Sensor Technology for Learning Support

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***Abstract*— One major technology revolution of the last 2-3 years is the broad integration of sensor technology into every day environments and end user products. This article explores the potential and possibilities of sensor technology for learning support. The author gives several examples and structures the potential implications according to different typical applications of learning technology.**

***Index Terms*—Immediate Feedback, sensor-based learning support, non-verbal communication**

I. Introduction

Tracking information about learners and their learning progress is at the core of computer based educational systems. Especially adaptive educational systems used learner tracking for personalization of interaction or assessment of learner skills. Learner modeling based on either student provided problem solutions or tracking of learning activities has been one main topic in the domain of Intelligent Tutoring Systems. Adaptive feedback, navigation support, and tutoring of computer-based systems was in most cases based on the assessment of performance of learners inferred from tracking information on tasks or usage information [1], [2]. In the field of learner modeling a variety of information was used to analyze the learners progress ranging from the learner's interaction history, analysis and data mining of footprints, to highly sophisticated assessment processes integrating a variety of methods [3]. In the field of competence assessment multi-method approaches have shown to be more accurate, these can include multiple-choice assessment, face-to-face assessment, as also social assessment procedures as 360º feedback. In general the more data is available about learner activities the more accurate adaptive systems can adapt to learners and support personalized learning. With the growth of ubiquitous computing facilities adaptive interactive system more and more took into account user tracking in physical space [4], [5] in modeling the user characteristics as also the relevant information in the learners environment. This has led to a variety of applications in the field of context-aware computing [6]–[9] ranging from new forms of intelligent objects to new user interfaces as also educational applications in cultural domains. In the field of mobile learning mostly location tracking technology was used to filter information to the location and context specific need of learners [10], [11].

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In the last years sensor technology has become a cheap and efficient method to collect data and give direct feedback to system users [12] and more and more sensor components are integrated into every day environments and the collected data can easily be aggregated and used for system adaptation. While the idea of using sensors in body area networks has been used already quite some time in physical education and advanced sports training, life logging and sensor tracking applications nowadays are used in a wide range of applications fields as health, nutrition, life-style, fitness, sleep, or productivity. The quantified-self[1] movement has brought awareness to the multiple use of sensors in everyday activities for creating personal awareness and possibilities for reflection for behavior change. The following article structures the potential of sensor technology according to the application for learning support on three levels, i.e. direct feedback, support for reflection, strategic coaching and long term analysis.

II. Sensor technology for learning support

The range of sensors being available for learning support in the last years has increased and broadened steadily. As the most popular example GPS location tracking technology has been used already in the late 90's for supporting field trips and location based city hunts [11], [13]. In the field of context-aware computing this has been extended to a variety of other sensors including sound, light, accelerometer, gyroscope, and others. Examples for creating context-aware artifacts and learning support can be seen in [9], [14]. Another line of developments of sensor-based information systems focused on the detailed tracking of human activities based on movement data. Beside the direct usage of accelerometer data also the algorithms for analyzing and segmenting the data streams have become more in the focus of research projects. In some cases already the detailed analysis of a single sensor as the water usage in a household allows for inferences on individual users in a household and their daily patterns and preferred devices [12]. Based on single sensor types or the combination of different low level sensors higher level sensor technologies for the detection of different movement patterns, the classification of activities, posture detection [15] and other have been developed [16].

A variety of sensor components has been used for different purposes and educational applications. Examples for recognizing and making use of different gestures are given in

[1] http://quantifiedself.com/

[17]. The educational potential of tangible user interfaces is analysed in [18]. Seen from the perspective of educational applications the level of granularity with which sensors can analyze the learner's environment and the relation to the educational objectives is often relevant. Therefore we would like to classify the sensor components here according to the level of granularity of the environment or physical context they can be used to identify. In general the following sensors are currently used in educational contexts:

- Object identification sensors: basically all types of technologies to identify objects as infrared, RFID, barcodes, QRcodes and visual tags can be used in educational applications to identify the learners focus of attention in an easy way. Learners just need to scan a tag and this automatically either gives filtered information for the identified object or enables special services associated [19].
- Location sensors: All kinds of location tracking sensors enable the identification of the learners physical environment, location in relation to relevant other Points of Interest or relevant learning activities. The technologies used for location detection are broad and range from GPS based solutions to triangulation approaches.
- Audio sensors can either be used to identify and recognize the users audio environment. Basically all kinds of analysis are possible based on audio sensors directly connected to the learner's environment via the users smartphone or audio installations.
- Visual sensors are most prominently used in video analysis either for face recognition or analysis but also for activity recognition and movement analysis.
- Accelerometers either directly integrated in wearable computing devices as snarphones or in Smartphones. This allows for movement analysis, activity or agility analysis.
- Magnetometer enable measurement of orientation, magnetic field, shaking, as also absolute orientation these are highly relevant in mobile augmented reality applications for linking augmentations to the user's visual field [20].

Based on the combination of these low level sensors high level "sensors" can be defined that enable the definition of complex adaption logics to the learner. For example [21] describes diverse new interaction scenarios for using wearable systems with sensor and indicator components to train experts, novices and even develop virtual models based on expert movements in different sports.

To be able to abstract from the specific technologies and to identify higher level characteristics of a user movement or the current environment the AICHE framework has been developed [22]. Basically the framework defines a basic sensor layer, which collects and aggregates sensor data that is used on a higher level in an instructional logic. In that sense also the position/location of a user has to be determined with a GPS sensor, an electronic compass, and probably even with an indoor location tracking solution to be able to continuously track the position of the user in relation to the relevant objects of instruction. An analysis of making use of sensors to detect different aspects of the users context and use them in mobile augmented reality applications for learning is given in [23].

III. How to Make Use of Sensor Data for Learning

Sensor data can be used for different purposes considering the learner support.

- Data Collection in inquiry-based learning approaches: collecting evidence for evaluating hypotheses is at the core of inquiry-based learning models. In most cases evidence is collected in a collaborative way and the collected data is also annotated with meta-data as in [13] or just used for collaborative reflection [24]. Different applications use distributed crowd-sensing approaches for noise measuring with mobile phone audio sensors [25] or measuring of specific pollution [26].
- Context-aware adaptation of information selection: In this case sensor data is used to filter information selection or the user interaction with a software system. Classical applications are location-based information systems, or object-based information systems in a museum or on field trips [27][28].
- Real-time feedback and reflection in action support: In this case the information from sensors is directly used for feedback to learners. Most popular applications come from the domain of sports [29]–[33], rehabilitation [15] and health training [34], [35].
- Assessment, analytics, and reflection about action support: Cheap and efficient collection and aggregation of sensor data makes it possible to do more long term assessment [36] or a comparison of different activities and analysis post-hoc [37].
- Notification for triggering user action. Users can either be notified of relevant changes in their current learning context or cues can be given for stimulating self-reflection or experience sampling [38], [39].
- Awareness support: Several applications use ambient and ubiquitous sensor technologies in combination with situated displays to foster user awareness and reflection in action [40], [41].

In general terms sensor-data can be used for different educational functions ranging from evidence collection, to monitoring, assessment, or filtering functions, it supports reflection and notification of environmental changes relevant for the learning objectives.

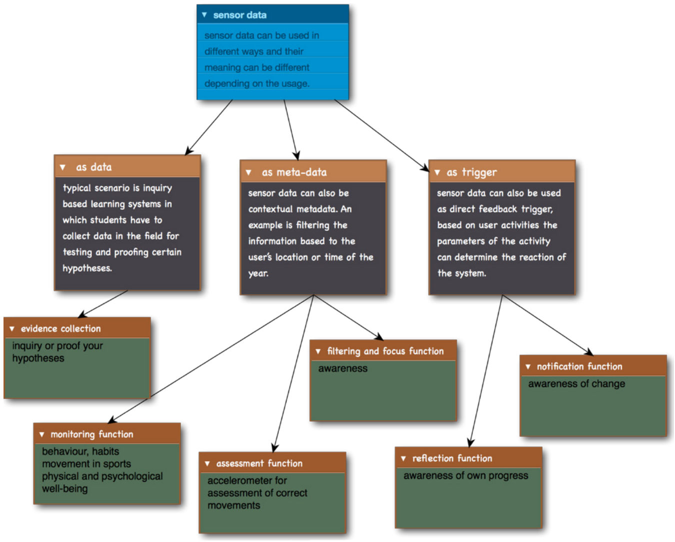

Figure 1: Functions of sensor data in educational settings

IV. KEY CHALLENGES AND RESEARCH QUESTIONS

The research on designing efficient and effective personalized as also collaborative technology-enhanced learning is confronted with new challenges based on the rapid development of sensor technology. On the one hand this enables the integration of learning support in every day environment and takes learning into the actual learning and performance environments. On the other hand this allows for an analysis of learner behavior sometimes not even possible by a human coach either based on the high granularity of analysis as in wearable computing devices or connected to the cheap long-term data collection as also the integration of multiple data-sources in distributed sensor systems.

Already some forms of new user-interfaces and physical learning objects have been developed linked to natural learning environments and interactions of learners. While most of the current developments are linked to physical activities and the monitoring of body movements in sport or health, the development of algorithms for audio and video sensor data analysis already now enable much more fine-grained analysis of human gestures, facial or tonal expressions. Examples already now support the analysis of emotions [42] in human computer dialogue. Tangible objects and Internet of Things making use of sensor technology enable the implicit tracking of user activities and recording for analysis and reflection.

Real-time data applications can extend current learning support into different directions. One key question is how the integration of feedback and learning support in real-world environments can be implemented in a way to be efficient and distracting. Embedding and integrating ambient and personal displays into learning and performance support systems while not reducing the user performance or avoiding attention split. Without doubt the analysis and integration of multiple sensor components and the trend towards wearable and implanted sensor technology definitely will show an unforeseen level of information about single users as also their environment for supporting personalized learning.

The integration of distributed sensor systems and their relevance for learning support is another key question in which the distributed support of learning activities as also the analysis of learning activities based on multiple sources of data and crowd-sensing applications is another relevant research area.

The authors hope to demonstrate the remarkable potential sensor technology can give to instructional designers and technology experts to develop systems that can embed learning support in real world interactions and develop technology enhanced learning solutions that are effective, efficient, enjoyful, relevant, personal, and engaging.

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