose a knowledge-driven reasoning with a data-driven technique. Machine Learning (ML) algorithm as Random Forest is used to predict the initial activity label, where the accuracy of several ML algorithms (e.g., Random Forest Naïve Bayes, K-Nearest Neighbor) is well explored in previous work [15]. Then, a modular ontology, which represents the user's context, is applied for the purpose of enhancing and refining the predicted activity label derived from ML reasoning. This ontology was merged by means of activity recognition rules that are based on users' history as well as their current contexts.

D. Ontology and rules-based model

In order to process dynamic context, we provide a modular ontology for a semantic description of heterogeneous elderly's profiles with elderly's situation management and efficient service provisioning. Thus, we developed a modular ontology that offers a better selection of relevant service among a large number of services. The selection process of services is moving along a set of inference rules that are based on the current elderly's context, their needs and their inferred situations. This ontology consists of a set of interrelated ontologies, known as elderly, activity, sensor, device, process, situation, service, time and location. The general relationships among these different ontologies are depicted in Figure 2.

1) Elderly ontology: Is subclass of the context that represents and captures the elderly context within a changing environment. Figure 3 describes information about the elderly, which can alter the inferred service. An elderly has an elderly profile and an elderly constraint. Elderly profile is limited to some personal information, such as name, age, telephone, address and health status, as the elderly can be healthy or unhealthy (suffers from disease or disability). Also, it contains a medical profile that refers to the medical history of elderly including type of diseases, treatments and risk factors. As for the elderly constraint, it consists of two main branches: elderly preferences, which cover preferred entertainment content, preferred exercises (yoga, walking, biking, etc.) and preferred emergency contacts, and elderly requirements that deal with the elderly needs, such as what suggested exercises that elderly must perform.

2) Activity ontology: Describes the several physical activities that can be performed by an end user.

3) Sensor ontology: Manages perceived raw sensory data to monitor elderly's activities. It is built on top of SSN ontology [16] to represent mobile built-in sensors and their operations.

4) Device ontology: Defines knowledge about devices that are used to record raw sensory data.

5) Process ontology: Descibes different techniques that are used to interpret perceived raw sensory data and their relationships that make up activity recognition process.

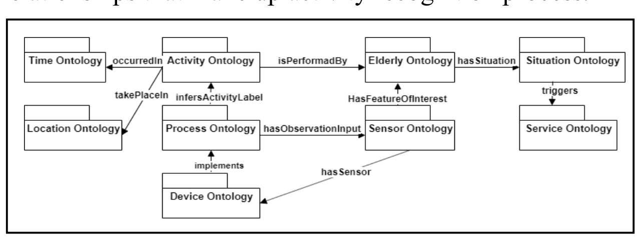

Figure 2. The core structure of our ontology and their relationships.

6) Situation ontology: Contributes to identify the possible situations depending on elderly contextual information to provide relevant service selection in order to meet their needs as closely as possible. As illustrated in Figure 4, situation consists of pertinent conditions that can be composed of the currently available context information to throughly understand elderly and improve their situation identification. A situation has different proprieties to characterize it, such as name, time, location and others. An elderly situation, which is sub concept of situation, can be either a daily situation binding a normal situation or a irregular situation related to urgent situation, such as, elderly's health issues.

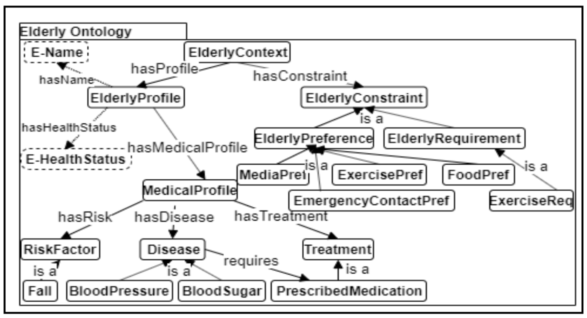

Figure 3. Excerpt of Elderly ontology.

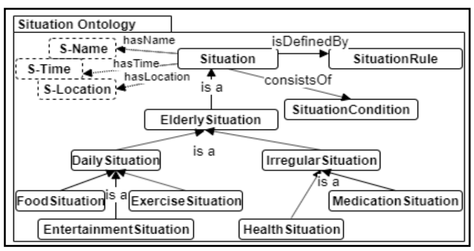

Figure 4. Excerpt of Situation ontology.

7) Service ontology: Provides a way for describing context-triggered services through the context and situation aware-based reasoning results. This sub-ontology for semantic service description adopts basic concepts and relations from a service ontology called OWL-S [17] since it is tailored to services in general along with the Web services and the semantic Web. It expands the OWL-S ontology to include additional features, such as elderly service, elderly service profile and elderly service model that extend, respectively, the OWL-S elements: service, service profile and service model. These elements are the core concepts of our service ontology as illustrated in Figure 5. An elderly service is triggered by an inferred situation. Each elderly service presents a profile to describe its characteristics by defining its name, input, output, precondition and intended purpose. Additionally, an elderly service profile can have a category. This elderly service category is divided into two basic categories: physological elderly services and safety elderly services. Moreover, elderly service is described by a model that deals with its internal structure. This elderly service model executes its own method, which defines the operational description related to the elderly service profile, to carry out the corresponding service.

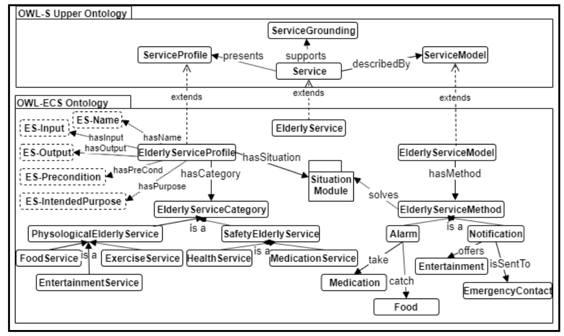

Figure 5. An excerpt of Service ontology.

8) Time ontology: Represents the time notion in the context, which can be used to indicate the time of performed activity.

9) Location ontology: Decribes the location of occurred activity.

V. IMPLEMENTATION AND POTENTIALS SCENARIOS

This section describes some implementation details of our approach, potential usage scenario and experimentation results.

A. Prototype implementation

First, we have implemented our modular ontology model based on OWL-DL using the Protégé tool. Second, Jena rule language as a syntax is used to express rules and to increase the expressivity of the ontology. The Jena inference rules are introduced to infer new knowledge that are related to the user's context, such as user activity, location and so on, the user's situations and user's needed services to adapt the interaction with the elderly and assist them. For instance, the Music service is an Entertainment situation that has Music as a media preference (see Figure 6). Then, we have developed a mobile application as a proof of concept. This application is basically implemented in Android environment and written in Java. For the purpose of activity recognition, we considered a hybrid activity recognition method, which combines data-driven on inertial sensor data from mobile devices and knowledge-driven. So, the implemented application is leveraging the smartphone's sensing capabilities as GPS and accelerometer for the localization and the detection of human activity, respectively. And finally, to validate the selection of appropriate needed service, our application integrated the modular ontology and a raft of inference rules discussed above.

B. Potential scenario

To demonstrate that our proposed prototype has the potential to infer current situations and determine relevant services for the elderly based on their profile information, their current physical activities, their current locations and

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time, we consider the following scenario depicting a typical real-life situation.

```
[Music-Service-rule:
(?EldCtx rdf:type uni:ElderlyContext)(?EldProf rdf:type uni:ElderlyProfile)
(?EldPref rdf:type uni:MediaPref)(?EldCtx uni:hasProfile ?EldProf)
(?EldCtx uni:hasConstraint ?EldPref)(?EldPref uni:E-MediaPrefName 'Music')
(?EldSit rdf:type uni:EntertainmentSituation)(?EldSit uni:S-Name 'Entertainment need')
(?EldProf uni:represents ?EldSit)(?EldServ rdf:type uni:ElderlyService)
(?EldServProf rdf:type uni:ElderlyServiceProfile)
(?EldServ uni:hasServiceProfile ?EldServProf)(?ProfileCat rdf:type uni:EntertainmentService)
(?EldServProf uni:hasCategory ?ProfileCat)(?EldServProf uni:hasSituation ?EldSit)
->
(?EldServProf uni:ES-IntendedPurpose 'Music Service')]
```

Figure 6. An example of inference rule.

There are two elderly, named David and Sarah which are sitting in their living rooms during the morning after they had breakfast. But, they each have pretty different context profiles. First, David prefers cycling as physical exercise. He has a healthy status and has not any disease, risk factor and exercise requirement. Second, Sarah prefers walking as physical exercise. She has an unhealthy health status and suffers from diabetes disease. She adheres to Yoga as a regular physical exercise routine prescribed by her doctor and has not any risk factors. This situation provides an exercise need and the application triggers a notification service to convince David to get out and enjoy some cycling and to remind Sarah that she must make some Yoga as suggested by her doctor, as exhibited in Figures 7 and 8.

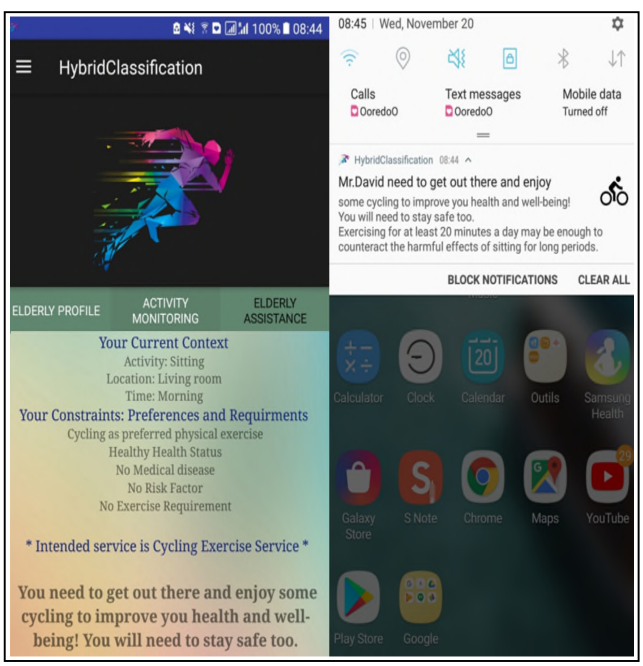

Figure 7. Interfaces for elderly assistance: Notification for Cycling service.

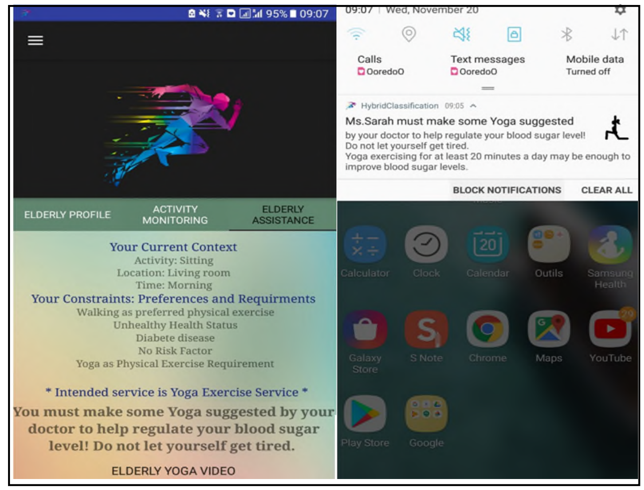

Figure 8. Interfaces for elderly assistance: Notification for Yoga service.

C. *Evaluation and discussion*

User satisfaction is commonly applied evaluation criterion for services in general. In our case, this criterion assesses the degree of elderly satisfaction with the provided services. Nevertheless, the evaluation of the elderly satisfaction from their perspectives is a critical step, which can be done with questionnaires. We decided to choose the Client Satisfaction Questionnaire-8 (CSQ-8) [18] as a reference to assess elderly satisfaction to evaluate and refine afterward our provided services for the elderly as optimally as possible. We chose CSQ since it offers a quick assessment of the client satisfaction of the services received. On this basis, our questionnaire that is conducted based on CSQ-8, consists of 8 questions ranging from Q1 to Q8. Each question should be answered using a response scale from 1 to 4, total score goes from 8 (great dissatisfaction) to 32 (great satisfaction). For the purpose of this evaluation, the questionnaire was completed by 10 elderly living alone who will use the application as an aid in their daily life and have heterogeneous context profiles. After receiving feedback from the elderly, we analyzed the collected responses outlined in Table I.

TABLE I. SCORES ON ELDERLY SATISFACTION QUESTIONNAIRE

Questionnaire	Scale Score			
	1	*2*	*3*	*4*
Q1. How would you rate the effeciency of services you have received?	0	4	4	2
Q2. Did you get the kind of service you expected?	1	4	3	2
Q3. To what extent has our application met your needs and intends?	1	5	2	2
Q4. Would you recommend our application a friend?	0	6	3	1
Q5. How satified are you with the amount of help and assitance you received through offered services?	1	3	3	3
Q6. Have the services you received help you to deal more effectively with your daily situations?	0	3	5	2
Q7. In an overall, general sense, how satisfied are you with the service you have received?	0	6	3	1
Q8. Would you reuse our application?	2	4	3	1

Based on the analysis results, the mean overall score for the questionnaire was 25.8. We concluded that the majority of elderly was mostly satisfied with the proposed application. The elderly were more satisfied with the provided services and less inclined to recommend the application to a friend or family member.

VI. CONCLUSIONS

The concept of smart environment for elders is still evolving, which may lack the mobility for elderly to simultaneously move around and maintain their daily assistance. Smartphone is a convenient device to provide mobility for assisting elderly. In this paper, we have presented an AAL system that monitors elderly in their mobile smart environments using smartphone devices in order to relieve burden of stress among elderly. The proposed system promotes services based on elderly's situations. These situations may vary based on the current elderly's needs, which are highly context dependent, and their profiles, such as their preferences, requirements, health status and so on. Moreover, we have introduced the experimental results of elderly test that show the effectiveness of our proposed system where a great number of elderly are satisfied. Despite that, we deemed indispensable to develop further new intelligent services for the elderly with a consideration of the rest of Maslow's hierarchy levels to undertake more robust evaluation results. Hence, we intend to shift our focus to the love and belonging level of Maslow's needs that could be met by socializing with others. We also plan to include other kind of smartphone sensors to keep a good control of the elderly's environment and to allow a faster response to the elderly's needs and situations at hand. Through this proposed approach, we aim to take on the history information of elderly to improve the evaluation results. Additionally, our future work includes evaluating our approach on more adequate population.

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