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Robotic Assistance in Medication Management: Development and Evaluation of a Prototype

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Abstract. An increasing number of elderly people and the prevalence of multimorbid conditions often lead to age-related problems for patients in handling their common polypharmaceutical, domestic everyday medication. Ambient Assisted Living therefore provides means to support an elderly's everyday life. In the present paper we investigated the viability of using a commercial mass-produced humanoid robot system to support the domestic medication of an elderly person. A prototypical software application based on the NAO-robot platform was implemented to remind the patient for drug intakes, check for drug-drug-interactions, document the compliance and assist through the complete process of individual medication. A technical and functional evaluation of the system in a laboratory setting revealed versatile and viable results, though further investigations are needed to examine the practical use in an applied field.

Keywords. Ambient Assisted Living, humanoid robot, medication management

1. Introduction

Our society is currently influenced by a demographic transition. Socio-economic factors as well as medical progress lead to a rising life expectancy and a decline in birthrate. Statistical trends in Europe show, that life expectancy for a newborn in the year 2002 is expected to be 74.5 years, which is estimated to rise to 77.4 years for newborns in 2012 [1]. European population is ageing rapidly. A far reaching consequence of this trend is the need for an increased number of nursing services in future which can hardly be provided by our current healthcare system.

The old and elderly are also more likely to develop multimorbid diseases, which often need to be treated through multiple medications, also known as polypharmacy. Age-related impairment in cognitive, visual, fine and gross motor skills lead to problems in taking the right drug at the right time in the right dosage. Studies show, ~60% of patients >75 years need to take 6 or more drugs per day [2], 17% of people >70 years have harmful practical problems with their everyday medication [3] and ~50% of all chronically ill patients >60 years are not compliant to their medication [4].

The rapid evolution of information and communication technology (ICT) produced viable assistive systems in the last decade. Most attention is currently given to Ambient Assisted Living (AAL) which comprises technical products, services and concepts to individually support people in need of care managing their everyday life properly [5]. Smartphone-Apps, reminder-systems, intelligent drug boxes and many other systems

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turned out to be useful for the elderly in administering medication for different cases and situations.

Apart from core ICT also the domain of robots showed a remarkable development in the past. Even humanoid robots as off-the-shelf products have emerged more frequently because they tend to have a high potential as assistive systems.

However, little effort is given to AAL making use of (humanoid) robots though there do exist affordable systems with feasible hardware. Hence, it's not clear if such humanoid robots are suitable for homecare medication assistance scenarios.

In this study we used the humanoid robot *NAO* to investigate, if and to what extend a mass-produced robot system can be used to manage and support the everyday medication of an elderly person at home. The current paper addresses in particular the development process of the prototype application.

2. Methods

NAO is a 57cm tall robot system made from Aldebaran robotics [6] which has 14 motors (results in 25 Degrees of freedom), cameras (960p@30fps with fixed focus), loudspeakers, microphones, sonars, gyroscopes, accelerometers, force sensitive resistors, touch- and pressure sensors and LEDs. A Linux Gentoo OS runs on an Intel Atom platform and allows accessing all actors and sensors through a service called NAOqi, which provides all necessary software interfaces. *NAO* is freely programmable using Python or C++, provides hardware interfaces for LAN, WLAN as well as USB. Further information about the robot is available online at Aldebaran's website [6].

With regard to the planned application a literature review was conducted first, to find out problems for the elderly in the domain of domestic medication as well as initial functional and non-functional requirements for an assistive medication management system (user and system requirements). We searched for publications in PubMed and Google Scholar between 1995 and 2013 using the search term depicted in figure 1. These results were then refined in cooperation with a physician, who provided his view and expertise on the problem. Resulting requirements were then modeled in UML use-cases to show the aims of the proposed medication management support system (MMS).

(automatic OR technical OR AAL OR "Ambient Assisted Living" OR assisted)
AND (drug OR pill OR medication) AND (dispenser OR planner OR reminder OR documentation OR tracer OR monitoring) AND (system OR robot OR assistant)

Figure 1. Used search term for PubMed and Google Scholar.

The software development was based on a prototype approach combined with an iterative development of components: First a base prototype acting as the main component was developed which got iteratively extended by more specific components. Each component in this sense is responsible for a well-defined task according to the requirements. An iteration cycle is composed of requirements engineering, system design, implementation and testing. All components were designed through different UML diagrams (class diagrams, activity diagrams, sequence diagrams as well as flowcharts) and a prototype was implemented using Python 2.7. Each component needed to pass several unit tests.

After developing the components separately, an integration step combined all elements and tested the overall MMS in a final technical and functional evaluation under laboratory conditions. This evaluation encompassed a final test-scenario dealing with different medications and situations. In this paper our main attention is given to the test of the drug identification component.

3. Results

3.1. Requirements Engineering

The requirements gathering step lead to the main problems given in Table 1. According to those problems the following requirements/aims were derived:

- The MMS is able to support the domestic medication process to avoid intakes of wrong drugs, wrong times or wrong dosages.
- The MMS reminds the patient at the right time to take the drugs.
- The MMS checks every intake and warns the patient before intake if necessary.
- The MMS manages a full documentation of all intakes, remotely accessible by authorized users.
- The MMS administers all prescriptions and allows remote edit of prescriptions for authorized users.

Those requirements were then used to model relevant uses cases as shown in the use-case diagram in figure 2 which maps the requirements to the robot system setting.

Table 1. Main identified problems and consequences in the medication process of elderlies gathered from literature review and physician input.

Problem	Consequence
Identifying drug/medication	Patient takes wrong drug.
Timetable	Patient takes drug at wrong time or forgets to take it.
Dosage	Patient takes the wrong dosage of a drug.
	Patient forgets that a drug has already been taken and takes it again.
Drug handling	Patient is not able to open drug box.

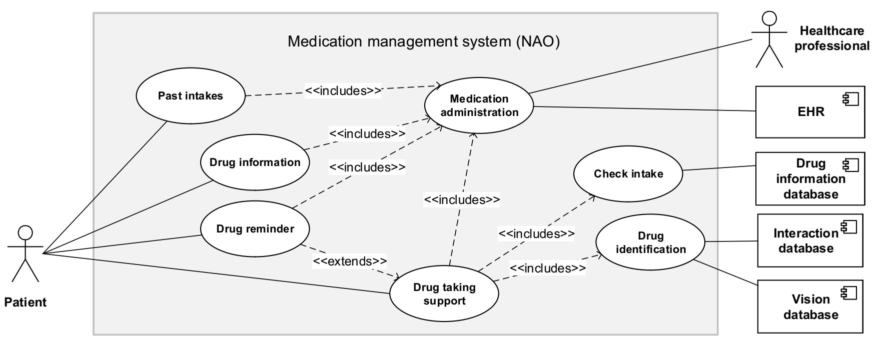

Figure 2. Use case diagram of proposed MMS.

3.2. Software architecture

In general, a software architecture describes the different layers of well-separated intercommunicating components. The *NAO* system with its determined modular structure claims for an architecture with high cohesion and low coupling. We designed a 5-layered software architecture comprising the levels in figure 3. The layer for the MMS is fully decoupled from the robot system connected through an interface level. The AAL-middleware represents a mediation level in order to execute more than one application in parallel (e.g. in addition to medication assistance an application for handling emergency cases). Each level has interfaces to connect with the adjacent levels and all are realized through different technologies. Choregraphe is Aldebaran's provided IDE for developing *NAO* applications and accessing standard-functions in a useful way.

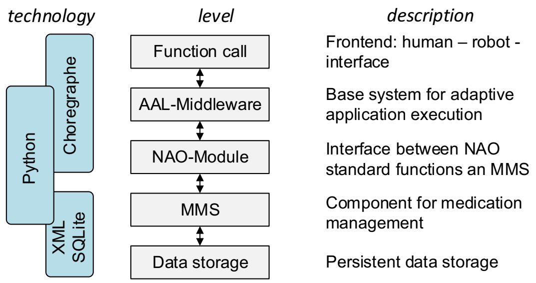

Figure 3. Implemented software architecture showing the different levels with utilized technologies.

3.3. Developed components

According to the use-cases and derived requirements, the following components were implemented in the MMS according to the proposed architecture and development process:

- *Medication administration:* The robot knows prescribed drugs as well as the specific regime. All intakes were documented in a medication history.
- *Medication identification:* Through its cameras the robot is able to detect and identify drug boxes by using either vision recognition (feature-based with prior object learning) or barcode scanning.
- *Drug–drug interaction checker:* An implementation of a drug-drug interaction database allows the robot to check for interactions between medications.
- *Reminding function:* The robot reminds the person to take the drugs.
- *Remote connection:* Authorized persons can access the documentation and administration using a client-server connection (XML-based).
- *Communication with a standard-based electronic health record (EHR):* The robot can import medications from a standards-based HL7 CDA document.

The communication between the user and *NAO* is entirely done verbally by speech-control using the standard speech recognition functions.

3.4. Evaluation

All components were tested through several unit tests during implementation. For the drug box identification, a set of real drug boxes were manually tested with the robot's cameras for recognition under different distances, orientations, occlusions and movement of drug boxes during the recognition process. Twenty different boxes have undergone three testing rounds for all aforementioned settings for both feature-based recognition and barcode scanning. The complete test protocol can be requested from the authors.

In good light conditions (daylight) and the preferred distance of 15 cm in front of the camera 100% (n=60) of drug boxes were identified right with no false positives (n=0) for both identification types. Feature-based identification shows very good results to changed orientation (98.3% recognition rate) and moved test objects (96.7%). Barcode scanning lead to worse results for orientation (26.7%) and movement (33.3%). This was due to the fixed focused cameras, which also led to problems in distance for barcode scanning, as the maximum focus was attained with holding the box in a 15 cm distance.

4. Discussion

In this paper we investigated if an off-the-shelf humanoid robot system with unmodified hardware was able to support the everyday medication process of an elderly person. For this project we chose the humanoid robot *NAO*. The system provides a very well designed architecture, where NAOqi is acting as an interface between software and hardware and allows the use of predefined functions in own projects. Beside the versatile access from a technical perspective, *NAO* offers a very intuitive way of human-machine-interaction through speech, vision and movement. The system has already been used in other healthcare related projects [7], also revealing that the childish appearance leads to high acceptance for people of all generations [8,9].

The evaluation of the implemented prototype reveals potential for using a free-programmable robot to support the everyday medication process and to provide support in polypharmaceutical settings on a cognitive base. The recognition component exposed very good detection rates, though it might be too specific for practical use in the sense of just detecting pre-learned drug boxes. More complex detection methods, e.g. utilizing RFID, or more specialized methods, e.g. to identify the different pills without box, will be needed. Other available robot systems, focusing on medication management, as well as pill dispensing systems [10] are often limited to the domain of medication support. However, one big advantage of *NAO* is that the system is also able to handle additional problem domains (e.g. emergency detection), all within one system without changing hardware and only adapting its software. Physical limitations, e.g. difficulties for a patient to open a drug box, could not be solved by this robot as hardware is limited.

As the system was only evaluated under laboratory conditions, further investigations are needed to examine the practical use of the proposed system in an applied field. Upcomming robot systems could even contribute to more acceptable results: Aldebaran robotics has already developed *Pepper*, which is a 130 cm tall humanoid robot, driving on omnidirectional wheels and offering better hardware like a chest-integrated tablet. As this system uses the same architecture as *NAO*, applications can be easily transferred.

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