HOME ROBOTS AND AMBIENT FACIAL INTERFACES: TOWARDS BUILDING A NOVEL TELEHEALTH PLATFORM FOR DRUG COMPLIANCE

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Abstract

We present herein a unified approach to caring elderly in their own homes. Our application relates to Ambient Assisted Living (AAL) and contains many novel elements of interfaces and interaction. We developed an architecture called *Life Style and Health Management System* (LHMS) using mobile platforms and deployed this in the context of home-based care. Our platform combines *low-cost computing* with *wearable sensors*, bi-directional *visual communication*, *services and applications* and *effectors* that can be instructed to carry out certain task in the patient's own environment. The later of these technologies introduce simple, special purpose robots in the home to help them lead a normal life. These robots incorporate autonomous behavior, local intelligence and human-centered interaction, such as facial information processing and *Ambient Facial Interfaces*.

1. Introduction

Caring for people in their home offers many advantages to patients, home-based services and insurers. Telehealth is one of many techniques that may assist in this aim, via ambient assisted living (AAL) [7]. The term AAL includes assistance in carrying out daily activities, health and activity monitoring, enhancing safety and security, gaining access to social, medical and emergency systems, and facilitating social contacts, all in the comfort of the patient's home. This reduces the need for caregivers, personal nursing services or transfer to nursing homes.

To address the needs of AAL we have previously developed a life style and health management system using mobile platforms and technology [8, 9,16]. Our system can be instructed to carry out certain tasks in the patient's own environment. We have also developed a home-robot that carries medicine, checks compliance of hydration and dietary goals and expresses emotions using its digital face. We argue that such robots represent an important part of future healthcare whereas smart mobile platforms, such as home robots may carry out tasks of carrying even helping the elderly to get out of the bed when they are ill or moving them around after surgery. The facial interface for such home-robotic applications is of critical importance bringing them closer to mimic face-to-face interactions.

2. Compliance Monitoring and Home Care

An important factor in the success of medicine is how closely the doctor's instructions are followed by the patient, i.e. the level of compliance. By compliance we mean the adherence to a drug regimen, as in taking the correct medications in the prescribed dosage and on time. During the treatment of chronic diseases, the compliance of patients is often below 50%, i.e. more than half of patients do not take their medications correctly. Recent research shows that patient compliance can only reach satisfactory levels if the patients receive guidance, support and instructions [4]. Clearly poor compliance may result in the weakening or loss of the therapeutic effect, cause the condition of the patient to worsen, and may even lead to death in some cases. Epilepsy, asthma, diabetes, hypertonia, heart deficiency and depression are common diseases, which require continuous and disciplined care. It is possible to live with these diseases, perhaps completely symptom free, if they are treated properly. However, incorrect or insufficient treatment can lead to severe complications, and a loss of quality of life or even life itself. Various studies show that the compliance for these diseases over long periods is almost always below 50%, and often as little as 20% [4, 2, 11].

Studies suggest that nearly 70% of people simply do nothing when faced with the necessity of some sort of change in their lifestyle to help improve their health [5,6]. Figure 1 summarizes compliance levels for frequent illnesses in Hungary [12].

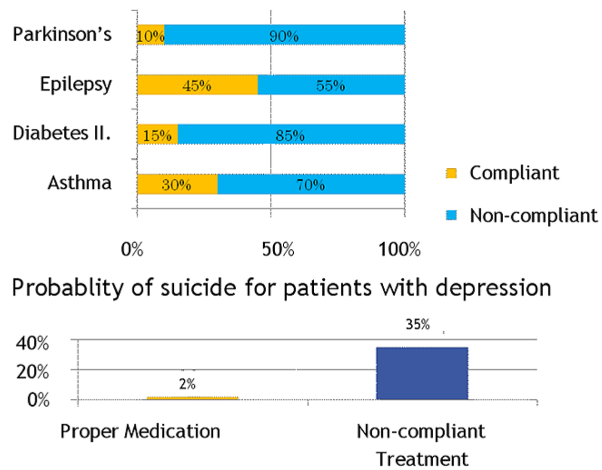

Figure 1. Compliance levels and problems rising from non-compliance based on Hungarian statistics.

3. Robots in the Home Assisting the Elderly

Home robots offer a new way to communicate and interact with patients while they remain in their own homes. Most probably the first line of robotics entering hospitals and eventually the homes of elderly will be robots that are strong enough to lift someone out of their bed and help them to get into w wheelchair, the bath tub or carry them around if needed. Such robots are likely successors of current military robot technology, such as those developed by *iRobot* and others. This trend may partially help in overcoming the ever increasing shortage of nurses, a problem that is becoming even more critical in aging societies. At the same time a second, parallel trend of robots represent small and specialized units that are designed for well-defined specific tasks and thus are cheaper to produce. They help around the household and carry out small jobs of comfort, even allow the elderly to communicate with family members in a new way. One such example is *ConnectR*, is a virtual visiting robot (iRobot) [3]. In our current application we wish to take this approach one step further and provide these autonomous platforms with more intelligence and implement human--centered tasks. Specifically our robotic system can perform face recognition to help locate people in rooms, and has an RFID interface to identify pill bottles and to monitor food intake. It also has a facial display (see below) to provide feedback to patients, for example about compliance. Figure 2 shows our overall concept of our AAL solution that includes wearable sensors, reliable and redundant communication, Effectors (which is the subject of this paper), as well as services and applications ranging from dietary advice, medication home delivery and social interaction sites. At the center of these lies an intelligent module with animated facial interface (a virtual baby in this example) that serves as the central channel of communication between the user and the system. The role of *effectors* become important when sensory data received by the telemonitoring data server indicates that there is something happening in the home that needs to be attended to. One such example is to be able to centrally monitor an intelligent pill dispenser or to instruct a robotic platform to go and look for a person in the home in case of a likely accident or emergency. Another example is to help people with compliance and carry their medication, drinks and such after them acting as a reminder to take the pills needed or drink more to avoid dehydration, etc.

Figure 2. Overall modules of compliance monitoring for Ambeint Assisted Living (AAL) and the role of effectors/robots in the home.

We have built a such a robot as demonstrated in action Figures 3 and 4. It uses a small mobile device (UMPC) with a built-in camera and touch screen. The UMPC is mounted on the robot and used for finding faces in the room for the purpose of approaching people and autonomous navigation when no people are in sight. Attached to the device is an RFID reader mounted as a service tray for keeping medicine bottles on; this is used for intake monitoring. A facial interface is used to provide an easy-to-understand display for the elderly to know if they are complying with all requirements. Finally, the basic system elements and hardware components needed to implement the above functionality are shown in Figure 5. In the order of importance these elements are as follows:

- A moving and programmable robotic platform capable of autonomous behaviors as well as remotely controlled operation (iRobot Create).
- An Ultra mobile PC as the heart of the system and intelligence, face detection, communication, sensory processing and emotional display algorithms (ASUS R2H).
- A miniature programmable display and buttons for visual interface purposes (Optimus)

- RFID reader and tags attached to different objects, like bottles and pill dispensers for intake monitoring (AVEA).
- Tablet dispenser for drug compliance monitoring (Bang and Olufsen)

In the following sections we briefly describe the core functionality of our prototype solution and introduce the role of each unit in a bit more detail.

Figure 3. AAL Compliance robot in the home using face recognition, AFI's and an intelligent pilldespenser combined with RFID technology.

Figure 4. Ambinet Facial Interfaces or AFI's provide instant visual feedback and easy-to-understand display of compliance levels.

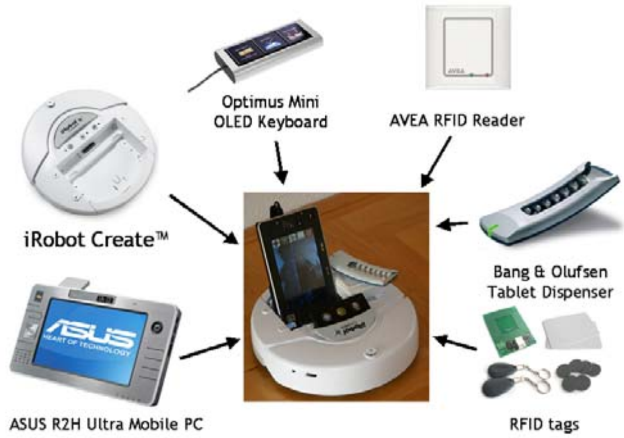

Figure 5. Hardware components integrated into our AAL robotic prototype solution.

Intake monitoring

RFID tags are attached to a tablet dispenser [1] with its own compliance reminder capabilities and also to the bottom of milk bottles, food items or any other object to be recognized. Drug intake (i.e. level of compliance) is monitored by checking whether the user removed the tablet dispenser from the tray and returned it there subsequently. Similarly, drinking bottles and food items may be scanned when taken out of the refrigerator, allowing the system to keep track of hydration levels and dietary intake, based on the product information stored in a database.

Whenever an RFID tag is scanned by the reader, its identifier is looked up in a table, which could indicate that certain levels should be modified by a given amount. For example, the RFID tag placed on a water bottle could be associated with the information that patient's water level should be increased by 2 dl, which translates to the assumption that scanning the water bottle is followed by drinking a glass of water.
Of course at the moment the actual intake is not yet monitored, but rather it is assumed that each time somebody picks up the bottle, they are drinking one or two cups of its content. Changes can be positive and also negative. For example, IDs placed on alcoholic beverages should be associated with negative water level changes, since alcohol consumption leads to dehydration. In addition to external events of scanning an RFID tag, internal time based triggers also modify monitored levels. Specifically, all amounts are decreased regularly at a predefined rate, modeling the natural loss of water and calories, and the decay of the effect of drugs taken. For example, considering the general advice that everyone should drink about 2 liters of water every day, setting a decay rate of 0.8 dl per hour seems adequate. The accuracy of the decay rate could be improved by using estimates of the physical activity of the patient, measured with wearable sensors. Figure 6 summarizes the above in a more visual format. In the future we expect intelligent fluid containers, pill dispensers and similar devices appearing on the healthcare market, which subsequently (with the help of proper communication interfaces) may all be readily integrated into our own framework. One example of that trend already happening in the field of monitoring medicine intake is Cypak [13], where tiny circuits are printed on blister packs to keep track of when a pill was taken.

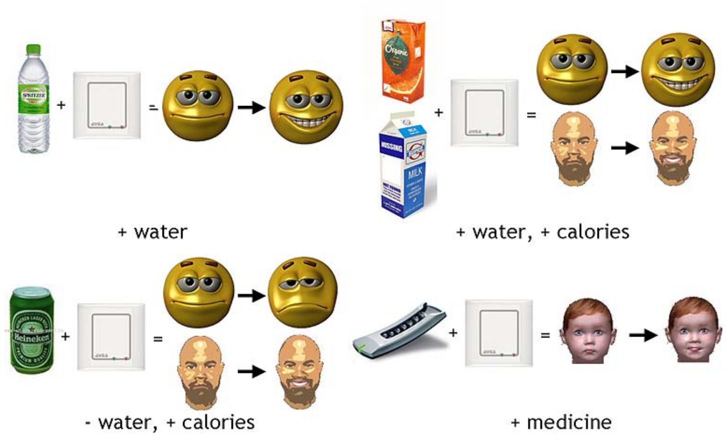

Figure6. Visual summary of intake-monitoring algorithms.

Facial interface

The Ambient Facial Interface is designed to provide visual feedback on compliance levels in a manner that can be readily understood. It uses a realistic animated face to display facial expressions. These digital faces are controlled by the compliance data derived from the monitoring system. The facial expressions are arranged in a sequence, thus forming a scale from "good" to "bad" using a continuous expression space sampled in 10 points with zero referring to a sad expression, five being neutral and 10 as the maximum of positive smile. The faces we use maybe express up to 60 different facial expressions using a parametric model of human emotions. They may be constructed as 3D head models of existing people (virtual baby), cartoonized faces (black person) or stylized characters (happy face), as well as from actual photographs of family members (not shown in the figure). The basis of their operation is our refined ability to discern differences in facial expressions (used in visualizing multivariate statistics known as Chernoff faces) and the evolutionary aspect of these abilities evolving over millions of years [8]. In other words, our ability to discern facial signals is very sensitive and people can read the slightest changes in facial expressions very easily irrespective of age, cognitive state or capabilities even with visual impairments. Therefore they are ambient in the sense that we understand their meaning instantly often even knowingly understanding them without much intellectual processing. Figure 7 demonstrates how 3D animated parametric facial expressions are built and used in the context of AFIs. Whichever type of face (3D, photo or cartoon) we choose from the above as the primary form of display, their number one goal in our solution is to provide immediate *feedback on compliance levels at a glance.*

The final integrated system can of course not only display the faces but show the history charts of the estimates on the screen of the mini-PC and provide immediate feedback of the current levels using the Ambient Facial Interfaces. Each monitored value is displayed via a different face, while the value itself determines the expressed emotion, e.g. very low levels result in sad faces, approaching the normal levels causes the facial expressions to change towards happiness, while further increase (i.e. overdosing) will cause the faces to show anger or disappointment. The faces themselves are displayed on a special keyboard with three buttons (see Figure 5). Each button displays a face of choice, and when one of them is pushed, the corresponding face and history chart is shown on the main display, i.e. screen of the UMPC, for closer observation (see also in Figures 3 and 4).

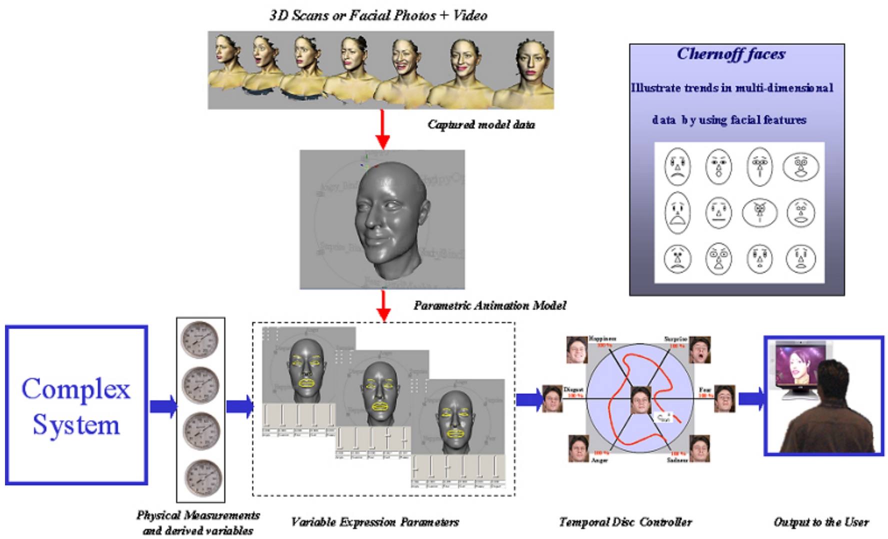

Figure7. Building 3D models for parametric facial animation expressing emotions in response to the state of a complex system, such as health status and compliance levels.

Compliance

In addition to passively monitoring compliance and consumption, the prototype system is also able to take action when the monitored levels indicate a need for it. For example, when the controller detects that it is time to take the next dose of medication, it starts up the robot and navigates it through the apartment. When it detects a human face on the image captured by the built-in camera, it approaches the person in sight. It then plays a short video clip reminding the patient to take their drugs.

The robot is equipped with sensors for detecting obstacles. These sensors include bump sensors on the front, wheel drop sensors to detect stairs, and an infrared sensor, which can be activated by an external source to confine the robot within a limited region. The two-way Bluetooth communication between the robot and the controlling UMPC on top of it carries the status of the signals in one direction and the commands to control the robot in the other. Part of the navigational algorithm, such as the triggers reacting to dangerous situations (i.e. wheel drop implies stairs) is also run on the robot itself, which reduces the reaction time.

4. Telelink and Central Database

The WiFi capability of the UMPC allows the system to connect to a central database through the Internet. The robot has Bluetooth to connect with the UMPC which in turn uses Wifi for the Internet and remote control. The central database can be located in the health care facility responsible for the treatment of the patient, or in an even more central location. The purpose of this connection is to transmit the current health status of the patient, so that medical staff can review the data, and decide whether human intervention is necessary. Such intervention could take the form of a telephone call or a personal visit, whichever seems necessary to improve medication compliance. To avoid transmitting confidential data, our system does not record any video images. It uses the video stream internally for navigation, and any monitoring data are transmitted in a encrypted form to the server. For a demonstration video of the robot in action, please refer to [14, 15].

6. Conclusion and Future Work

The prototype system we implemented is a proof of concept demonstrating how home-robotics may be used in the field of Ambient Assisted Living and beyond. We devised methods and integrated off-the-shelf hardware elements to offer a simple yet efficient way of keeping track of food and liquid consumption as well as medicine intake. Based on our initial concept future development will involve programmable liquid containers and intelligent pill dispensers with memory to improve upon our initial model. Secondly, we introduced a novel display technology that works independent of age, race or language using non-verbal facial gestures as a primary interface towards the user. The technology, called Ambient Facial Interfaces (AFIs) provides clear and easy to understand feedback on the monitored values. Finally we demonstrated that autonomous robots may be used as remotely instructed intelligent platforms that may become a companion of elderly people or patients confined to the comfort of their homes, while it can also take some limited action of search and delivering reminders. The platform's telelink capability allows medical personnel to follow events remotely and contact the patient when necessary.

The navigational performance of the system for now is somewhat limited, requiring more research to be carried out in the future. First, room exploration is performed by a random walk. Second, finding faces has its limits since the algorithm is sensitive to changes in lighting conditions, and finally, the viewport of the camera is also limited, i.e. the robot is not able to see what is behind its back. Furthermore, consumption monitoring is not entirely accurate but within the range of 10% error (an acceptable result for liquid intake) since the consumed amount is a fixed parameter built into the system. For pill dispensers this value is more precise due to the fact that the amount of intake is more accurately quantized.

Given all the limitations, however, we argue that simple and low-cost robots may soon become part of everyday life of not only the young, but the elderly living alone or in isolation. Such robots may open up new opportunities for providing services and care in a way never before considered possible.

7. References

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