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PLAY UP! A SMART KNOWLEDGE-BASED SYSTEM USING GAMES FOR PREVENTING FALLS IN ELDERLY PEOPLE

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Abstract

Falls in elderly people are becoming a serious problem not only impacting quality of life but also putting a financial burden on the healthcare system. Research has shown that regular exercise and maintaining an active lifestyle can help to reduce the risk of falling. Computer games can be used to support and motivate elderly people in exercising regularly in a playful way. In this paper we present a cloud-enabled knowledge-based system (KBS) for personalization and data analysis of exercise games. We discuss the architecture, interfaces as well as privacy and security issues and present results from an evaluation within a living lab scenario.

Keywords – ***Data analytics, serious games, cloud-based computing, ambient assisted living, eHealth***

1. Introduction

The economic Policy Committee estimated that in 2050 one in three Europeans will be older than 65 years [1]. More than 30% of the people in this age group fall at least once a year. In the group of people older than 80 years, 50% experience at least one fall per year. Aside from personal discomfort and potential long-stay hospitalisation this puts a huge burden on healthcare finance [2]. There is robust evidence that exercises reduce the risk and rate of falls [3]. Technology-based solutions can help to make preventive measures cost- and time-efficient. Especially in the field of fall prevention, video games turned out to be an especially motivating and entertaining way to keep physical fitness with elderly people [4]. These games are commonly referred to as *serious games. Serious gaming* can be described as achieving a (health) goal by playing a game [4, 5]. Various efforts have been made to use serious games for exercising and rehabilitation, including technologies as personal computers, robots and Nintendo's WII [4]. While commercial solutions are available, an evaluation shows that these games have problems regarding usability and could even lead to a negative health outcome when played by elderly people [5].

The 3-year EU-funded project *iStoppFalls* tries to combine serious gaming and outcomes of fall prevention research to design a system that helps elderly people to take preventive measures for fall prevention at their homes.

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End-users are equipped with a smart TV, a PC running the computer games, a wearable Senior Mobility Monitor[1] (SMM) with a necklace to track daily activity as well as movements during the games, and a set-top-box orchestrating the whole client environment. The PC is connected to a Microsoft KINECT Sensor tracking movements in front of the television visually. During exercising and game playing (including reaction, balance and strength exercises), a biomechanical model is used to track and evaluate the end-user's movement. Aside from recording sensor data, end-users are filling out online risk assessment questionnaires on a regular basis using the set-top-box. The set-top-box and the PC are connected with a remote cloud-enabled knowledge-based system (KBS) that collects data (questionnaires and sensor data), manages the devices and adapts games and exercises according to training progress and individual training plans. Moreover, the set-top-box provides health advices, educational material and performance reports for end-users. A social media platform can be accessed by end-users to enhance user experience with social interaction.

In this paper we focus on the architecture and implementation of the KBS and its interaction with other system components. We discuss interfaces, security as well as privacy issues and results and experiences of using KBS within a living lab evaluation.

2. Methods

2. 1. Basic interfaces and data management

KBS is a web-based platform providing a user interface for technicians and researchers as well as 24 HTTP-interfaces for exchanging data with devices. These interfaces can be divided into six groups (see *Table 1*).

Table 1: KBS Interfaces

Interface	Examples
User management	Registration of new users (using the set-top-box; performed by authorized technicians)
Device management	Registration of new devices, gathering and updating device information (using the set-top-box – managed by technicians)
Sensor data transfer	Results of exercises and games; results of online questionnaires (PCs and set-top-box)
Health advisor and educational material	Generation of text-based health hints, HTML and PDF-based educational material (set-top-box)
Device and software configuration	Configuration of game parameters; Configuration of online questionnaires (PC and set-top-box)
Personalization services	Personalized training schedules (PC)

Interfaces for sensor data transfer are generic and not limited to a particular health domain. The KBS handles three types of sensor data: *unstructured or bulk data* (e.g. raw sensor logs as produced by KINECT), *semi-structured data* (e.g. CSV-Files produced by a sensor) and *structured data* (high-level sensor readings such as heart rate). Unstructured and semi-structured are transferred as

[1] Equipped with an accelerometer

files, structured data is represented in JavaScript Object Notation (JSON)-Format, a light-weight data transfer format. Simple structured data (e.g. a heart rate reading) can be configured in KBS web interface while more complex types (such as exercise measurement results) are modelled in KBS module code. Data itself is stored within a relational database. Raw sensor logs are kept in the file system being referenced in the relational database.

All interfaces have been designed following the Representational State Transfer (REST) principle for web services. [6]

2. 2. Security and privacy management

KBS uses a light-weight version of the Open Authentication Protocol (OAuth) [7] to authenticate any incoming data transfer based on HMAC-SHA1 signatures. Each device is provided with a remote access id (identifying the device) and a remote access key only known to KBS and the device itself. Whenever the device wants to transmit or request data, it creates a signature of the HTTP request based on Uniform Resource Locator (URL), URL parameters and current date and attaches this signature to the request. KBS verifies this signature based on the remote access key assigned to this device. Key exchange is done during system setup which is done by a technician at the user's home.

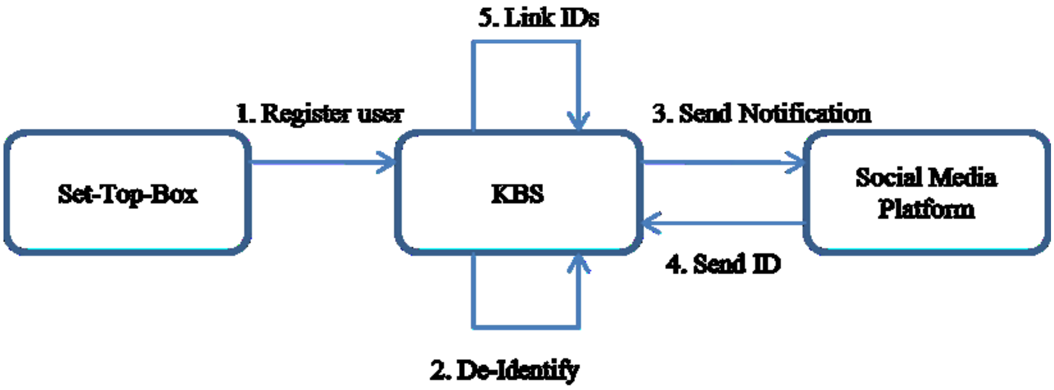

Figure 1: Identity management

KBS de-identifies person-related information during user registration[1]. Person-related information is transferred to the social media platform. The social media platform returns its local ID and KBS links all IDs and keeps this linkage in its database as *Figure 1* suggests.

Whenever the set-top-box wants to display content from the social media platform for a specific user, it can resolve its local identifier with KBS. This workflow follows the *Integration the Healthcare Enterprise* (IHE) integration profile PIX (Patient Identifier Cross-Reference) [8].

2. 3. Data analysis and transfer components

The KINECT sensor monitors and records in the PC all the actions and movements of the users when they are playing the games or doing the assessment exercises. The PC also stores the continuous records of activity recorded by the SMM, which are transmitted to the computer via Bluetooth at least once a day. All these data are processed with GNU Octave [9], in order to obtain the following results: (a) periodic assessments of the risk of falling, based on the criteria published in [10], (b) exercise performance summaries based on normality patterns, and (c) measures of daily

[1] Meaning first name, last name, date of birth (replaced by age for research purposes) and address (country is kept)

activity based on individual history. These calculations are done on the local machine, transforming the raw data provided by the sensors into convenient summaries in JSON or CSV format. Part of the analysis is based on biomechanical parameters, like ranges of motion and execution times, initially obtained from previous studies [11,12]. However, possible variations in those normality patterns are expected since the application context of *iStoppFalls* is different from those studies. Thus, the system is prepared to learn from the observed records, and adjust those parameters automatically. KBS keeps a JSON file with the biomechanical parameters that is requested by the analysis module of the PC when an updated version is detected, before performing a new analysis. The most recent version of the file is locally copied in the PC, so that the analysis can be done even if there is no Internet connection.

2. 4. Personalizing end-user experience: Individual training schedules and health advisor

The strength and balance exercises are individualized in terms of the number of repetitions, sets and the additional weights which can be used to make the exercises more challenging. For each exercise different levels from easy to hard are predefined and the XML-definitions are stored in the KBS. Before each training session the exergame requests the user-specific training plan from the KBS. After the session the results are transmitted back to the KBS. The system processes the data and automatically generates the new training plan for the next session, which currently is implemented by a simple set of rules. The progression rules are based on evidence-based guidelines as described in the Otago exercise program [13]. Users have to confirm proceeding to next level before performing the exercises.

The health advisor module creates text-based health hints taken from the area of fall prevention. 31 text messages have been selected from educational material. They can be actively requested by end-users using the set-top-box.

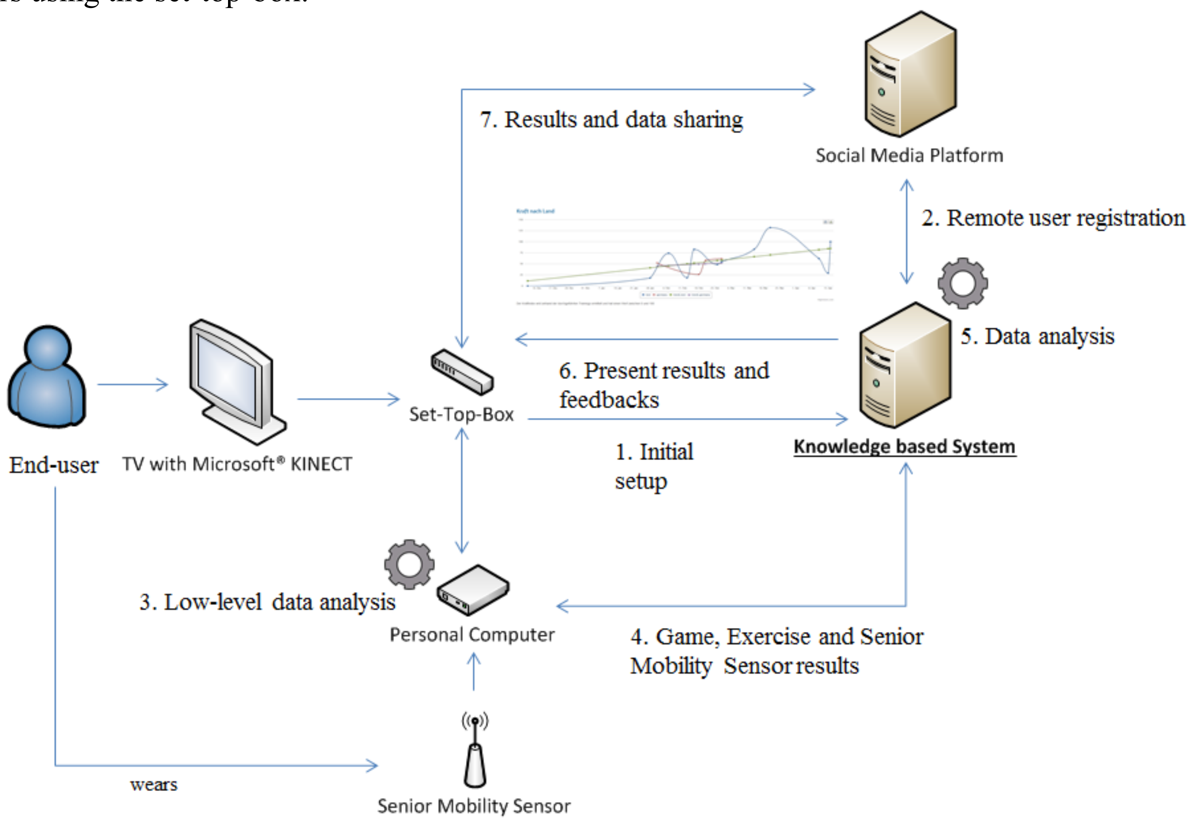

Figure 2: Identity management

3. Results

Figure 2 shows the overall system architecture and interactions of all components: End-users are registered on the set-top-box by an authorized technician. Technicians enter personal information and information on the devices that are used. This information is submitted to KBS (1) which in return relays personal data to the social media platform. There, an user account is created, identifiers are linked in KBS. KBS creates access remote access keys for the set-top-box and the personal computer which are then used to transmit and receive data. Remote access keys are directly linked to end-user accounts. As a result incoming data can be directly linked to end-users.

After successful registration, end-users can start using the system. After each gaming session, local data analysis as described in chapter 2.3 on KINECT and senior mobility sensor data is performed. (3) This results are then sent to KBS (4). KBS adapts training plans and gaming parameters and performs long term analysis as described in chapter 2.4. (5) Long term analysis results (improvements in balance, strength and reaction time) can be retrieved by end-users using the set-top-box. (6) Finally end-users can share their data using the set-top-box. (7) Shared data is made available to other users on the social media platform.

4. Discussion

A huge problem was the sheer amount of the data that is created by the individual sensors. While it was originally planned to transfer every data item to the KBS, it turned out to be practically impossible. Everyday several hundred MBs of data can potentially be created per user. Having in mind, that end-users might not have high-speed internet access or data transfer limits are enforced, we decided to compress data wherever possible and leaving raw data (especially as created by the KINECT and SMM sensors) on the client machine. This is also the reason why parts of the data analysis are performed on the client PC. Furthermore, training plan schedules are based on previous studies. It has yet to be evaluated how the data collected so far can be used in future data analysis tasks, especially when it comes to predict long-term fall risk.

While identity management follows IHE principles, proprietary interfaces for user registration are currently used, mainly because of existing interfaces. However, KBS could be made fully IHE-aware by using a HL7 router, such as *Mirth* [14]. Furthermore, in order to increase privacy, the linked identifier tables could be moved to a separate database. Overall security could be increased by using a private/public key exchange infrastructure instead of the shared-secret-based authentication described earlier.

Finally, one can argue that data analytics can be completely done on the client. However, moving such services into the cloud has significant advantages, especially easier maintainability (such remote administration of content, algorithms and software).

5. Conclusion

We have presented a cloud-based and privacy-preserving architecture for a knowledge-based system in a serious gaming environment, supporting elderly people in preventing falls. The system has been shipped and is currently used in a living-lab scenario with 36 German end-users.
The sheer amount of data created by modern sensors still remains an issue, so data analysis hast to be done partly on the client and on the server. The evaluation will end in April 2013 followed by a

re-design of the system based on end-user experiences. After re-design the system will be evaluated in a clinical trial with 250 people from four different countries.

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