UbiSpoon: Pervasive Monitoring of Nervous System Diseases through Daily Life

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Abstract
Nervous system diseases may affect a person's sensation, movement, and gland or organ functions. Various clinical scales have been developed to measure motor functions of patients, but most existing test methods are time-consuming, limiting their application for mass subjects. We present UbiSpoon, a pervasive system design for monitoring of activities of people potentially suffering nervous system diseases. Our design demonstrates the potential to be integrated into patients' everyday tasks. Also, we adopt an assisted data channel for the sake of segmenting activity sequence and identifying tremor type for further analysis.

Author Keywords
Healthcare; ubiquitous computing; nervous system diseases; motor ability; motion capture

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Nervous system diseases, such as Parkinson's disease (PD), Stroke, and Huntington's disease, are common

diseases that cause motor and mental impairments, which are usually followed by serious symptoms and consequently lead to high death rates. To detect such diseases, various clinical scales have been used to measure motor functions of potential patients. The widely used tests include the Action Research Arm Test (ARAT), the Wolf Motor Function Test (WMFT), the Function Ability Scale (FAS), and the Fugl-Meyer Assessment (FMA). However, these tests generally consume considerable amount of time for completion. Also, they often require the presence of clinical experts during the whole process for a test to observe and rate a subject's activities.

To improve the efficiency of testing and reduce the work-load of clinical experts, we develop UbiSpoon, a pervasive computing system, for people potentially suffering nervous system diseases. This test can be integrated into a person's daily life, collect motion data from the person, and segment relevant data for future analysis. The system is designed to achieve non-intrusive monitoring through tracking and sensing everyday tasks intelligently, in our case, the use of the spoon. Our design also allows the collection of important motion data of people from their daily activities performed in their familiar, more natural living environments, rather than from artificially designed activities conducted in a clinic or a hospital, an environment that may make people uncomfortable.

In this paper, we offer two main contributions: a design of an integrated spoon-ball hardware system and a well-designed activity sequence segmentation methodology for the purpose of analyzing different kinds of nervous system diseases. The hardware system aims to sense daily activities (e.g. using a spoon for scooping) as well as to collect data during this process. Also, given that different nervous system diseases own their particular tremor characteristics (e.g. resting, posture, etc.), the segmentation methodology separates the incoming data stream into subsequences that reflect distinct tremor types and makes it possible for future analysis.

Related Work

This work particularly pertains to activity sensing with sensors and nervous system diseases inspection.

Activity Sensing

Recognizing user activity via wearable sensors has long been studied. Massive research has been done by using different types of sensors and different modeling approaches. Accelerometers [9] are probably the most frequently used sensors, because of their capability to recognize simple and repetitive body motions. Currently, biosensors, such as electromyography (EMG) [3] and electroencephalogram (EEG) [5], become increasingly popular in the activity sensing field. Now, researchers are interested in using sensors in existing gadgets, such as smart phones [4], to assist activity recognition. However, these research works require special external devices, and most of these devices are expensive and inaccessible for most the time.

Nervous System Diseases Inspection

Various diseases causing movement disorders have been targeted by researchers, mostly Parkinson's disease [6], but also including post stroke [2] and autism spectrum disorders [1]. One group studied both normal people and people with upper body physical difficulties. They measured and described motor capabilities of IT equipment users and found that some people who with same disease got much different scores [7]. However, in these works, they solely address inspection itself and leave behind the idea to develop always accessible and pervasive inspection methods.

While previous research has addressed user activity recognition and inspection of nervous system diseases via different methods, we consider that building a pervasive sensing system to sense user's activities and to collect data for inspection analysis would be a promising idea to enable pervasive and intelligent inspection for individuals.

System Design

Design Properties

Unobtrusive Instrumentation. Currently, when taking function assessment tests, people are asked to perform tasks with some facilities that exist exclusively in clinical environments. To enable truly pervasive and non-intrusive monitoring in daily life, we need a test that is simple and natural for users to perform. Thus, we adopt spoon as the primary sensing element for activity recognition, as spoons are easily accessible and widely used in daily life. This approach incorporates monitoring of nervous system diseases into everyday tasks.

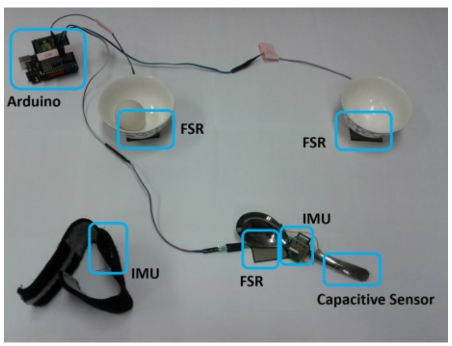

Figure 1. Hardware design of UbiSpoon.

Dual-Data Channel. We create two data channels, a primary one and an assisted one. The primary channel is used for collecting the IMU data that reflects tremor. Data from peripheral sensors is streamed in the assisted channel to contribute to the segmentation of activity sequence and future analysis concerning tremor categories.

Hardware Design

Our proof-of-concept system consists of three principal components. The first one is the spoon appropriated as a sensing element and the primary data input channel. An Arduino-based capacitive sensor with analog output is attached to the spoon to not only detect touch, also distinguish different touch gestures (e.g. pinch, grasp, etc.). We also attach an IMU module on the handle to collect data regarding movement of the spoon. The IMU module contains a tri-axis accelerometer (MMA7455L by Freescale Semiconductor, range: ±8g, sensitivity: 0.01563g) and a tri-axis gyroscope (ITG-3200 by InvenSense, range: ±2000°/s, sensitivity: 0.06957°/s). Data is transmitted via Bluetooth (RN-41) at 115200 Bd.

The second component is a wristband with an IMU module sewed in. It adopts the identical modules of IMU and Bluetooth to read and transmit data respectively. The IMU data on this component is used to collect data concerning movement of the wrist instead of the manipulating object, designed to gather sufficient data to construct a comprehensive data set for disease analysis.

The last component is an integrated sensing environment with Force-Sensing Resistors (FSR406 by Interlink Electronics, range: 0.1-10kg, resolution: 0.5% of full scale) to monitor pressure changes. In our prototype system, we incorporate two bowls and a rubber ball into the environment to imitate the tasks performed in daily life. Two FSRs are attached at the bottom of the bowls to measure pressure change inside the bowl. We also install one on the surface on which the spoon is placed, for the purpose of sensing force change when picking-up/dropping down the spoon. All sensors introduced in this system are sampled at a frequency of 512Hz (See Figure 2).

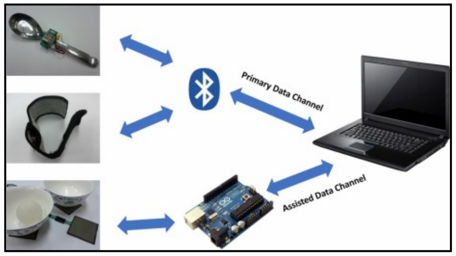

Figure 2. Primary data channel vs. assisted data channel.

Data Channels

- Primary Data Channel

The primary data channel collects the data that is used for future analysis of details regarding tremor. Since IMU modules are ideal for measuring and reporting parameters concerning movements (such as velocity, orientation, etc.), and nervous system diseases are generally accompanied by movement disorder that affects motor abilities, we collect data from both IMU modules for future analysis of tremor status.

- Assisted Data Channel

Although tremors are the most common type of all involuntary movements associated with nervous system diseases, they can be further assessed and classified into four categories (resting, contraction, posture, and intention tremors) by which position most accentuates the tremor [8]. Different diseases have their own characteristics of tremors. For instance, tremors are worse at rest for Parkinsonian syndromes and at intention for stroke and Guillain–Barré syndrome. Thus, in addition to collect motion data, it is also important to extract tremor features from the data so that further analysis can be conducted to identify what type of nervous system diseases a user may suffer. To prepare a future analysis to achieve this, we add an assisted data channel for segmenting the action sequence as well as marking each sub-sequence with a specific tremor category in the future.

Figure 3. A volunteer is participating in the preliminary study.

The assisted data channel consists of incoming data streams from all sensors other than the two IMU modules in our system, i.e. the FSRs and the capacitive sensor. The segmentation is achieved by recording the time node upon the trigger of specific sensor events, including measurements dropping down/going up to certain values. Both of the data channels are demonstrated in Figure 2.

Preliminary Study

We conduct a preliminary study to investigate the potential of our system in collecting and segmenting incoming data stream for both patients and normal people. Specifically, we want to obtain the data from the additional channel and wish to observe prospective patterns for data segmentation.

Participants

Study was conducted in a small village near Beijing, China. Participants volunteered to contribute to the data collection when a local hospital was conducting an epidemiological investigation. We collected data from 300 participants (83 males and 217 females), and the average age of volunteers is 58.55 years old. Sixteen of them reported nervous system diseases symptoms/histories, accounting for 5.3% of the total sample.

Tasks/sub-actions

To prepare for the eventual understanding of how the system works in an opportunistic manner, we designed a unified task for all participants to perform for the current phase, which imitates the tasks performed in daily life. This prescribed activity sequence helps us comparing patterns from additional channel between individuals to observe potential patterns for data segmentation. A participant was provided with the following instruction:

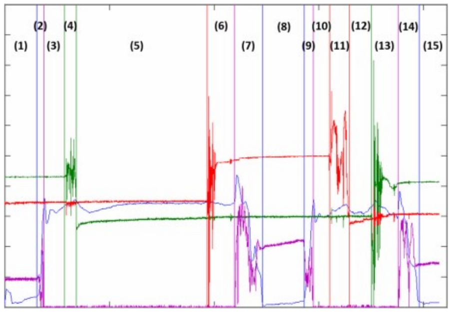

Figure 4. Data from assisted channel for normal people.

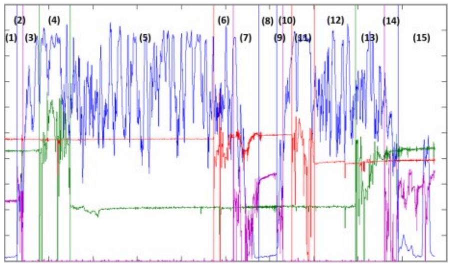

Figure 5. Data from assisted channel for people suffering from nervous system diseases.

1. Sit in front of the desk and relax.
2. Use the dominant hand to pick up the spoon.
3. Reach the left bowl to scoop the ball inside.
4. Move the spoon with the ball from left bowl to the middle of two bowls and hold it for 10 seconds (designed for tracking resting tremor).
5. Reach the right bowl and drop the ball inside.
6. Move the empty spoon to the original position.
7. Put the spoon down.
8. Repeat step 2 to 7 in reverse direction, i.e. scoop the up ball from right side and drop it in the left ball, without hold if for 10 seconds.

Procedure and Measurements

To help them to get familiar with the study process, participants were given a trial under the instruction of a system designer. Also, a note with detailed description of the process was attached by the table to inform the participants about the next step to take (See Figure 3). The system designer was always at present in case the participant lost the idea about how to perform the task. Each participant was required to complete a whole process once he or she finished the trial. Data from all the sensors (three FSRs, two IMUs and one capacitive sensor) was recorded during the complete process.

Preliminary Findings

Our preliminary result suggests that the assisted sensor data collected during the study could be classified into exactly two categories by their very unique representations: the trivial and the patient's. Figure 4 and 5 illustrate two typical data plots from assisted channel of tests taken by a normal people and a patient. The purple, green and red signals are FSR measurements from under the spoon, the left and the right bowl respectively. The blue signal is the measurement from the capacitive sensor.

Through the figures, we observe that the patterns of signals from FSRs remain relatively consistent between normal people and patients. Taking the green signal for instance, the measurement remains constant at the beginning before a sudden drop to a relatively steady value. Then it climbs back and stabilizes at a certain value approximately equal to the original value upon the beginning of the study.

However, the measurement from capacitive sensor differs significantly between the two kinds. Specifically, while the plot from Figure 4 manifests relatively smooth, the one from Figure 5 vibrates severely. This is mostly caused by the constant tremor of the patient's hand. Nevertheless, the second plot exhibits a pattern consistent with the first one, the pattern of *rising edge – stationary phase – falling edge*, except that the second plot demonstrates its stationary phase in a manner of constantly vibrating around a certain value high enough above the initial state.

Furthermore, by recording the time node upon the trigger of each sensor event (the sudden change of a measurement or surpassing a threshold), we are able to segment the user activity sequence into fifteen subsequences. The detailed task of each subsequence is denoted in Table 1.

The result from the preliminary study is encouraging. It indicates that our system design exhibits the similar patterns for both normal people and patients on the same tasks. Furthermore, it would benefit the

Order	Task
1	Reach for the spoon
2	Pick up the spoon
3	Reach for the left bowl
4	Scoop up the ball
5	Move to the middle and hold for 10 seconds
6	Drop down the ball and reach the original position
7	Put the spoon down
8	Reach for spoon
9	Pick up the spoon
10	Reach for the right bowl
11	Scoop up the ball
12	Reach for the left bowl and drop the ball down
13	Reach for the original position
14	Put the spoon down
15	Relax

Table 1. Individual tasks of subsequences.

segmentation process for activity sequence and eventually helps reflecting distinct tremor type for future analysis.

Discussion and Future Work

In this paper, we presented a system to detect nervous system diseases through daily life activities. By integrating motion capture sensors into articles for daily use, our system can collect activity data from people. Also, with data from the designed assisted channel, our system demonstrates the potential to reflect tremor type for clinical analysis. In addition, with data from both normal people and people suffering from nervous system diseases, we can build models that can warn people potential nervous system diseases in early time.

In the future, we will collect more data from patients to build richer and more representative data sets. Then, we will explore and develop better machine-learning or statistical models for disease detection.

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