A Review of Different Applications of Wireless Sensor Network (WSN) in Monitoring Rehabilitation

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***Abstract*—Parkinson's disease is a neurodegenerative brain disorder that affects movement. The lack of dopamine in the brain cells causes patients have lesser ability to regulate movement and emotions as time goes on. There is no cure for this disease. Although drug therapies are successful for some patients, most of the patients usually develop motor complications. In this paper, we presented our work towards the comparison of several wireless sensor network (WSN) systems for monitoring Parkinson's patients. The designs of each system are explored. The parts being considered to design a wireless sensor network and limitations are discussed. These findings helped us to suggest a possible wireless sensor network system to supervise Parkinson's diseases patients for a more extended period of time**.

***Index Terms*—Wireless Sensor Network (WSN); Rehabilitation; Parkinson's Disease**.

I. INTRODUCTION

Wireless Sensor Networks (WSN) has brought many benefits to humans, directly and indirectly, and its existence can be recognised in every field. The study of diseases that affect motor ability is the potential usage of the wireless sensor networks. To better understand the disease and develop more effective treatments, small wearable sensors that measure limb movements, posture, and physiological conditions can yield high-resolution and quantitative data [1-9].

Automatic rehabilitation is a type of therapy with the purpose to wholly or partially recover the neurocognitive function and motor abilities of a patient. Thus, a perfect machine-controlled recovery system is needed by the affected patients, and it can also provide the correct result without lagging. It is also cost-effective for the users. As a result, the whole process can quickly help the patients return to their previous stage. Patients currently use rehabilitation systems after a major operation, chronic pain, sensory loss, stroke, unpredicted pain, severe accident, brain injury, Parkinson 's disease, psychological disorder, and sports-related injury due to the fast advances in medical technology worldwide. The cardiopulmonary, neurological orthopaedics, pediatric and integumentary is the common area that is subjected to rehabilitation treatment to the patients [2][9].

Parkinson's disease (PD) is a disease affecting the nervous system. Parkinson's disease is a deteriorating condition, and patients suffer from impairs speech, motor skills and other functions. The lack of dopamine in brain cells of a human being is the cause of Parkinson's disease, and it is reflected in the form of motor complications. The Parkinson's disease's progress is slow and may take many years. There is a limited medical treatment which can reduce the symptoms of Parkinson's disease. Bradykinesia, postural instability, rigidity and tremor are the four symptoms of the Parkinson's disease patients. Foot pressure analysis, finger motion analysis and the Unified Parkinson's Disease Rating Scale (UPDRS) are used to classify Parkinson's disease based on bradykinesia. For Parkinson's disease, current therapy is based primarily on augmentation or replacement of dopamine, the biosynthetic precursor levodopa or other drugs that activate dopamine receptors These therapies always success in alleviating the abnormal movements, but most of the patients eventually develop motor complications as a result of these treatments [3].

A collection of low power sensor nodes which are connected wirelessly can be defined as wireless sensor network (WSN). It is a network system that assists in interconnecting sensor nodes between each other [4]. A wireless body sensor network (BSN) is beneficial to observe the activities and moving conditions of the Parkinson's disease patients. The real-time monitoring of the patients is provided continuously from the patient's body. The various wireless sensor nodes are attached on the physique of Parkinson's disease patients or fitted into their shoes or clothes so that the activities and physiological conditions can regularly be altered, and an alarm will be generated in case of emergency. However, the attached sensors would cause discomfort to the patients depending on the sensor's size and its position on the body. Another solution is to deploy the sensors within the room confinement so that the patient's activity could easily be monitored. In case of the patient falling due to gait instability, the sensors also capable of detecting the event and alerted the authorities for immediate assistance. There is a suggestion to study the mobility pattern of the patients in their daily activity. This data can be used to train our system to predict the falls when the patient's show the symptoms that precede a fall [6].

II. LITERATURE REVIEW

Wireless sensor networks (WSN) are devices containing sensing, computing and communication elements that are used to monitor physical and environment condition by giving its controllers the ability to measure, collect and react. Today, these devices are being used in a variety of fields such as environment, military, health, home and also commercial due to its advantages [7].

The wireless sensor network with nodes mobility can be used in healthcare environments that will monitor patients continually and always remains under medical care. These bring many benefits to the patient's sensor nodes over the network arrangement. The network infrastructure provides remote access to the patient's nodes. Thus, when the network terminal is available, the patient's state can be supervised [8]. The focus should be on the main structures, the utility and the scopes of the sensor nodes before consideration of the sensor node's organisation and the function. The features and the function can directly affect the capabilities of the whole wireless sensor network. The application requirement must be stated clearly to coordinate the development of both wireless sensor network and the sensor nodes.

The wireless sensors network in the medical field can be classified into Sensor Fusion-Based Activity Recognition for Parkinson Patients who are related to hardware-based design. Furthermore, Sensor Fusion-Based Activity Recognition for Parkinson Patients can also relate to the activity recognition for the methods and the algorithms. Besides that, Sensor Fusion-Based Activity Recognition for Parkinson Patients makes the information flow between patients and medical side to be more efficient [5].

To manage the disease at the particular stage and to look for different complication's to the patient health: Treatment, as always, should be tailored to the needs of the individual. Patients should be helped to make informed decisions about their care and try to involve the cares as much as the patient will allow. The Aims are to communicate information about the disease, help the patient accept the diagnosis, reduce distress and minimise symptoms and, ultimately, improve prognosis [5]. The disease at the particular stage can be managed, and complication in patient health can be detected. Treatment is always ready for the needs of the individual. The purposes are to communicate information about the disease and help the patient to accept the diagnosis to distress and minimise the symptoms and ultimately to improve prognosis. Ongoing patient with the career support will have the better effect during the treatment [6].

The wireless body area sensor reviews in this article will describe in detail about healthcare monitoring. The primary purpose is to review a method for intra-body temperature monitoring based on a new intra-body sensor configuration, communication and desktop application tool summaries. This work will also study the relationship between temperature variations and women health conditions as part of the data collection for a new biosensor [7].

III. REVIEW ON WSN FOR REHABILITATION

We begin by describing the reviewed articles and summarising them in the following section.

A. *Intelligent sensor network for rehabilitation of Parkinson's patients[11]*

Body sensor network with a combination of an intelligent network operating device (iNODE) with force sensitive resistor – step detection in both feet, and combination of an intelligent network operating device (iNODE) with two respiratory inductive plethysmography – monitoring thoracic and abdominal respiration. It also consisted of one coordinating network operating device (cNODE - communication coordinator), iNODE system that is optimised for lossless in data storage for offline analysis and wireless communication for flexibility and mobility connection

B. *A Wearable Wireless Sensing System for Upper Limb Home Rehabilitation [12]*

Wearable sensor module with an Optical Linear Encoder (OLE) for joint angles measurement, accelerometer to give the orientations of the limb segment and a digital signal controller (DSC) to connect with the sensor module and forming a sensor network. It also consisted of a CAN controller to transmit data, and a radio transceiver CC2420 to enable communication between sensor and base station wirelessly. The material of sensor module design is thinly stretched plaster which is lightweight with small obstructions to limbs movement. It equipped with CAN bus for fast data transmission, and wireless communication for mobility. Overall, the system design is low cost, and practical for personal or home use.

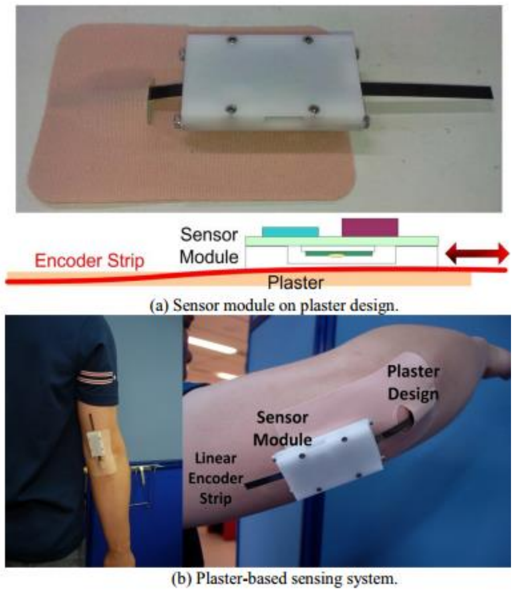

Figure 1: Plaster design of sensor module [12]

C. *Network-based Mobile Gait Rehabilitation System [13]*

The system has Smart Shoes with four air pressure sensors which provide ground contact force measurement during walking. The results are extracted of gait phase information. It also has a compact rotary series elastic actuator (cRSEA) to give assistive torque, and MBStarPlus as the wireless protocol with the benefit of high sampling rate & lower power consumption. A linear quadratic Gaussian (LQG) controller and disturbance observer (DOG) are equipped to deal packet loss in the system.

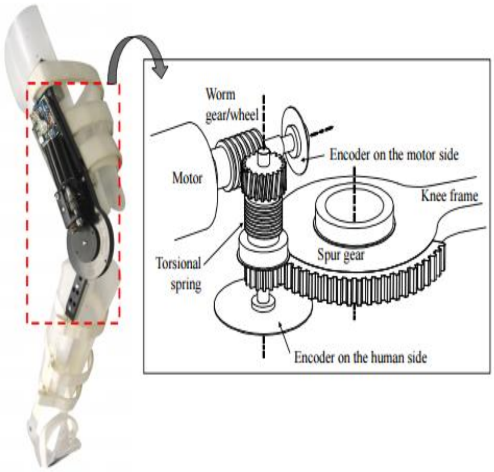

Figure 2: A compact rotary series elastic actuator (cRSEA) and the mechanism [13]

D. *Accelerometer-based Wireless Body Area Network in Post-Acute Rehabilitation [14]*

Part 1 (to compare measurement between motion and time during real-life physical therapy with active time estimation) - Wireless body area network (WBAN) of 3D accelerometer modules for hip, wrist and ankle

Part 2 (to assess the differences in active time estimation)

- An accelerometer module at the hip
- A receiver – to collect signal data transmitted and send to a Tablet PC.
- Wireless communication – Efficient in data collection

E. *A Wireless body area network intelligent for computer assisted physical rehabilitation*

It is developed based on a wireless body area network (WBAN) with ActiS sensor which contains a standard Telos sensor platform & an Intelligent Signal Processing daughtercard (ISPM). There is also two perpendicular dual-axis accelerometers with one bio-amplifier with ECG signal conditional that are added into ISPM to extend its capability. Wireless protocol is ZigBee that enable the wireless communication. It is also equipped with a microcontroller MSP430F1232 for ultra-low power operation. WBAN is low-cost & unattended ambulatory monitoring with applications of physical rehabilitation & an ambulatory monitoring. However, there are limitations and issues such as configuration and customisation, ideal integration, regularity, further utilisation of common off-the-shelf components, security and privacy, and social problem.

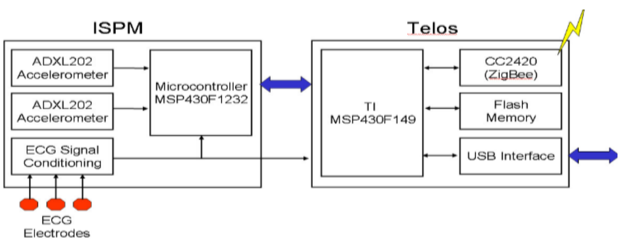

Figure 3: Block diagram of sensor activity [15]

F. *Real-time Gait Monitoring for Parkinson Disease*

Wireless wearable sensors with a computer-based control, a wireless module to transmit signal, and a motion detector that consisted of one tri-axis accelerometer, one tri-axis gyroscope with one tri-axis digital compass. The functions of the system are to monitor gait movement and posture. The prototype sensor module is built with microprocessor, sensors, battery & communication module. The sensors are separated with communication modules that allow integration of new sensors into the network. Accelerometer with ultra-high performance, low-g acceleration, and low-pass filters is equipped to monitor the body posture. A gyroscope with specification of 2000 degree/second of full sampling rate is utilized to monitor the gait patterns. Overall, the system is considered low-cost with wireless communication capability.

G. *Gait Rehabilitation Assessment based on Microwave Doppler Radars*

A rehabilitation system for gait capture with the application of microwave Doppler radars in four wheels walkers. The system includes:

- Data Collection – motion signals (shifts in the reflected waves) for each side captured by the radar array
- Short-time Fourier transform (STFT) to express set of Doppler signatures spectrogram that is created when walking
- Gabor Transform spectrogram – for gait velocities extraction
- Gait velocity estimation - leg velocity corresponds to the frequency shift with the highest reflected energy
- Estimation of the rehabilitation progress - usage or wheeled walkers with motion detection capabilities based on Doppler radar sensor array

Figure 4: Four wheels walker with 2X FMCW Doppler radar [17]

H. *Intelligent Sensor Network for the Rehabilitation of Parkinson's Patients*

A sensor network rehabilitation system for motion/step detection, phase calculation and phase coordination

Step detection:

By comparing the interval of rising edges with falling edges and time threshold to eliminate artefact

Respiratory phase:

- 256-point fast Fourier transform (FFT) - to estimate the current dominant frequency
- FIR filter – to prevent distortion of the phase
- Hilbert transform – to form a real signal
- Phase coordination: Kuiper's test – to quantify coordination degree

I. WSN (Wagyromag) for Monitoring and Processing Human Body Movement in Healthcare Applications

Wagyromag (**w**ireless **a**ccelerometer, **gyr**oscope and **mag**netometer) as a wireless sensor network to monitor and process human body movement. It consisted of a Wagyromag sensor that performed measurement of body part tilt angle based on accelerometer, gyroscope and magnetometer values. It also consisted of accelerometer-aided calibration, gyroscope calibration, ellipsoid-fitting calibration and magnetometer calibration.

Sensor fusion is implemented using Least Mean Squares filter and Recursive Least Squares filters. The processing steps are:

- VisIMU – to read and store sensor data
- Calibration – to reduce error and to express data on acceleration, angular velocity and magnetic field that used to compute the position
- Adaptation filtering on sensor fusion– for extract kinetics information, to improve the accuracy of measurement

J. Gait Analysis Using Wearable Sensors

Kinematic and kinetic parameters of a human being can determine by using gait phase in gait analysis. During human being performance, their faults can be recognised.

Process: Combination of GRF and kinematic information on the foot and determine the moments from the ankle. The kinetic calculation in shank is calculated by using kinetic information taken from the ankle. From shank to the thigh and from thigh to hip are carried out using the same procedure.

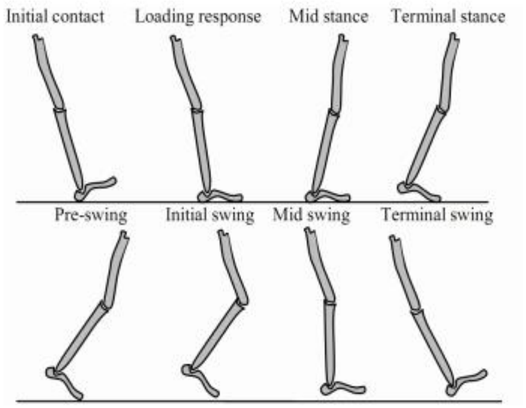

Figure 5: Gait phase of normal walking [35]

K. Use of Multiple Wearable Inertial Sensors in Upper Limb Motion Tracking [35]

The original gyroscopic signals were high-pass filter used to reduce internal drift, while the original acceleration signals were low-pass filter used to remove high-frequency noise. To determine the position of an arm, the inertial measurement is required to convert from sensor coordinate system to world coordinate system.

L. Application of Wearable Inertial Sensors in Stroke Rehabilitation

The sensor is used to express arm in 3-dimensional space and also in real time. Before the experiment carries out, Qualysis marker attaches to one side of the wrist joint, an MT9 inertial sensor mounted to another side. Later we need to run calibration for aligning the coordinate system of the inertial sensor.

IV. RESEARCH METHODOLOGY

This section discusses the research method used to review the articles. A critical literature search was performed on journals and articles which are related to the topic. Generally, the rehabilitation field is too broad to be probed. Therefore, the articles' scope is set to "The Wireless Sensor System on Monitoring the Parkinson Disease Patients". The keywords are "wireless sensor network" and "Parkinson disease". The reviewed journals and articles were published within the last ten years. The papers and information were read and comprehended. The information was then extracted and depicted using our own words and sentences. Each sentence or paragraph for each information is cited with reference to its original source.

V. DISCUSSION

A literature search on wireless sensor network (WSN) monitoring for rehabilitation has been done to gather the relevant articles. To design a network system for rehabilitation, there are three critical parts namely sensor nodes design, communication protocol and also the signal processing which to be considered. Based on a review of previous research, most of the researchers have designed their integrated sensors by combining different kinds of sensor. In the WSN rehabilitation system for Parkinson's patients, the force sensitive resistor, air pressure sensor and motion sensor are commonly used to detect the force or motion in gait exercise. Besides these sensors, the accelerometer and gyroscope can also be used as the motion detector during gait exercise.

The accelerometer is an inertia sensor that can be used to measure acceleration along its sensitive axis while the gyroscope is an angular velocity sensor [21]. There are also other devices used in WSN design such as bio-amplifier with ECG (Electrocardiogram) sensor that can be applied to monitor heart activities. There are other factors such as cost, wearability and power consumption that we need to consider while designing a WSN. The communication protocol is also crucial in WSN rehabilitation system which plays the role of transmitting the data from the sensor for the signal process. Next, there are few steps namely data collection, calibration, error reduction, filter and fusion that are important in the signal process so that a more accurate data can be obtained.

A. Data Collection

In the 1980s, the Formal Concept Analysis was introduced. The analysis is a tool or method to analyse what type of information can be obtained. The data must be a unit, meaningful and easy to understand by humans. Formal indicate that data processing is a formal mathematical entity which does not have the same concept compared with human thinking. Besides that, the fundamental data of formal concept that can be pointed out by formal indicate is formal context and formal background in human knowledge. Another example is the traditional network. The network is the IP address, data transmitted in it and physical address of node linked to data-centric characteristics of the sensor network. Information of each node delivered quickly and efficiently to the user. The data collection protocol is a sensor node, and research shows how the data transmitted to the base station. The protocol also can make the data collection process used to transmit and receive data, energy used of each node and extend the system life cycle. The data collection tools can be divided into a few types namely are observation, document review, interviews, focus groups, surveys and case studies. Each tool has its own advantages. For observation as an example, the data can be collected where or when the event or activity starts. For document review, it is inexpensive and unobtrusive. For the interview, the respondents can directly describe the essential points. Focus group are quick and easy to set up. For surveys, one advantage of it is to reduce the chance of evaluator. For case studies, the advantage is this tool is powerful in portraying the program to outsiders [21].

B. *Calibration*

Sensor calibration is used to remove structural error in sensor output so that the sensor performance can be improved. By improving sensor performance, there is a way by calibrating the sensors where hardware can be added to their products so that sensor output correction can be activated, and calibration routines can be added into their design process to perform individual sensor calibration. There are few advantages of the calibration of sensors. The first advantage is the calibration can make sure that instrument drift is minimised. Even the highest quality product will provide inaccurate measurement, so calibration is the most important role so that the measurement value can be more accurate. The second advantage is the quality of the products can remain high and consistent over time as this is ensured by the calibration. Calibration is necessary because if the product accuracy, repeatability, uncertainty and confidence level are not of good quality, the process in manufacture will be affected. In food safety, calibration also has the vital role because the food quality will affect human being's health. Calibration interval, error limits and the standard can be defined as one of the advantages. The product must have small error limit, especially for the measuring product because if it is not accurate, the result measured by using the product will be affected [25].

C. *Error Reduction*

Error reduction is almost the same with the calibration, but the process or method is not the same. There are four types of methods. The first method is categorised by different types of error from the input data. The second method is described as the general method to detect an error, the third one is developing algorithms to correct the error, and the last one is testing algorithms on data for evaluation of performance [28].

D. *Filtering*

Filters can be classified into four different filters which are high pass filter, low pass filter, band pass filter, and band stop filter. A high-pass filter allows high-frequency signals from easy passage to load from a source and low-frequency signals from difficult passage. A capacitor is inserted in series by capacitive high-pass filters with the load; inductive high-pass filters insert a resistor and an inductor in series and parallel respectively with the load [27]. A circuit or electronic device that lets signals between two specific frequencies to pass is a bandpass filter, but signals from other frequencies will be discriminated [32]. A particular frequency band of signals that set up between two points are blocked by the band stop filter while signals either from lower or higher frequencies of the same frequency band are allowed [33]. A circuit which high-frequency signals from difficult passage but low-frequency signals from the easy passage are a low-pass filter [34].

E. *Fusion*

Data fusion or information fusion or sensor fusion is a combination of sensory data from disparate sources. There are few advantages of the sensor fusion. The first advantage is robustness and reliability. This advantage can help maintain information from the system even if partial failure happens. Temporal coverage and extended spatial of fusion is the second advantage. It can be measured by one sensor only while other sensors are not supported. Data retention also is considered as an advantage. A sensor will verify the measurement with other sensors within the same domain to maintain correctness. Uncertainty and ambiguity decrease is the fourth advantage. This advantage can reduce the set of ambiguous interpretation from measurement data by joining information. Robustness against interference also is one of the advantages. When the dimensionality of the measurement space increases, vulnerable against interference of the system becomes less. One last advantage is the improvement of the resolution of the sensors. Higher resolution is gained with the single sensor after measurement of multiple independent sensors of same the property fused [26].

F. *Advantages and Limitations*

Wireless sensor networks (WSN) are devices containing sensing, computing and communication elements that are used to monitor physical and environment condition by given the ability to its controllers on measuring, collecting and reacting [24]. There are some advantages WSN use in rehabilitation system. For example, mobility enables it to handle areal shifting and to maintain routing. Low setup costs and robustness are also advantages found in a WSN. Besides that, heterogeneity of nodes which monitors data of the different sensors can be converted into digital signals and then transmitted and unattended operation which help in saving time and minimising effort. A summary of comparison between visual motion tracking and WSN rehabilitation is presented in [23]. However, there are some limitations in WSN such as security issues, lower data rates and communication failures due to phenomenon effect such as reflection, refraction and diffraction.

Table 1 shows the experimental results of 10 randomly selected issues. The first column of the table shows the sample name; the latter three columns show the runtime of three algorithms corresponding to each issue which the unit of data in seconds (s). For each test case, the test was repeated ten times, and the mean value was recorded as the experimental results.

Table 1
Experimental Results of 10 Issues

Visual Motion Tracking	WSN based Solutions
Expensive	Low cost
High accuracy	Good accuracy
High complexity	Low complexity
Moderate automation	High automation
High feedback	Moderate feedback
Low mobility	High mobility
High comfort	Good comfort
NA in multi-modality	High multi-modality

VI. Conclusion

Rehabilitation is the health care process for the Parkinson's patient that will help them to keep, restore or improve their motor capabilities. The process can be done by physical therapy, gait exercise, the activity of daily living recognition. During the process, it is necessary for patients to be monitored and corrected to achieve optimal rehabilitation outcomes. Hence, the use of different applications of the wireless sensor network in rehabilitation system has been discussed. A research review has shown that wireless sensor networks have made rehabilitation systems more efficient and systematic. Besides that, the physical rehabilitation system presented in this paper can be applied to post-stroke patients or physically disabled patients due to accidents. Thus, wireless sensor networks bring many benefits to the rehabilitation system.

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