ARCHANGEL: An architecture for ubiquitous, intelligent, transparent behaviour monitoring for active ageing and independent living through the early detection of signs of medical problems.

1 Problem Statement

The world population of people over the age of 65 is growing rapidly at a rate of 800,000 per month. As a consequence, the healthcare and medicare market already constitutes a major part of the European economy and it will only expand in years to come. Recent advances in sensor technology, cellular networks and information technology promise to improve the well-being of the elderly by assisting them in their daily activities and monitoring their health status, thus enabling them to lead their lives to a larger extent independently from healthcare institutions and their caretakers.

However, the comparatively slow adoption of such systems indicates that there are certain factors prohibiting their acceptance and use. For example, most available home-care systems monitor the health of individuals suffering from diagnosed chronic diseases (heart disease, lung disorders, diabetes, etc.); as such, they depend on customised, costly, and difficult to use health monitoring equipment, such as cardiographic monitors, and they often confine patients to their homes. Less attention **has been given to monitoring and maintaining the personal wellness of those elderly people who have not been diagnosed with any serious or chronic disease** and who, therefore, wish or should be encouraged to live a normal life, both inside **and outside their homes.** The quality of life of this larger population depends upon and may decline as a result of combined and (in some cases) not easily measurable physical and psychological factors. Existing work in the direction of monitoring and improving their lives, however, is limited to a) interactive facilities for consultation with doctors, which, while simplifying some regular examinations, do not take advantage of the full potential offered by the latest advances in information and communication technologies, and b) satellite location tracking systems, which, while allowing people suffering from memory and orientation problems to be easily traced, do not otherwise exploit the wealth of data gathered by the location sensors.

While sudden changes and, more generally, unexpected patterns in the daily behaviour of elderly people are difficult to detect via medical data only, it is very likely that i) such unexpected patterns can be detected by combining machine learning and input from a larger variety of sensors, and ii) that they can be used as signs that a certain disease, illness or health condition is getting worse or that is about to occur. Of course, detecting these early signs is far from trivial, if we consider the uniqueness of each individual's personality, behaviour, and the diverse effects of different diseases upon this behaviour.

Furthermore, early detection should not come at the cost **of confining the elderly to their homes, nor should it rely on the assumption that elderly users will learn to control complex equipment.**

The aim of the ARCHANGEL project is to realise a holistic framework that will exhibit all these principles and test its performance in a controlled trial setting. In this context, **the project aims to design, implement, and validate a cost-effective, secure (not compromising the monitored person's privacy), adaptable and interoperable framework for learning and monitoring the daily behaviour and personal routines of the elderly using advanced sensor networking, machine learning, and controlled interaction with caretakers. The resulting system will be based on off-the-shelf sensors and positioning-enabled cellular phones**.

2 Expected Outcomes

The ARCHANGEL architecture comprises two major components: the Monitoring Environment consisting of the software and hardware components that gather, format and encrypt the sensor data for the monitored individuals, and the Diagnostic Environment consisting of the software components that: 1) identify high-level events, 2) construct a behaviour model for each individual, 3) allow entering hand-crafted monitoring rules, 4) use both the behaviour models and the hand-crafted rules to detect conditions that require a caretaker's attention, and 5) extract generic patterns representing correlations between known diagnoses and aggregated behavioural models, which are then compared against individuals' behavioural models and diagnostic data to asses possible health risks. More specifically, the two major components have the following sub-components:

<u>Monitoring Environment</u>

- An **Indoor Area Component (IAC)**, to be installed in homes and public places, comprising off-the-shelf environmental sensors embedded in various places within a house monitoring the behaviour in the everyday life of the elderly within their home environment, and an indoor gateway to gather, aggregate and process these data, producing a stream of standardized encrypted messages and allowing multi-interface communications with the URC (see below). Sensors will secure their transmissions in order to prevent eavesdropping into the user's home.
- An **Outdoor Area Component (OAC)**, that is, software for satellite positioning-enabled cell phones that generates standardized encrypted messages containing location data and transmits them to the URC

(see below). This allows the system to keep track of monitored individuals and for their caretakers to contact them wherever required.

- A **User Registrar Component (URC)**, to gather and redistribute the encrypted standardized messages for each tracked individual to the Diagnostic Environment that has registered to receive them, after authenticating its identity.

Diagnostic Environment

- An **Event Recogniser Component (ERC)**, which will employ machine learning to identify higher level events from lower level sensor and positioning readings. The ERC will be trained to recognise the appropriate events by the caretakers via a menu driven user interface.

- A **Behaviour Modelling Component (BMC)**, which will employ unsupervised statistical machine learning to create personalised behavioural model(s) of each monitored individual, based on the data received via the URC over a training period. These models will then be used to detect deviations from normal behaviour, and deviations will be visible as high level events within the RBC (see below), thus allowing the caretakers to specify rules to handle them.

- A **Rule-Based Component (RBC),** which will monitor the presence or absence of events and other conditions and notify a caretaker when necessary. The RBC will provide a user interface allowing the doctors and caretakers to enter (and view) its rules and their underlying ontology in **controlled natural language via menu-based interaction.**

- A **Data Mining Component (DMC),** which will discover previously unknown and potentially useful patterns (e.g., correlations) between behaviours and medical problems. **These patterns contribute to global medical knowledge. They can also be matched against the behaviours of individual persons being monitored to detect possible health risks.**

3 Schedule

The subsequent paragraphs present the detailed work to be performed in the project in terms of the methodology followed and measurable results expected.

- **Task A. State-of-the-art analysis, system, and trials specification**

This task will begin at the start of the project with the goal of gaining a deeper understanding of the current state-of-the-art in the technological areas related to the project. The candidate technologies and components to be utilised in the ARCHANGEL system will be studied and evaluated with respect to the project requirements, taking into account not only technological criteria but also socioeconomic ones. It will include analysis of available sensors and interfaces to cell phones, and a detailed survey of and analysis of existing rule-based inferencing engines and menu-based natural language interfaces.

- **Task B. Development of the Monitoring and Diagnostic Environments**

The first aim of this task will be to specify and develop the ARCHANGEL monitoring environment, comprising off-the-shelf environmental sensors monitoring the behaviour in the everyday life of the elderly. Particular attention will be paid to the flexibility of the chosen components, so as to allow modifications to their predefined behaviours to achieve improved security and efficiency. Then, a prototype based on a PDA positioning-enabled phone (e.g. GPS) will be build, utilising a developed software component for wirelessly transmitting the position of the user. The design and the implementation of the component will be developed in a modular, wireless technology-independent way in order to ensure maximum compatibility with existing wireless standards such as GPRS, 3G, and WLAN. The location and user parameters will be encoded and sent to the URC (see above) via the appropriate IP-based interfaces.

This task will also develop the ARCHANGEL Diagnostic Environment, consisting of the Event Recogniser, the Rule-based System, the Behaviour Monitoring System, the Data Mining Component, and their associated user interfaces.

- **Task C. System integration and trials**

This task will be concerned with the integration and evaluation of the components developed in the previous task. The system will first be installed in the laboratory for integration testing purposes, and then it will pass an alpha test in the laboratory with predefined events to confirm that it operates according to its specifications, and fine tune its performance. Finally, the results of the system trial will be evaluated with respect to specific criteria defined in advance.

4 Use of Microsoft Technologies

We will make use of Visual Studio 2005, Windows Mobile 6 and ActiveSync, .NET Compact Framework 2.0, and Microsoft SQL Server.

5 Related Research

One direction of prior related work is monitoring the health of elderly people by exploiting sensors for medical data that are of particular importance for each particular person, such as glucose levels for a diabetic. In these projects the objective is to combine sensors and expert systems to allow elderly people to monitor their health without visits to or from medical personnel. Expert systems have found uses in disease diagnosis, drug effects, surgery and post-operative care, intensive care and trauma management. Some successful examples of health care expert systems are APACHE III [1], designed to compare an individual's profile against 18,000 cases in its working memory, predicting with 95% accuracy the individual's death risk in the hospital; ICONS [2], which offers antibiotic therapy advice and provides a rapid presentation of suitable antibiotics therapy for the monitored individuals; DiagnosisPro [3], which considers signs, symptoms and lab results to generate a list of possible diseases arranged in hierarchical format; and Dxplain [4], which also produces a ranked list of diagnoses and lists clinical manifestations, if any, that would be unusual or atypical for each of the specific diseases.

6 Dissemination and Evaluation

For Evaluation, see Section 8. For dissemination, we plan to publish results related to our software prototype in international conferences, preferably oriented towards Health Information Systems.

7 Benefit to Under-served Communities

The ARCHANGEL project will focus its efforts towards supporting the general elderly population, rather than people with predisposition to specific medical conditions or already diagnosed patients. The goal is to enable the elderly population to lead normal, independent and happy lives, in their own homes and on their own, with less worry about developing conditions. The technologies developed in the ARCHANGEL project will make a positive difference from the lives of elderly people, at a point when life expectancy in the developed world is rising and medical conditions that come with age, often minor if detected early, affect a larger percentage of the population. The key idea of ARCHANGEL is to **process the vast information that will be easy to acquire in the near future from various sensors embedded in normal settings in a non intrusive manner and alert the people themselves, or their caretakers, to changes in their condition which may signify impeding problems.**

8 Testing and Deployment

The system will first be installed in the laboratory for integration testing purposes, and then it will pass an alpha test in the laboratory with predefined events to confirm that it operated according to its specification and fine tune its performance.

System integration in the laboratory

This task will integrate the two main ARCHANGEL components developed in the previous phase of the project, namely, the ARCHANGEL Monitoring and Diagnostic Environments. While the specification of the interfaces between the two systems will ensure that they will be able to interoperate by exchanging XML records over IP, an **integration testing phase will ensure that if any unforeseen incompatibilities exist between the system components they will be resolved before alpha testing begins.**

Alpha test in the laboratory with predefined events

Following the verification of the system functionality, we will proceed with the evaluation of overall system operation in a laboratory environment, i.e., an alpha test. At this stage the Monitoring Environment will be fed with a series of sensor data and the Diagnostic Environment with a set of predefined medical use cases representing real-life medical user scenarios. The results of the Event Recogniser, the Behaviour Modelling System and the Rule-Based System will be evaluated against the expected ones, which will have been calculated in advance. Because the tests will be performed in a laboratory, the ARCHANGEL users will be simulated. Software simulation will also be used to generate realistic steams of sensor/positional readings and events from multiple simulated monitored persons, and the resulting streams will be collected. The Data Mining System will then be run to compare its outcomes with expected results. The successful completion of the alpha test and this project may initiate a possible beta test where the engineers will be substituted with real people and the system will react to unknown events.

References

[1] http://www.apache-msi.com

[2] http://www.med.uni-rostock.de

[3] http://www.medtech.com

[4] http://www.lcs.mgh.harvard.edu/projects/dxplain.html