Context-Aware Computing : From Neuroscience to Mobile Devices

HAUPTSEMINAR

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Problem description:

The technology enabling context awareness in mobile devices includes wireless, ambient intelligence, user interfaces, powerful search engine capabilities, power management, software, mobile computing, and myriad perceiving and data-collecting sensors. Added to this list are such human factor enablers as emotional state, biophysiological condition, goals and social interaction that, when combined with the technological factors, provide the potential for a meaningful and individualized experience. Central to this perspective is the connection between participation, action, and understanding of the context, including physical context, and/or responding to the affordances of a particular action. This redefines the notions of motion, space, place and how they are represented and synergistically exploited for guiding subsequent actions. The purpose of this advanced seminar is to investigate aspects from neuroscience providing insight into neural processing mechanisms involved in multisensory fusion for contextual awareness known to be present in humans. Transferring "brain-like" processing principles to technology in order to design intelligent multisensory processors is an emergent trend in mobile devices for enabling natural user experience, efficient spatial navigation capabilities, or even physical rehabilitation.

Tasks:

- Explore neuroscience studies focusing on multisensory fusion for contextual awareness.
- Provide an overview on existing context-aware neurally inspired technologies for user experience and navigation.
- Provide an overview on existing neurally inspired technologies for contextual awareness in rehabilitation devices.
- Extract the main design principles from the presented technologies and their future trends.

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Abstract

The presence of multiple sensors in mobile devices enables ubiquitous computing, allowing one user to have a better experience while using its mobile device. Context-aware sensing is also interesting in healthcare for proposing a better rehabilitation. This advanced seminar goes into the possibility offered by sensor fusion for context awareness and provide an overview of existing technologies for navigation and user experience on mobile devices. The second part focuses on home based rehabilitation with context awareness and Body Sensor Network.

Contents

1 Introduction

Context-aware computing in mobile devices enables the device to get conscious about the environment in which they are used, their own status and to adapt themselves appropriately with these context information. The presence of multiple sensors in mobile devices make them fusing multiple sources of information to get a global meaning from a scenario, just " like " humans are doing with multiple sensory inputs. In order for the devices to do so, a middleware for context-aware computing [RCAdR] and a context-modelling scheme have to be defined. Context-aware devices can improve the experience of one user by adapting the device in order to propose better solutions or by clever advising one user's regarding its intents. Applications are mostly in navigation, location, activity recognition,healthcare and social networking.[OY]
Pervasing computing is also widely used in healthcare for remote patient monitoring, rehabilitation or assisted living for elderly people.
The goals of this advanced seminar were targeted in the following manner :
first it is briefly discuss how humans can retrieve the context, then it is explained how it is done with the technology and finally the possibility of integrating humans preferences and humans observations within the sensor data to be fused is explored. The second part explains how adaptive applications are designed and provides an overview of existing technologies for context-awareness in mobile devices, emerging trends and future challenges. Finally, we focus on real-world instantiations in rehabilitation devices and BSN and mark the potential sensor fusion algorithms used in these scenarios.

2 Retrieving the context with sensors and human perception

2.1 Definition of the notion of context

The notion of context covers the physical phenomena describing our spatial-temporal environment and social interactions. In their daily experience, humans can naturally give a global meaning to a scenario where multiple sensory information are involved. Context is also a useful information for mobile devices. In information retrieval the context can be represented in four different categories defined in [OY] :

- Device context(connectivity,communication etc)

- User context (profile, geographic position, neighbours, social situation etc)

- Physical context (temperature, noise level etc)

- Temporal context (day, week, month, season etc)

Different techniques can be used for context-modelling, the final goal is to obtain a robust and adaptable solution which is able to handle heterogeneity, coexistence of several context information coming from different sources, relationships between context information etc. Different schemes can be used for context modelling but the Ontology based one is the most widely used. This technique uses semantic attributes to represent context related attributes and relationship. In [OY] it is emphasized that this method is good for giving an abstract model and explicit relations. It also allows knowledge share, reuse, handling of redundancy. The major drawback of the ontology approach is its complex and computationally expensive data retrieval.

2.2 How can humans retrieve the context from multiple senses ?

While investigating how perceptual awareness occurs in the human brain,[CQ09] pointed out that two different process are involved in a conscious perception :

- **Perceptual awareness**, which is linked to a boost in the activity of object-selective neural assemblies in high level visual areas.

- **Contextual awareness** : Some neurons located in the MTL region provide an explicit and abstract representation of the meaning the stimuli. The cells involved in this process are described as concept cells.

[Kan01] described the regions involved in awareness for multiple sensory inputs.

- The lateral occipital complex (LOC), a large region in the ventral pathway responds strongly to images and objects

- The neural correlates of awareness of mention occurs in MT/ST

- The fusiform face area responds strongly to faces stimuli

- The parahippocampal place area (PPA) is reactive to images of places.

Finally multiple units are involved in the awareness process. The relevant corticals areas extend from V1 to MT and the face area. [Kan01] suggests that in order to obtain Contextual Awareness from Perceptual Awareness, the information provided by the stimuli has to accessed most rest of the brain. From another point of view, [CT04] analyses that "Multisensory interactions happened both at early and late stages of processing via a parallel network of feedforward and feedback connections". By late stages of processing it is here meant that the unisensory signals are first elaborated in their respective dedicated cortices.

2.3   Sensor fusion for context retrieving

In order to cope with Context-Awareness a layered system architecture referred as Context-Aware Middleware is chosen. [RCAdR] discussed the requirements that one middleware should have :

- It has to support dynamic context discovery

- It has to be independent of the architecture and contain multiple mechanisms for accessing context information.

- The context management and context inference handler have to be separated.

Mobile devices contains multiple sensors which has to be combined in order to offer an efficient retrieval of the context. [EMM08] proposed the following framework for multi-sensory applications capable of determining the best fusion solution in given conditions.
The framework include the following blocks :

- **Context management module** : Responsible for keeping an updated record of the context. Two channels are available for accessing context information.

  – Virtual sensors : They consist in a source from software applications and /or services and a semantic data obtained through cognitive inference.

  – The subscription service module, which notifies updates in context variables to the appropriate entities.

- **The data fusion module**, which is responsible for preprocessing the data and contains the fusion algorithm.
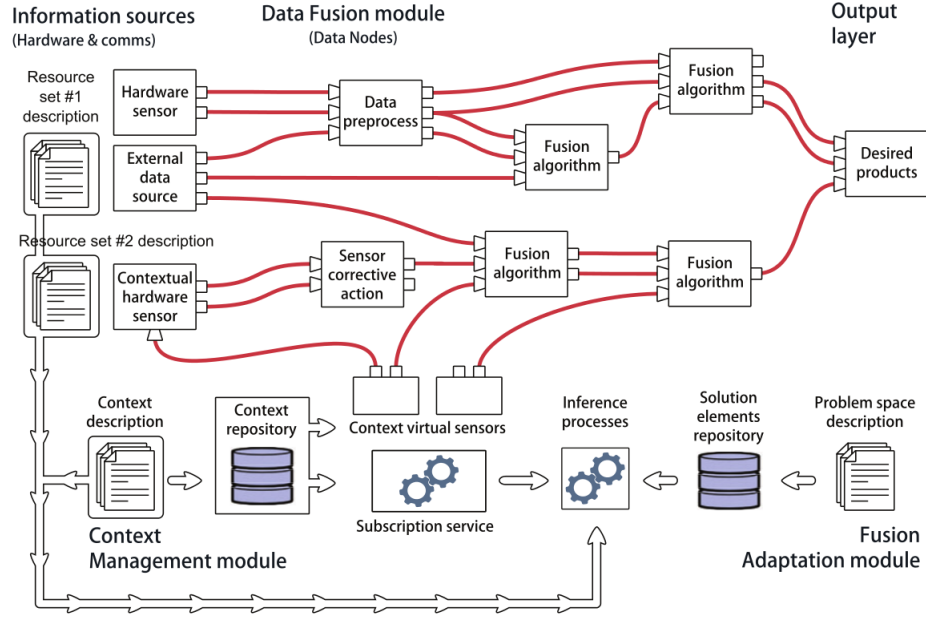
Figure 2.1: Architecture of the sensor fusion system

- **The fusion adaptation module**, which consists in the problem space description, the repository of solutions elements and the inference process. The space is described through ontologies. The inference process is "in charge of combining the available solution element to create the sensor fusion system expected to deliver the best performance in the present conditions".

The latter solution described how sensor fusion is working at the sensor level, but context can also be inferred at the feature level and the decision level 2.4. [SSES14, OY]. Retrieving context at the feature level begins with a preprocessing of sensory data, some features are then extracted from the data (mean, deviation, entropy etc). The features which should be extracted have to be selected. Features are then introduced in classification techniques, which consists in machine learning algorithm. Classification techniques help by collecting the preferences of the user and some context element in order to adapt the engine. At the end, the user should be able to accept or decline the proposed adaptation[VGM12]. The learning process is triggered when new patterns helping the adaptation engine to perform new adaptations are identified or when one user is negating an adaptation.

2.4 Combine sensor-fusion and human data

In the previous section, the fusion of information was introduced at the sensory and feature level, it can also be done at the decision level [SSES14]. At this level the

inputs can be various sources of information (knowledge, sensors, historical context, user preferences). In [GW06] a solution for fusing the information at this level is proposed. "The idea is to use these techniques to develop local and global context rulesets,policies, models and ontologies so that these can be applied for awareness purposes". The proposed architecture is the following :
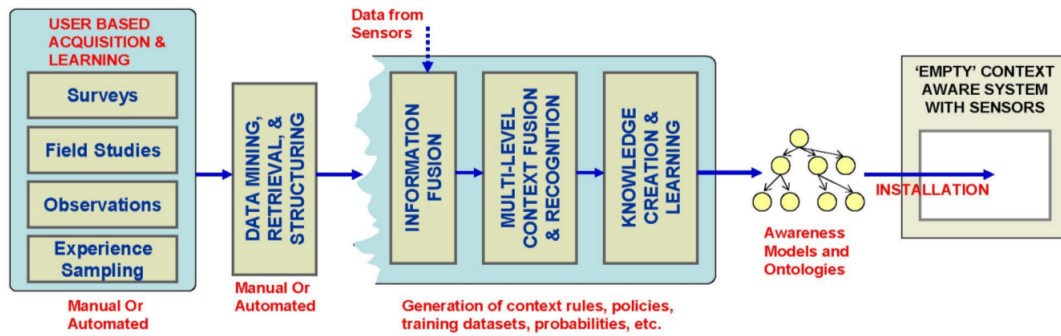

Figure 2.2:   Architecture of the sensor fusion system

Once the various sources of information are fused, the data is used in a training phase of classification algorithms to generate the awareness model and ontologies. This approach allows some advantages which are not possible with a sensors only acquisition [GW06] :

- User preferences, environmental characteristics can be taken into account.

- The collected data is truly representative to one scenario.

- Uncertainty can be taken into account

The author suggests to combine the sensor based context acquisition with the human perspective based context acquisition.

3 Context-aware applications in mobile devices

3.1 Motivation

Nowadays smartphones are equipped with a multitude of sophisticated sensors such as GPS, accelerometer ,microphone, magnetometer, camera,WiFi etc. By combining these sensors, adding context-awareness and intelligence interesting applications for enhancing one user's experience can be designed.
Smartphones are carried by the user all day long, thus they are the ideal platform for sensing human activities [SSES14], useful sensors for such a goal are accelerometer, microphone, WiFi and GPS. Using the GPS and data gathered from street maps enables an efficient outdoor tracking. For indoor tracking, the WiFi can be used (MAC address can be tagged to identify a familiar environment) [OY]. Healthcare is also an important domain of application [HM14]. Context aware applications can also help a group of user by collecting their preferences from social network and improve social interaction [AB10].

3.2 Structure of a context-aware application

Applications which adapts to the context in which they are used is an interesting concept for improving the experience of one user. In [MDL09], Context Aware adaptable Applications are introduced. For such applications two different paradigms exist :

- **Self adaptive application** refers to applications able to capture the context and modify their behaviour. The activity of the application can also participate in the modification of the context, making the whole system working in nested loops. In such a paradigm, there is no separation of concerns between capture of the context and adaptation, which makes maintainability and the evolution of the application more difficult.

- **Supervised adaptation** relies on a platform inserted between the application and the context. The architecture of the system is the following :
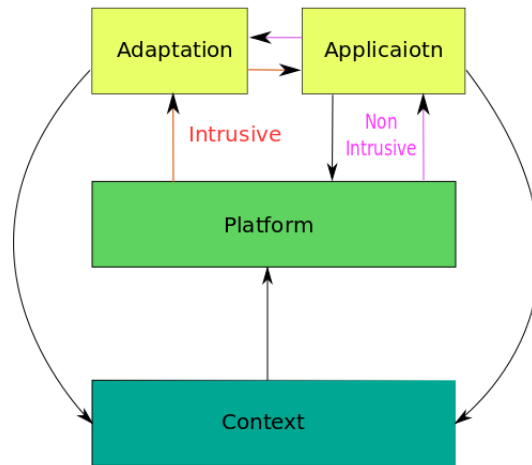
Figure 3.1:   Supervised adaptation

A platform accesses to the context and allows the application to consult it.
In such a system both the platform and the application are adaptable. The
platform can participate to the adaptation process in two different ways :

- **A non intrusive way** : The platform monitors the context and send
  notifications to the application and the latter performs its adaptation
  itself.

- **An intrusive way** : The platform monitors the context and modifies
  the application. These modifications are monitored by the application.

3.3   Overview of existing technologies for user experience and navigation

Context-aware applications for navigation usually rely on several sensors for detect-
ing the position of the user (GPS), the orientation of the device (accelerometer)
and street maps data. In [FL15] an adaptive user interface model to predict one
user's intent effectively with their spatial experience is introduced. The proposed
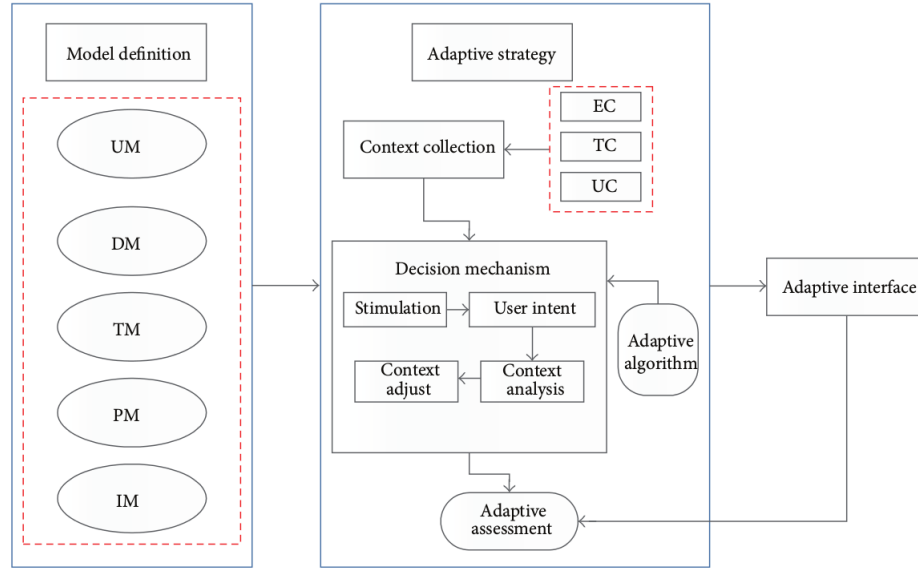architecture is the following :

Figure 3.2: Context adaptive user interface

The model definition contains the user model, the task model, the interaction model, the domain model, the environment model and the presentation model. The adaptive strategy consists in identifying one user's interaction patterns and predict dynamically the most likely future actions on the UI. This requires a storage of interaction patterns and the use of one machine learning algorithm.

Smartphones are carried by an user all over the day, making them an interesting tool for human activity recognition. In [SSES14] a pedestrian navigation system that is aware of user's activity and device's position is introduced. Sensor fusion is done at multiple level in order to achieve different goals :

- The sensor level is well suited for location determination.

- The feature level is robust in identifying the user activity, but not reliable for the device orientation and the position.

- The decision level can be combined with the feature level to cope with the problem of device's orientation and position identification at the feature level.

The navigation system combines GPS and video data by using a Kalman filter. The GPS provides the position, while the velocity between two frames is computed with a computer vision algorithm. In the Kalman filter, a scale factor depending on the user activity's is used to compute the new position.

In [HM14] a context aware mobile application architecture model for health care system is introduced.
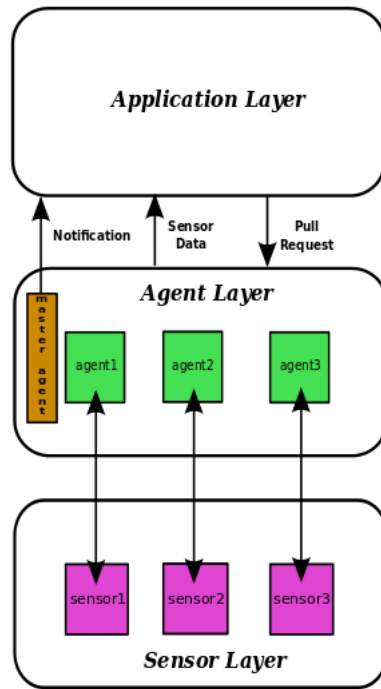
Figure 3.3:   Context aware mobile application architecture

- The sensor layer contains physical and virtual sensors

- In the agent layer, one agent is associated to each sensor. Agents decide whether sensor data should be sent to the next layer depending on a threshold. One agent is also responsible for sending notifications to one observer.

- In the application layer, data can be pull when notifications are received. The application is registered to certain agents which can send notifications.

This architecture offers flexibility, it can be used regardless of the type of sensors (two requirements from [RCAdR]). It is also interesting for its energy efficiency, some data which are not giving new context information won't be further processed. This architecture was used for patients suffering from diabetes or heart disease. The solution uses heartbeat sensor, blood pressure sensor, blood sugar volume sensor, HDL LDL volume sensor. The implemented architecture decides whether an ambulance should be called by using a regression model (in the application layer).

Context-awareness also serves social situation. In [SSES14] mobile data (data from smartphones, accelerator, location), sensor data (from fixed sensor network) and social data (from social network) are fused together. This approach allows to take

one user's preferences as input for the fusion, which can enhance the daily experience of one individual or a group of individuals by suggesting recommendation (music,movies, etc). The key challenges of such an application are :

- **Data managing** : The data is coming from three different sources, it has to be managed in real time and the data size can be huge.

- **Data mining** : The pattern analysis is an incremental process, new data has to be integrated to previously discovered patterns or to be used for the creation of new patterns. These patterns are combined with real time data to propose the appropriate recommendation.

- **Privacy** : This kind of application heavily tracks the user in its everyday life. To preserve privacy, the authors chose a modified version of the K-anonymity problem : "Given a partial release of data from a private data set, wherein all data is quasi-identifiable, the released data must map to at least k distinct sets of individuals within the data set".

3.4 Challenges and future trends

Although actual mobile phones have good computational performances and robust sensors, making them an interesting tool for context sensing and context inference, they are still many challenges which need to be faced. The most important one is the power consumption. Sensing data and making computations in real-time consume a lot of battery.
In order to face with this problem, several approaches are possible :

- Work in [OY] suggest to compress the data, which helps in reducing the amount of data to be processed on the phone or transferred to further location.

- A new trend consists in using mobile cloud [NG15], this is motivated by the limitation of processing power and data storage in mobiles devices. Computationally expensive and resource demanding tasks are tansferred to the cloud, but this requires an always on connectivity, which is also power consuming. In [OY] the authors also pointed out that with a cloud architecture security threats can happened at multiple levels (application level, web lebel, network level, physical level).

- Another research area is in the framework design [OY], a balance has to be found between accuracy in context-sensing and power consumption during data processing. The framework of the future should decrease the amount of redundant computational operations (via basic signal processing) by not letting go further power consuming processing of data which are not bringing new changes in the context inference.

4 Context-awareness in rehabilitation devices

4.1 Motivation

Home based rehabilitation is an interesting trend for elderly people or for people suffering from physical injuries. The recent technological advancements enables a very modern home-based rehabilitation which is supervised by the therapist at distance [AK14, THL13]. Simpler systems which are working with animatronic biofeedback can also be used for the elderly [BG15], who might be scared with complicated virtual games applications for rehabilitation purposes.
Case study carried out with both of the approaches [AK14, THL13, BG15] have shown an increase in the motivation of the patient while performing the exercises.

4.2 Contextually adaptive home-based rehabilitation framework

Home based rehabilitation requires a sensing of the patient while performing the exercises, the therapist should also have access to these data to adapt the treatment if necessary. In [AK14] a framework for home-based rehabilitation is introduced. The framework is taking the performance of the patient into account while playing virutal reality games, but also the psychological and the environment conditions.
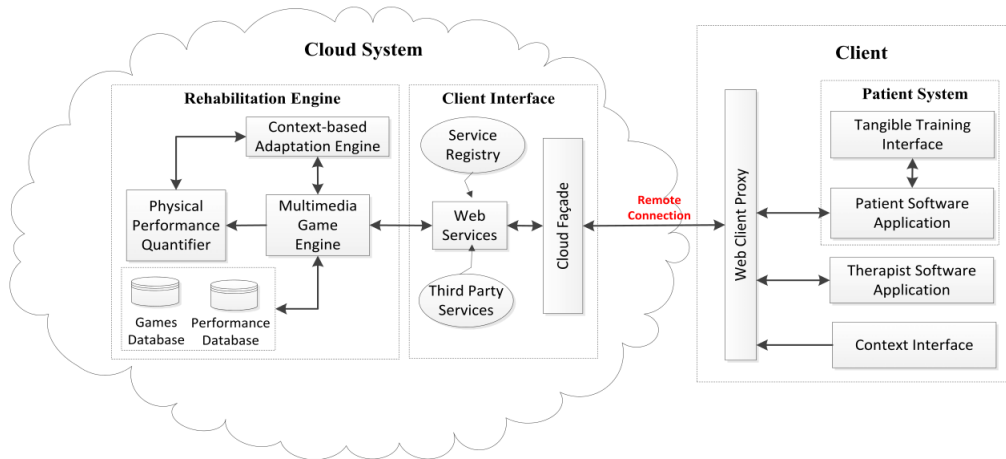

Figure 4.1: [AK14]Contextually adaptive home-based rehabilitation framework

The client part serves the patient and the therapist. From the therapist's perspective, the framework is helping by giving a record of the performances of one patient, but also its physiological and psychological state. These data help the therapist in

customizing the adaptation of the virtual exercises. This model also enables the therapist to select the context parameters that may affect the patient and define their correlations with the patient's ability to perform a task. From the patient's side, it is possible to check information concerning the treatment plan and select the exercises prescribed by the therapist. The system also includes a cloud consisting of a client interface and a rehabilitation engine. The rehabilitation engine analyses all the performance data and adjusts the gaming engine depending on how well the exercises are performed. The context based adaptation engine controls the intensity level of the tasks.

4.3   Overview of existing technologies for home-based rehabilitation

In [BG15] a home-based rehabilitation based on animatronic biofeedback is proposed. The system relies on sensor, a context-aware mobile application and a robot, whose movement indicate how well the exercise was performed. The application sends command to move the robot when biofeedback is required. This solution is cheap in comparison to existing systems based on audio feedback, and easier to understand for the elderlies. The sensors used for this system are the electromyograph, which provide a direct measurement of the recruitment of one or several group of muscles and the accelerometer for biomechanical assessment. The muscle contraction is detected with one processing block (filtering of the signal and computation of the envelope of EMG signal) and one decision block. The output value is compared with a threshold, defined as a percentage of the maximum voluntary contraction. Authors from [THL13] proposed a home based-rehabilitation framework for spinocerebellar ataxia patients. While performing the exercises at home, the system measures the motion of the patient through a camera, its balance (foot pressure capture + computation of the centre of gravity and centre of pressure) and compare it with the data stored in a template database. When necessary, the therapist could be notified that providing feedback to a patient is necessary and interact with him through VOIP. A therapist can follow the exercise session of six patients simultaneously. Feedback is also provided to the patient through virtual game scenario and virtual coach instructions.

4.4   Body Sensor Network

Body Sensor Network consists in interconnecting sensors on the human body in order to take measurements or perform actions. By introducing context-awareness in Body Sensor Network, environmental factors and the state of patient can be evaluated [KK07, KK10]. Context-awareness is achieved with the mapping of sensory data with existing context profiles through classification algorithms. In most cases, this requires a training phase in order to build the context profiles. [KK07, KK10] listed requirements needed for context-aware Body Sensor Network :

- The system has to be noise resilient, therefore the context retrieving algorithm has to be able to detect noise in raw data and reduce its effect.

- The system has to learn new contexts and keep a record of the previous one encountered.

- Features selection has to be used in order to have an efficient data mining.

The following table lists the classification algorithms usually used in Body Sensor Network with their advantages and drawbacks.

Classification algorithm	Advantages	Drawbacks
Artificial Neural Network	Noise resilient	May not remain adaptive over time(KSOM without clustering)
	Can perform on-line learning without user intervention	Scalability problem for real-world scenarios
Bayesian Network	(Naïve Bayse) Computationally efficient	Not exhaustive in objects and relations representation (real-world applications)
	Allows features selection	Require a training phase to classify activities
	Can reduce power consumption (feature selection)	
Hidden Markov Model	Smoothness	Can be computationally expensive
	Can recognize sequence of activities	A training phase is necessary
	Can handle noise	Can confuse events if the trained model is too general

4.5 Challenges and future trends

One interesting research topic is the detection of the emotional state of the patient while performing the rehabilitation exercises. Channels that can be used are audio, face and body gesture, internal physiological state. In [JJ15], the author investigates the possibility to recover tiredness, tension, pain and satisfaction by analysing the kinematic and pressure exerted upon a gripping and the facial expression of the patient. To analyse the data properly, a synchronization is necessary between the video frames and the pressure measurement. Several features are then used as inputs for a classification algorithm (here support vector machine). According to specialists, it is difficult to label tension and pain.

5 Conclusion

The technical progress in mobile phones allow an efficient use of sensor fusion for ubiquitous computing. The sensor fusion middleware proposed in the literature enables a splitting between the sensors layer and the inference layer, offering a separation of concerns. Ontologies are the most spread technique for context modelling. Context data can be fused at three different levels : The sensory level, the feature level and the decision level. Knowing at which level context data should be fused depend on the kind of fused data we want to obtain. The feature level is well suited for activity recognition because of its learning capabilities, at the decision level it is possible to introduce one user's preferences.

Existing context-aware applications for user navigation recognizes user position at the sensory-level fusion, activity recognition can be performed at the feature-level fusion and the decision-level fusion. Such applications relies on maps stored on the phone and sensors such as the GPS, accelerometer, gyroscope, magnetometer and camera to improve one user's experience Smartphones can also be used to monitor one's patient physiological data and call an ambulance if necessary.

Context aware applications can not only improve one user's experience, but also the experience of a group of individuals by incorporating data from social networks in the fusion process. Energy awareness, robust data acquisition and finding a balance between accuracy during context-sensing and power consumption during data processing are remaining challenges in the development of context-aware applications. An emerging trend to face the energy and storage problem is mobile cloud computing. In such a paradigm expensive computations and resource demanding tasks are transferred to the cloud, but this required an always on connectivity.

Modern solutions offerings context-awareness in home-based rehabilitation are achieved by using a client-interface which serves both the patient and the therapist and a cloud interface for adapting the rehabilitation exercises depending on the patients performances.

Body Sensor Network are also taking advantage of context-awareness. Three learning algorithms paradigms offerings noise resilience are widely used (Artificial Neural Networks, Bayesian Networks, Hidden Markov Models) .One current research topic in home-based rehabilitation is to look for solutions enabling an efficient detection of the emotional state of the patient while performing the exercises.

List of Figures

Bibliography

[AB10]   Xinyu Xing Richard Han Qin Lv Shivakant Mishra Karim Seada Aaron Beach, Mike Gartrell. Fusing mobile, sensor, and social data to fully enable context-aware computing. *Proceedings of the Eleventh Workshop on Mobile Computing Systems and Applications*, (1):60–65, 2010.

[AC14]   Cristian Axenie, Jorg Conradt, Cortically inspired sensor fusion network for mobile robot egomotion estimation, Special Issue on "Emerging Spatial Competences: From Machine Perception to Sensorimotor Intelligence", 71:69-82, 2015.

[BG15]   José Guerreiro Luis Gardeazabal andJulio Abascal Borja Gamecho, Hugo Silva. A Context-Aware Application to Increase Elderly Users Compliance with Physical Rehabilitation Exercises at Home via Animatronic Biofeedback. *Journal of Medical Systems*, (39):1–11, 2015.

[CQ09]   Alberto Capurro and Rodrigo Quian Quiroga. The Neural Correlates of Perceputal Awareness. pages 1–10, 2009.

[CT04]   Gemma A. Calvert and Thomas Thesen. Multisensory integration : methodological approaches and emerging principles in the human brain. *Journal of Physiology*, (98):191–205, 2004.

[EMM08] Jesus Garcia Enrique Marti and José M. Molina. Adaptive sensor fusion architecture through ontology modeling and automatic reasoning . *Information Fusion (Fusion), 2015 18th International Conference on*, (18):1144–1151, 2008.

[FL15]   Jiangfan Feng and Yanhong Liu. Intelligent Context-Aware and Adaptive Interface for Mobile LBS. *Computational Intelligence and Neuroscience*, (2015):1–10, 2015.

[GW06]   Ashish Godbole and Waleed W.Smari. Human Perspective Based Context Acquisition, Learning and Awareness in the Design of Context Aware Systems. *Military Communications Conference, 2006. MILCOM 2006. IEEE*, pages 1–8, 2006.

[HM14]   Hussein Hazimeh Jihad Nairn Mohamed Alameh Hamid Mcheick, Hassan Sbeity. Context aware mobile application architecture (CAMAA) for health care systems. *Humanitarian Technology Conference - (IHTC), 2014 IEEE Canada International*, (1):1–5, 2014.

[JJ15]   L.Enrique Sucar Lorena Palafox Jorge Hernández-Franco Jesús J.Rivas,
           Felipe Orihuela-Espina. Detecting affective states in virtual rehabilita-
           tion. *Pervasive Computing Technologies for Healthcare (PervasiveHealth)*,
           (9):287–292, 2015.

[Kan01]   Nancy Kanwisher. Neural events and perceptual awareness. *Cognition*,
           (79):89–113, 2001.

[KK07]   Barbara T. Korel and Simon G. M. Koo. Addressing Context Awareness
           Techniques in Body Sensor Networks. *Advanced Information Networking
           and Applications Workshops*, (2):798–803, 2007.

[KK10]   Barbara T. Korel and Simon G. M. Koo. A Survey on Context-Aware
           Sensing for Body Sensor Networks. *Wireless Sensor Network*, (2):571–583,
           2010.

[MDL09]   Philippe Roose Marc Dalmanu and Sophie Laplace. Context Aware
           Adaptable Applications - A global approach. *IJSCI International Journal
           of Computer Science*, (1):13–25, 2009.

[NG15]   Amit Agarwal Neha Gupta. Context aware Mobile Cloud Computing:
           Review. *Computing for Sustainable Global Development (INDIACom),
           2015 2nd International Conference on*, (1):1061–1065, 2015.

[OY]   Zhengguo Sheng Victor C. M. Leung-Wilfrido Moreno Kin K. Leung
           Ozgur Yurur, Chi Harold Liu. Context-Awareness for Mobile Sensing
           : A Survey and Future Directions. *Communications Surveys and Tutori-
           als,IEEE*, 1(99):1–28.

[RCAdR]   Thiago Senador de Siqueira Ricardo Couto A. da Rocha, Markus Endler.
           Middleware for ubiquitous context-awareness. *Proceedings of the 6th in-
           ternational workshop on Middleware for pervasive and ad-hoc computing*,
           1(6):43–48.

[SSES14]   Adel Moussa Sara Saeedi and Naser El-Sheimy. Context-Aware Personal
           Navigation Using Embedded Sensor Fusion in Smartphones. *Sensors*,
           (14):5742–5767, 2014.

[THL13]   Rong-Rong Chen Ya-Ling Chen Tung-Hung Lu, Hsing-Chen Lin. Motion-
           Sensing Based Management System for Smart Context-Awareness Reha-
           bilitation Healthcare. *Advances in Internet of Things*, (3):1–7, 2013.

[VGM12]   Nesrine Mezhoudi andJean Vanderdonckt Vivian Genaro Motti. Machine
           Learning in the Support of Context-Aware Adaptation. pages 1–4, 2012.

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