A Robotic Cloud Ecosystem for Elderly Care and Ageing Well: The GrowMeUp Approach

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Abstract— **Robotic systems in Ageing Well, like GrowMeUp, are among those assistive technologies, providing companionship and offering functionality related to the support of active and independent living, monitoring and maintaining safety, and enhancement of health and psychological well-being of the elderly. The work presented in this paper is based on the context of GrowMeUp project and focuses on presenting the main novelties introduced with the GrowMeUp system, providing a robotic cloud ecosystem, able to support, encourage and engage the older persons to stay socially involved and longer active and independent, in carrying out their daily life at home. Emphasis is given on the important issues of end user's acceptance, usability and affordability and how technologies like cloud computing and different learning and intelligent dialoguing mechanisms are brought together in one solution to address these issues.**

Keywords— **Ageing Well, Care Robots, Cloud Technologies, machine learning, intelligent dialogue.**

I. Introduction

Service Robots have the potential to become key components in coping with Europe's demographic changes in the coming years. This is a very promising technology that lies at the intersection between the industry and service sector. Already, several FP6, FP7, H2020 and AAL research projects have been dedicating efforts to go beyond the development of mechanical features and equip robots with Information and Communications Technology (ICT) services and functionality which will permit their use and acceptance in the personal support and care domain [1]. GrowMeUp are among those initiatives, aiming to increase the years of independent and active living, and the Quality of Life (QoL) of older persons.

Specifically, the GrowMeUp project [2] aims to provide an innovative and affordable service robotic system to support older persons in carrying out their daily life activities in their home environment by considering older persons' capability degradations over the ageing process. To achieve this, the GrowMeUp solution develops new breakthroughs for active and assisted living, by bringing together state of the art: i) cloud computing technologies and ii) combination of different types of learning mechanisms, including sharing and distributing knowledge between different robots, in enhancing and adjusting the older person service provision to cover evolving needs and preferences over the ageing process. The combination of cloud computing technologies and different learning mechanisms will provide an affordable solution as the robot's computational load and learning effort will be reduced. In addition, if the robot needs to be replaced by a new unit, the older person's personal data, as well as the knowledge previously stored in the old unit, can be downloaded from the cloud knowledge base, making it instantly operational. Furthermore, to enhance the engagement, satisfaction and acceptance of the older person in using the GrowMu robot, implicit daily activities support are provided in a human like way characterized by behaviour and emotional understanding, intelligent dialoguing and personalized services provision.

What follows will present a review of the relevant systems that employ robotic technologies for supporting aging well followed by a discussion on the architecture and the novelties that GrowMeUp brings in the area of elderly care. The expected benefits of these novelties to the QoL of the elderly and their caregivers will also be given.

II. Robotic Systems In Ageing Well

There is growing attention for assistive technologies to support seniors to stay independent and active as long as possible in their preferred home environment. Robotic systems are among those initiatives offering functionality related to the support of independent living, monitoring and maintaining safety or enhancement of health and psychological wellbeing of elders by providing companionship. However, most of those initiatives are focusing more on technological research innovation giving less emphasis on the important issues of end user's acceptance, usability and affordability. Such projects include among others the CompanionAble [3] and Echord-Astromobile [4] robots which offer services for supporting older adults to preserve their independence and safety at home. Accompany [5] consists of a robotic companion as part of an intelligent environment, providing services to elderly users in a motivating and socially acceptable manner, to facilitate independent living at home. The system provides physical, cognitive and social assistance in everyday home tasks, and contributes to the reablement of the user. Florence, KSERA, MobiServ and SRS [6][7] are assistive robots supporting older persons with one or more physical disabilities. The SocialRobot system [8] is a friendly and affordable mobile platform providing simple guidance and monitoring.

We acknowledge the functionality and the usefulness of the state of the art service robotics initiatives in supporting older persons to remain longer independent at home, however the following shortcomings have been identified with service provision.

First of all, service robots have not been capable to understand and learn emerging services demands over time (like one of older persons at home) because their systems have relied on knowing in advance the specifics of every possible situation they might encounter. Each response to a contingency has to be programmed in advance. This is one of the main reasons why, to date, robots have made few significant inroads into the older persons home care sphere. Furthermore, as service robots need to be programmed ahead to provide for all the possible service functionalities, that would be probably needed, their demands on-board computation is increasing enormously, requiring more expensive and more power consuming processors. This results in high cost solutions that are not affordable enough to be taken up by older persons care organizations providing for independent living setups, and even less by older persons living along at home.

Also, there is the need of more human-like daily life care provision that will evolve through time based on combining older person's behaviour understanding and recognition of the emotional states of older persons while they go about their daily activities in their home environment. Moreover, intelligent dialoguing needs to be provided, thus, making the system more engaging for the older persons who interact with it. The system needs for example to be able to hold multiple interactions and combine them with older person emotional states in a similar way humans do.

In addition, there are no appropriate plans of how a service robot will be best introduced in the daily life of an old person. It is mostly assumed that the older person will deal alone with the robot at home. Socialization aspects like: how the older persons could be continuously supported to use and accept a robot; how to reduce their fear of having a robot replacing a human carer; how older persons and the carers can benefit from a continuous care collaboration are not appropriately considered in existing solutions.

Moreover, services provided by existing service robots are usually static; this means that they provide mainly basic customization (i.e., defining older persons' schedules and medicine reminders). This fact is even more noticeable when the older persons needs change over time, requiring thus new services or a different kind of support. Even though some of the existing initiatives support the modification, or even the addition of new services, this is mostly not carried out automatically.

Finally, the lack of appropriate paradigms for designing home service robots which combine affective human-robot communication and evolving, adaptable service functionality leads to low user acceptance and makes it difficult for present service robots to enter the personal support and care domain at home.

III. Emerging Requirements And Cloud Robotics

A. Human Ability to Learn and Adapt Over Time

One of the main characteristics of older persons with light cognitive and physical problems living alone at home is that the speed and nature of degradation of their cognitive and functional capabilities cannot be totally predicted up front. Such degradations create changes on their needs and way of behaving while carrying out their daily life at home. Support provided to them yesterday needs to be adjusted to consider their degraded capabilities of today.

Currently, support to these people is provided by informal caregivers (close relatives, friends etc.) and includes mainly personalized assistance in carrying out their daily activities, considering their behaviour in their home environment and their emotional state. By observing and communicating with older persons through their daily life, caregivers are able to learn and adapt their service provision to cover new needs and preferences related to capabilities degradation over time. Furthermore, care givers often share care-related knowledge between them in an effort to handle new care demands that have not been encountered before.

Humans, especially in younger years, go through several stages of development and have the ability to learn different skills and behaviours. Bringing these learning and adaptation capabilities in robots has been fascinating to many researchers and brings important benefits especially in the acceptance of this complex technology by users.

Cynthia Breazeal, a veteran in the area, has shown that robots are more likely to be accepted by humans when they are modelled to show an infant like behaviour [9] where the robot evolves its knowledge and behavior according to its environment rather than behave like all knowing superior beings. Especially when these robots cannot achieve what is expected from them due to the current technological limitations, users become frustrated and lose interest and motivation to use the robot [10][11]. They are more likely to allow a robot supporting them if they can actively contribute in the development of its skills, and influence of what type of care and to what level will be provided to them over time.

This assumption was the main motivation for setting up a robot adopting an 'infant-like' behaviour and providing initially a minimum set of essential support services and evolve/learn through sharing over time.

B. Cloud Robotics in Aging Care

Care robots ban benefit from cloud technology in that it allows robots to share computational resources, information and data with each other, and to access new knowledge and skills. This opens a new paradigm in robotics that allows the deployment of inexpensive robots with low computation power and memory requirements by leveraging on the communications network and the elastic computing resources offered by the cloud infrastructure [12]. Specifically, Robotic applications will benefit from cloud infrastructure, which provides the following advantages over traditional networked robots: 1) Access to vast amounts of data. The robots can acquire information and knowledge to execute tasks through databases in the cloud. They do not have to deal with the creation and maintenance of such data; 2) Access to shared knowledge and new skills. The cloud provides a medium for the robots to share information and learn new skills and knowledge from each other. The cloud can host a database or library of skills or behaviours that map to different task requirements and environmental complexities; 3) Ability to offload computation-intensive tasks to the cloud. The robots only have to keep necessary sensors, actuators, and basic processing power to enable real-time actions (e.g., real-time control). The battery life is extended, and the robotic platform becomes lighter and less expensive with easier to maintain hardware. The maintenance of software on-board with the robots also becomes simpler, with less need for regular updates. As the cloud hardware can be upgraded independently from the robotic network, the operational life and usefulness of the robotic network can be easily extended.

Studies combining clouds and mobile robotic platforms are relatively new. One notable mention is the Davinci project, a software framework built around the Robotic Operation System (ROS), sharing the burden of Simultaneous Localization And Mapping (SLAM) algorithms between a team of robots and a cloud computing framework. The map was accessible by other robots as they joined the network [13]. The amount and type of information using distributed robots and clouds has been expanded in [14], developing a system for recognizing and grasping of common household objects. Using a PR2 Robot they exploit the functionalities of the Google Object Recognition Engine to access computing resources and an endless range of object information. The *GostaiNet* project provides seamless control of any compatible robot which can connect to the network. It enhances their capabilities with face recognition, speech synthesis, information access, etc., providing an SDK for developing services on demand [15][16][17]. The latest trend refers to the RobotEarth project [18].

At its core, it is a World Wide Web for robots where robots can share information and learn from each other. The database stores knowledge generated by humans and robots including: object locations, maps, software components, task knowledge (e.g. recipes) and object recognition models (e.g. images, objects models). At the same time it includes a powerful computation engine available to robots. State of the art shows this topic to be broadly focused towards two major application categories: 1) robots that require high processing power for solving computationally intense algorithms and 2) systems whose main function is to perform object recognition, locations, etc. capitalizing on the large pool of information provided by cloud when compared to systems that rely solely on their local information resources.

Thus, learning has an important part in the whole process. Approaches of machine learning such as supervised, unsupervised and reinforcement learning have been used for decades on emotion recognition [19], behaviour analysis [20] and dialogue management [21]. However, the use of learning on combining different levels, like learning of social skills and behaviours, has been less addressed by existing state of the art service robotics initiatives.

IV. The GrowMeUp Cloud Innovation

The main goal of GrowMeUp is to increase the years of independent and active living and the QoL of elderly with light physical or mental health problems who live alone. In this line, a service robot, the GrowMu robot, will be provided to the users, learn their habits and needs over time and enhance its functionalities to prevent the degradation of the users' abilities and to encourage them to stay longer active, independent and socially involved. Cloud computing technologies and machine learning algorithms will be used to increase the robot knowledge continuously. Also, a group of different GrowMu robots will be able to share and distribute their knowledge through the cloud. The robot will provide support to perform daily activities in a human like way by means of behaviour and emotional understanding, intelligent dialoguing and personalized services (see Section V).

GrowMeUp exploits cloud based technologies allowing robots to collectively infer knowledge previously accumulated by other robots. Such knowledge will accommodate ICT-service models and dialogue profiles that can be redistributed and effectively used by other robots. Moreover, GrowMeUp exploits information acquired through the experiences of all robots reporting back to the cloud so as to manage the information on the knowledge base (e.g., the cloud automatically accommodates new knowledge).

The cloud knowledge base also maintains a synchronized copy of the robot's local knowledge, mainly used as a backup in case of a faulty platform, increasing thus the reliability of the overall system. GrowMeUp ensures that older person's efforts in teaching his/her personal robot will not get lost, and that any replacement unit will keep assisting him according to his needs and preferences.

Additionally, GrowMeUp develops a cloud-based intelligent querying mechanism that allows robots to search the knowledge base for any information/models/profiles mainly based on keyword matching algorithms. For example, when requesting for a "cooking" guidance service for "pancakes", it will also search for that specific user's preferences, to infer over the most appropriate recipe (e.g., we know that a user has high blood pressure and we have a reasoning system that understands that salt is bad for him, looking thus for recipes that exclude or minimize salt).

Innovation is achieved with its ability to provide evolving, adaptable support combined with affective human-robot communication, while maintaining low complexity and cost. The use of a cloud knowledge base, allows the robot to increase its functionality to cover older persons capabilities degradations over time without increasing is onboard needed equipment and processing. It is designed not to abruptly replace existing personal skills or functioning social networks of the older adult but instead it offers gradually increasing support at the time when life starts to become increasingly challenging.

In GrowMeUp different types of learning will be combined to achieve novelty in having the GrowMu robot capable to learn how to provide support to older person's daily life over the ageing process and adapt to behaviour and emotional changes and aging capability degradation.

The fact that information can be shared between multiple robots through a cloud will make it possible for different robots to learn from each other and improve thus their skills. Of course, humans are not wirelessly interconnected through a collective cloud network that they learn from. However, the fact that humans easily can move around and interact with many people in remote environments, gives them enough opportunities to share with each other knowledge and to learn from each other. As nowadays robots are not able to experience the same mobility and interactions as human do, cloud computing will serve as a perfect alternative to facilitate knowledge and skills sharing between robots in improving older person's daily support.

Last but not least, it removes overheads for maintenance and updates. The communications network offered by a Cloud infrastructure allows robots to take advantage of the rapid increase in data transfer rates to offload tasks without hard real time requirements.

V. Overall System Architecture

The system architecture has been designed to address the different technical challenges and needs proposed in the goals of the project and in Section III of this paper. A scheme of the architecture is presented in Fig. 1. The core element in this architecture appears to be the Cloud Knowledge Base and the Cloud Service Layer. However, the following elements consist also novelties of this project: Behaviour Modelling using Context Analysis, Intelligent Dialogue Management, Decision Making based on Perceived Emotions and Context. The main contributions beyond state of the art are presented for each of the individual building blocks appear in Fig. 1.

A. Behaviour Understanding using Context Analysis

GrowMeUp develops a context aware behaviour model, which considers different types of contextual information. It goes beyond the state of the art by combining context and activity information together with the older person's preferences and emotions. Therefore, the behavioural model comprehensively represents most of the aspects and specificities of an older person's routine and habits. The combination is done from the hybridization of two methods: 1) probabilistic graphical representations and 2) an ontology representation of context and activity information. The model continuously adapts to the older persons daily routine and needs. This process is materialized with the development of a novel online statistical analysis and learning methods for the proposed models, supported and/or combining state of the art perception algorithms. In addition, end-users are involved in the ontology design process, identifying the relevant information types necessary to include in the models. The framework also includes the development of a semi-supervised mechanism so as to allow older persons to directly teach the robot new objects and inform it about tasks or preferences. This process will let older persons to directly refine existing models to fit their personal needs.

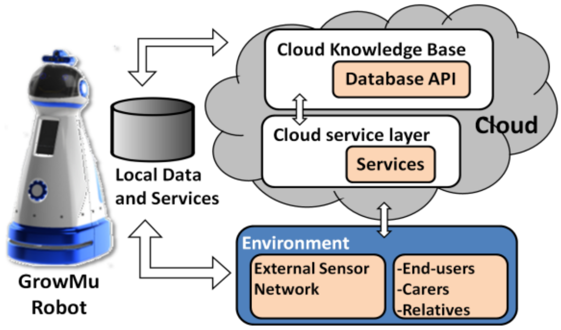

Fig.1 Overall System Architecture

B. Intelligent Dialogue Management

GrowMeUp project advances existing dialogue management systems by introducing new hierarchical agent-oriented dialogue management paradigms. These consist of an advanced belief structure that goes beyond the information state-based dialogue management approaches, incorporating it with episodic memory modelling as well as with hierarchical approach of dialogue structure. To achieve human-like behaviour, the dialogue management system also incorporates other components managing the emotional intelligence and social learning of the robot. Another key novelty is the exploitation of the behaviour understanding models and all associated knowledge to reinforce the dialogue profiles with additional information states. This paradigm allows the robotic platform to provide a highly flexible, multi-purpose and context dependent dialogue interaction with older persons. The belief structure is updated continuously by combining the analysis of current and past dialogues with perceived environment and older person's information, specifically their emotions.

C. Decision Making and Learning using Perceived Emotions and Context

GrowMeUp is improving the decision making process to consider different types of information related to emotions, behaviour understanding and dialogues. This enables a more human-like way of providing response to the older persons. The robot is able to perform older persons' behaviour and emotional understanding while the older persons go about their daily life over the ageing process, and monitor its dialogue interactions with the older persons. This approach makes the robot more attractive and more engaging to interact with. The learning paradigm is extended through the robot's ability to benefit from other robots learning experiences through the cloud network.

VI. Expected Benefits of GrowMeUp

A trial evaluation will allow us to evaluate the objectives set for the GrowMeUp project. The evaluation will involve two end user organisations ZUYDERLAND in the Netherlands and CARITAS in Portugal implicating elderlies and their caregivers in the process of interacting with the GrowMu Robot in real settings over a three months period.

GrowMeUp is expected to stimulate elderlies in exerting more effort to perform their daily activities over time. This will be achieved by considering elderlies daily activity behaviour changes in their home environment, and supported by emotionally-enriched human-computer interaction. The elderlies are treated as active collaborators, with whom the robot can interact, in expanding its knowledge about their personalized needs, capabilities and preferences over the ageing process. Moreover, by having the system early enough in their life, emerging capabilities degradations can be addressed in an early stage delaying thus further degradation. This will prolong their independent living at home and reduce frequent admissions to care institutions.

Moreover, their self-esteem will increase as the active interaction with the robot will give them the feeling that they manage the type and level of support that is provided to them over time. Elderlies have difficulties in emotionally accepting emerging capability degradations, for example difficulties in hearing, as this will imply their dependence on other people. Through the use of the GrowMu robot a social bonding will be created that will allow them to cope better and faster with such degradations. This will improve their autonomy leading to an improvement of their QoL.

Nowadays, support to the elderlies, living alone at home, is provided mainly by informal and formal carers and includes mainly non-continuous assistance in enabling and sustaining management of activities of daily life combined with emotional understanding and support. GrowMeUp through the use of the CoRobo-Net a bespoke social network that allows for an effective and continuous collaboration and communication between the elderlies and their formal/informal carers reducing thus unnecessary on-site visits. Therefore, it is expected that the efficiency and continuity of the way care is provided nowadays to elderlies will be highly improved, leading to reduction of: demand of care resources, and associated stress of the carers leading thus to an improvement of their QoL.

VII. Conclusions

The GrowMeUp approach delivers a prototype system that will be validated in a real life environment, providing companionship and offering functionality related to the support of independent living, monitoring and maintaining safety, and enhancement of health and psychological well-being of the elderly.

Thus, the contribution of this work lays primarily in employing state of the art cloud computing, robotic and social network technologies, as well as machine learning and intelligent dialoguing mechanisms integrated in this solution, enabling the GrowMeUp service robots to i) enhance the engagement, satisfaction and acceptance of the older person in using the GrowMu robot by providing a natural way to interact with the system, ii) share and distribute their knowledge and experience, through the cloud, with all the other robots of the GrowMeUp ecosystem, decreasing the robots learning effort, iii) extend and enhance their knowledge continuously over time, enhancing thus their functionality and also dynamically adapt the way services are provided, to compensate for the elder's degradation of abilities, over the ageing process and iv) split the computational processing between the cloud and the robot allowing for a decrease of the robot's on board computation resulting in considerable cost reductions of the GrowMu robot and provide an affordable solution.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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