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A System for Inference of Spatial Context of Parkinson's Disease Patients

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Abstract. This work proposes a concept for indoor ambulatory monitoring for Parkinson's disease patients. In the proposed concept, a wearable inertial sensor is kept as the main monitoring device through the day, and it is expanded by an ambient sensor system in the specific living areas with high estimated probability of occurrence of freezing of gait episode. The ambient sensor system supports decisions of the wearable sensor system by providing relevant spatial context information of the user, which is obtained through precise localization.

Keywords. personal health system, Parkinson's disease, indoor localization, data fusion, context awareness, 3D perception

Introduction

Freezing of gait (FOG) is one of the most disturbing and least understood symptoms in Parkinson's disease (PD). According to [1], FOG is defined as:

> An episodic inability (lasting seconds) to generate effective stepping in the absence of any known cause other than parkinsonism or high-level gait disorders. It is most commonly experienced during turning and step initiation but also when faced with spatial constraint, stress, and distraction. Focused attention and external stimuli (cues) can overcome the episode.

FOG is difficult to measure and it depends on the mix of external and internal factors such as surrounding environment, cognitive load and the current medication level. In [2], four types of contextual aspects influencing onset of FOG were presented:

- **Situational aspects.** FOG occurs on turns, start of walking, in narrow spaces, upon reaching the destination and in open spaces.
- **Local aspects.** FOG occurs at the same location every day.
- **Cognitive aspects.** FOG can be influenced by cognitive load, stress, anxiety, depression.
- **Physiological aspects.** FOG is characterized by shortened stride length, higher gait speed and increase in heart rate prior to freezing.

The best up to date example of an existing wearable system for automatic assistance to people with FOG is the system developed at ETH Zurich [3]. This system uses an inertial sensor (worn on waist, shank or upper leg) to observe motor symptoms

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of the patient, and upon recognition of the onset of FOG, it gives audio cueing feedback via headphones. This system did not address any other contextual aspects of FOG.

REMPARK [4] (Personal Health Device for the Remote and Autonomous Management of Parkinson's Disease) is an ongoing three and a half year project funded by the European Commission. The ultimate goal of the project is to develop a Personal Health System (PHS) with closed loop detection, response and treatment capabilities for management of PD patients. An important part of the final solution is the possibility to detect and act on FOG episode. To enable more precise and robust FOG detection algorithms, we want to take into account additional contextual aspects of the phenomena.

In this paper, we present the concept for a system able to infer spatial context of FOG patients in their home environment. The proposed system uses ambient sensors to expand sensing capabilities of our REMPARK wearable system.

1. Wearable Monitoring System

The REMPARK system is envisioned to offer support to PD patients on two different levels of interaction. At the first level, the wearable monitoring system will directly interact with the patient through real-time detection of disease symptoms and closed-loop automatic response by means of automatic gait guidance or medication injection. At the second level, the data provided by the first level, will be aggregated on the server of the relevant health service provider in order to enable patient's neurologist to regularly follow the evolution of their disease in a more effective manner. The latter would allow for medication treatment to be adapted based on the objective quantitative observations.

1.1. Body Area Network

Sensing components of the wearable monitoring system include two inertial sensor units. The waist sensor is used for the identification of basic movement related parameters such as posture, stride length and gait speed. The task of the wrist sensor is to detect symptoms of tremor and dyskinesia. Possible actuators are an injection pump for drug delivery, the auditory cuing system and a Functional Electrical Stimulation (FES) system. The FES actuator can be used both as a haptic cueing system, and as a step initiating device in the case of a detected FOG episode.

The smartphone is acting as the main control and communication unit of the whole Body Area Network (BAN). Furthermore, a smartphone is used as the main input device for providing necessary context information. Examples of context information retrieval are accessing outdoor location (via GPS), or acting as a user interface collecting patient's input (especially relevant for the non-motor symptoms). The phone device is not intended to be used as a wearable sensor, which means that it does not have to be fixed on the body of a user.

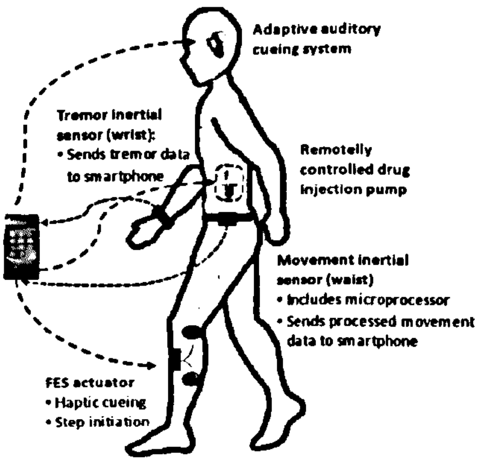

Figure 1. REMPARK BAN.

1.2. Acceptability and Usability

Reduced numbers of sensors and actuators and their reduced size will allow the system to be completely wearable. It is essential for patients not to feel stigmatized when wearing a personal health device. That is the reason why some other PHS have failed in winning the acceptance of PD patients. The expected sizes for the sensors are: 8 x 4 x 2 cm for the waist sensor (a light box to be worn on the belt), and 3 x 3 x 1 cm for the wrist sensor (similar to a watch). The auditory cueing system will only need a wireless Bluetooth headphone, while the FES system will be designed as a garment device to be worn on each leg. The subcutaneous injection pump, when used, would be a commercial one provided with telecommunication capabilities.

The presented wearable system is designed as modular. The combination of system components for each prospective user depends on his most prominent symptoms and a level of advancement of the disease. The intensity of the same symptom of PD often differs from person to person, resulting in the fact that PD is never manifested in exactly the same way for two different people. Furthermore, PD has different stages of progression, and it might not be required from the user to wear all existing components of the wearable system at once. In the early stage of PD, it might be sufficient to wear only one inertial sensor with a goal of collecting general long term information for better therapy management. This would give the person enough time to adapt to the notion of using a wearable system, which would then make it easier for them to accept additional system components as they become necessary in the later stages of the disease. FOG is the symptom which is characteristic for the advanced stage of PD. A suitable wearable system setup adjusted for FOG treatment would be a combination of the sensor at the waist along with one of the cueing devices.

2. Spatial Context Augmentation

Spatial context has high importance for detecting FOG, especially in everyday home environment. To fully estimate situational and local contextual aspects, the ideal system needs to have a possibility for precise indoor sub-meter localization.

Furthermore, it also needs to be able to track the changes in the environment, like the changes in the position of different pieces of furniture.

Sensor setup of the REMPARK wearable system does not support acquisition of necessary data for precise estimation of patient's location. Inertial data can be used only for short-term relative localization. To enable observation of the environment and absolute localization, we plan to use visual sensors capable of sensing both color and depth (i.e. MS Kinect, Asus Xtion). We propose the deployment of visual nodes in a non-overlapping mode through the patient's home, with cameras targeting the critical areas in terms of FOG occurrence. We call this concept Spatial Context Augmentation for Wearable Health System.

The block diagram of the general framework given in Figure 2 presents the main system components, along with the information flow between them. System components inside the blue full line represent the REMPARK wearable monitoring system. The components inside the red dashed line represent Spatial Context Augmentation system.

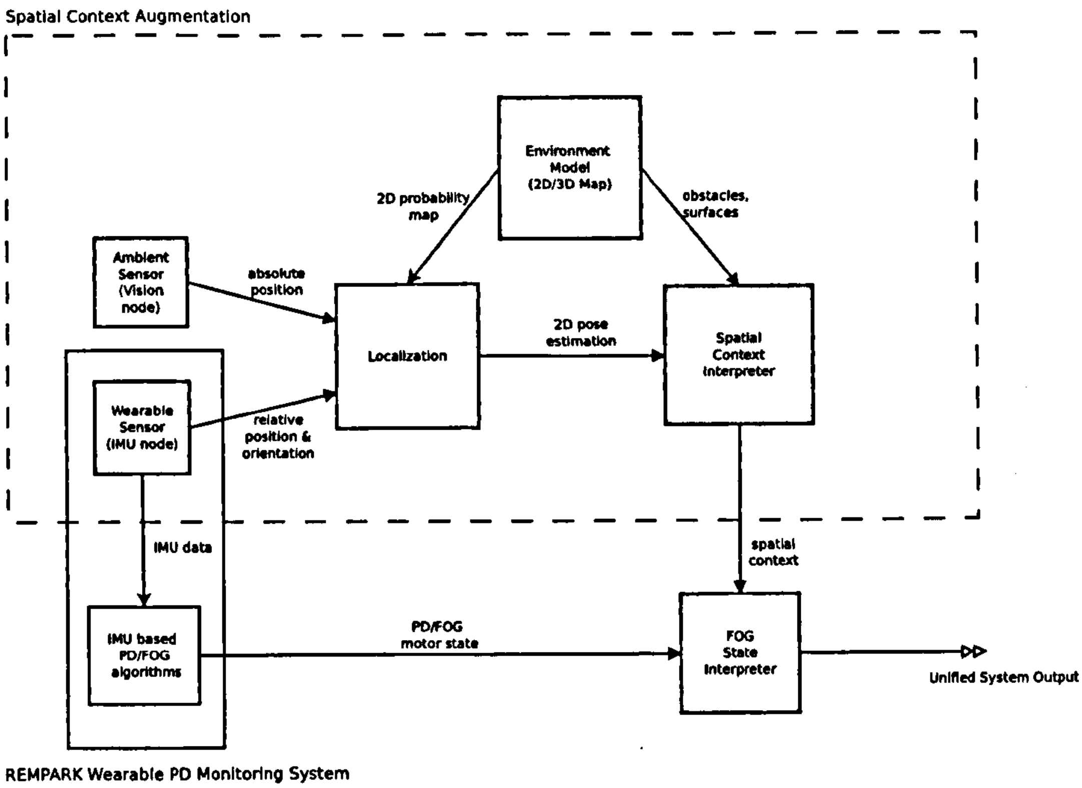

Figure 2. Wearable Monitoring System with Spatial Context Augmentation.

The Environment Model module contains a full three-dimensional (3D) model of the observed home space. The initial model is built at the system installation time by manual scanning [5], and it is maintained through periodic updates from vision nodes during system operation. Model data is updated when there are no tracked objects in the scene covered by a vision node. The Environment Model module has multiple roles in the system. First, updated depth image of the scene is used in the background subtraction process of the vision node trackers. Furthermore, 3D model is transformed into 2D floor-plan with calculated likelihood of walking at each coordinate of the floor grid. This probability map is then fed into the Localization module as an a priori probability. Lastly, Environment Model module segments full updated 3D model of the scene into horizontal and vertical elements, which represent floors, walls and pieces of furniture, and sends them to Spatial Context Interpreter for further processing.

Bayesian approach to sensor fusion is used for solving localization problems in Spatial Context Augmentation system. Particle filtering is used to combine a priori knowledge coming from the environment map and human movement models, with observations coming from visual and inertial sensors. Visual sensor provides likelihood of the patient position directly in the global frame of reference, while wearable sensor provides similar information by measurement in its own relative frame of reference. Correspondence between visual and inertial data is used for patient identification in a multiple non-overlapping visual node system.

Properties of the environment relevant to FOG, like obstacles, corners and narrow passages, are inferred in Spatial Context Interpreter module. These properties are given significance according to the specific influence they have on the observed patient. This is an adaptive component of the system. Inferred significance of environmental properties is then combined with estimated location of the patient, in order to produce the probability of his current spatial context to induce FOG episode.

FOG State Interpreter conducts high level probabilistic fusion of wearable system output with spatial context system output, in order to produce unified FOG detection.

2.1. Support Research of FOG

Similar to the REMPARK wearable system, the Spatial Context Augmentation system is envisioned to act on two levels. The first level is direct enhancement of the detection possibilities of the wearable system through additional context information, which was presented in this text so far. The second level of functionality is helping FOG patients on a broader perspective, through the collection of the data for the research of underlying causes of FOG.

The researchers who study FOG usually do clinical tests with the patients, and they need to come up with different ways to induce freezing episodes. Clinical environments are not people's natural environment, and their freezing episodes do not happen on the artificial polygons in the same way as they would happen in their homes. In the latest report on the state of FOG from August 2011 [6], it was stated that the lack of the data from home environment is one of the major problems in research of FOG phenomena.

Having cameras in a home environment to observe the areas where FOG most frequently occurs could give the necessary data. There are two main problems with having cameras to constantly record raw long-term visual data in the home environment for research purposes. The first problem, on the part of the observed person, is substantial privacy invasion because all collected video data has to be examined by other people. The second problem, on the part of the researcher, is that there is just too much data to be viewed and analyzed.

The standard technique for long-term video sensor use in Pervasive Healthcare Environments is to use on-node image processing, without recording raw visual data or sending it over a network. If the raw video recording of the scene for research purposes is done only when the person in the camera range is identified as the target PD patient, and when the system detects that there is a FOG episode, we can expect significant reduction in the amount of visual data that has to be viewed by the researchers. Furthermore, since the recording triggers only during walking action inside previously determined space, the privacy concerns would be reduced by excluding the possibility of recording video of all other, more private types of actions. We believe that the proposed concept which employs wearable sensors, color video and 3D perception could help researchers to get deeper insight into interaction between motor, visual and spatial symptoms of FOG, and help the research of its underlying causes.

3. Conclusion

In this paper we presented a concept for a system that should be able to infer spatial context information of Parkinson's disease patient, and use that information for improved detection of FOG symptom. In the spatial context analysis, we go beyond localization, as we are also trying to take into account characteristics of the surrounding home environment. From the pervasive healthcare environment we expect to be able to infer about spatio-visual context of the person experiencing freezing of gait. This kind of approach requires the ability of three-dimensional perception of space, so it relies heavily on the newest developments in 3D computer vision algorithms and recent availability of affordable range sensors.

REMPARK project started in November 2011 and currently both the wearable system and the spatial context augmentation system are in the prototyping phase.

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