DESIGN AND DEVELOPMENT OF MONITORING DEVICE FOR ARM REHABILITATION

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ABSTRACT

Arm rehabilitation activities require continuous monitoring process in order to provide information of rehabilitation results to be analyzed by therapist. The purpose of monitoring is to help them to improve rehabilitation process. Moreover, a portable and simple home-based rehabilitation device can help patients to improve daily rehabilitation activity. Some previous studies regarding home-based rehabilitation process have shown improvement in promoting human movement recovery. But existing rehabilitation devices are expensive and need to be supervised by physical therapist, which are complicated to be used at home. Some devices are not so efficient to be used at home due to large size and complex system. In this current work, flex sensor, force sensitive resistors and accelerometer were assessed in order to be implemented as a sensory unit for a portable arm rehabilitation device. Analog signal from the sensors will be conveyed to an Arduino microcontroller for data processing and logging. The device is equipped with online or portable data logging capabilities which can store daily activity results. The results of rehabilitation activity can be used for further monitoring and analysis. Experiments were carried out to determine the feasibility of each sensor towards the design of the new device. The experiments demonstrate the capabilities of the sensors to produce extended information regarding arm movement activity which can be implemented in the design. A liquid crystal display (LCD) monitor will show to the user the achievement of their exercise activity on daily basis. In conclusion, this project may pave a new way in the development of new arm rehabilitation monitoring device which can benefit human lives.

CHAPTER 1

INTRODUCTION

1.1   Research Background

Cerebrovascular disease or stroke is one of the most lethal diseases which claimed millions of lives every year. In Malaysia alone, according to the National Registration Department, stroke has become the 3rd main causes of death for the past 5 decades. From this reality, we can conclude that there are large numbers of stroke patients which fortunately recovered from this disease may suffer from post-stroke symptoms. These symptoms include the sudden loss of brain functions which caused by some disturbances in supplying blood to the brain. It may causes symptoms such as loss of vision functions, trouble to speak and difficulty to move one side of the body (Chee et. al.,2010). This disease clearly gives negative impact to the quality of life for the patients where it gives difficulties for them to carry out activities of daily living (ADL).

Stroke patient which mainly consists of elderly population may need to recover with the help of rehabilitation processes. Post-stroke rehabilitation is important for them to regain back the mobility and fitness to do the things they did previously. Post-stroke rehabilitation process may include physical activity which requires extensive exercise plus patient's self motivation to complete the process. Such rehabilitation process which needed the patients to do repetitive physical exercises may result to a less attractive and may result to loss of interest of completing rehabilitation processes. Because of this, motivational support from caregivers, family and friends are essential to promote advancement in recovery process from stroke.

Researchers from various institutions and companies have been actively searching ways on how to design devices and training procedures which incorporate

many high-tech systems that can help patients with disabilities and injuries. These systems maybe involve attaching devices to the affected human limbs in order to improve patient movement in any environment of rehabilitation. An unsupervised system which continuously monitors the rehabilitation of patients can be considered as an important method to analyze the improvement of rehabilitation and as a tool of displaying the results of certain tasks. This unsupervised monitoring system can be considered an important issue in the field of post-stroke rehabilitation

It is important for post-stroke patients to regain back the mobility and fitness to do the things they did previously. Post-stroke rehabilitation process may include physical activity which requires extensive exercise plus patient's self motivation to complete the process. Such rehabilitation process requires the patients to do repetitive physical exercises without knowing their improvement rate may result in loss of interest or de-motivated, thus the patients may struggle to complete the rehabilitation process.

Therefore, the work described in this paper involved the application of several sensors and the development of portable data logging method in the design and development of monitoring device for arm rehabilitation. We aim to produce a rehabilitation system which able to assist the rehabilitation of post-stroke patients or upper limb related patients in gaining quantified results or values which can motivate them to further use the device for rehabilitation. This system also will be included with portable data logging capabilities which enables clinician to do remote monitoring and provide an organized sets of data on daily basis everytime the user do rehabilitation workout at home.

1.2   Objectives

- The main objective of this project is to design and develop a device which is easy to wear, practical, low cost and low power consumption.
- The device will be equipped with monitoring system that can assist stroke patients with arm disability. This system consists of an Arduino Duemilanove microcontroller which read the analog data, process and transmits data to be logged into personal computer (PC) or secure digital (SD) card.
- The device will be made to enable storage of data for certain period of

days/weeks.

- The device will enable patients with arm disability caused by stroke disease or other illnesses to practise the rehabilitation process at home without the supervision of therapist.

- This project also will to determine the characteristic of flex sensors in human movement analysis. The device should be users-friendly, practical and low cost of production.

1.3   Scope of the Project

- The arm rehabilitation device will use flexible bend sensors or flex sensors attached to the elbow to detect arm bending movement.

- Force generated by movement on X, Y, Z axes will be sensed by accelerometer

- Small muscle movement activities will be sensed by Force Sensitive Resistors (FSRs) sensors.

- Arduino Duemilanove microcontroller will processed the analog data and transmit it to PC or SD memory card for data logging.

- Macro configured Excel files will be developed to automatically analyze all data from sensors which have been logged for easy interpretation of results.

1.4   Statement of Problem

Rehabilitation process are based on clinical assessment tools which can be execute by self-report (home base) and observer-rated (done at rehabilitation centre) (Roy et al., 2009). Observer-rated by caregivers can be time consuming and patients need to have repeated observations at rehabilitation centre which can be a burden to the health care cost. While the reason of post-stroke rehabilitation is to facilitating community integration, early discharge and home-base rehabilitation (with the support of caregiver) is the logical choice because the patients integration with

community can be commenced sooner (Nancy et al., 2000). Moreover, early home-base rehabilitation proved to promote a better physical health because it appeared to permit motor and functional gains that occurred with natural recovery and satisfaction with community integration (Nancy et al., 2000). Early discharge and home-based rehabilitation can reduce the usage of hospital beds without compromising clinical patient outcomes. However, for home-based rehabilitation with the support of caregivers, on behalf of the caregivers, they are exposed to the potential risk of poorer mental health (Anderson et al., 2000). Moreover, on behalf of patients, if they have financial restriction or no insurance coverage, then they need to face higher medical costs in order to have caregivers support at home.

Thus, how to effectively motivate patients to do the regular physical activity is an important research topic (Eriksson et al., 2005). Therefore, in this work, we propose the use of an assistive device as a substitution of caregivers supported rehabilitation. The device will focus on arm rehabilitation which will be based on arm motion tracking system by sensors which can continuously monitor patients arm movement and automatically logging the rehabilitation progress on daily or weekly basis.

1.5 Expected Results

- a wearable, light, simple-built, low cost, low power consumption sensory system can be produced.

- a data processing device which able to read, process and transmit data to PC or SD memory card for data logging process.

- an LCD display which can interact with user, able to display arm bending achievement levels.

- a data logging system which can logged all the processed data in text file.

- an opportunity to further research in designing wireless wearable arm rehabilitation monitoring device in the future.

CHAPTER 2

LITERATURE REVIEW

2.1   Introduction

In this chapter, we will review related papers, previous related thesis, internet articles and journal articles on work in the area of arm rehabilitation assistive device. But due to the vast research in this field, we will only consider a few papers. We will also describe the components which are being used to design the designed device which may pave way for further upgrade in the development of arm rehabilitation assistive device in the future.

As an overview, this paper presents an effort to designed and develop an arm rehabilitation monitoring device that is aimed at providing a systematic and continuous rehabilitation assistive method in health care area. Designing a monitoring device with sensor interfacing (flex sensor) and data logging capability (via personal computer) was the main goal of this project. The designed device was then upgraded by enhancing the capabilities to handle multiple sensors involving force sensitive resistor sensors and accelerometer. The data logging capabilities also were upgraded to be able to handle portable, wireless data logging through the usage of secure digital (SD) memory card. Due to the implementation of multi-sensor capabilities, the device uses the various principles of electrical signal extraction from these sensors through distinctive human movement activities to provide analyst with necessary information to calculate the information from each sensors. As a whole, the project involves the understanding in the aspect of software programming, signal processing, electronics and even physiology in order to develop a proper working rehabilitation device.

2.2   A Brief History of Stroke

The history of stroke can be tracked back since 2700 years ago, when Hippocrates, referred to as "the father of western medicine" (Grammaticos and Diamantis, 2008, Strong et al., 2007), was the earliest to describe the sudden paralysis which can be associated to stroke, more precisely ischemia stroke (Ashrafian, 2010, Thompson et al., 1996). Hippocrates first written in Greek term "Apoplexy", meaning "struck down with violence" to describe the effect of stroke. Then, in the year 1658, while dedicating his life at the University of Padua, Italy, Johan Jacob Wepfer in his book Apoplexia, described the cause of hemorrhagic stroke when he found out that when people died from apoplexy, they seems to suffer from a disruption of blood supply to their brains and some cases have their arteries blocked (Thompson et al., 1996). In simple term, it means that there had been a chronic bleeding in the brain. He also identified that the cause of ischemic stroke was due to the disruption or blockage of the blood vessel which supplies the blood to the brain. Eventually, Rudolph Virchow {1821~1902}, a German refered to as "the father of modern pathology", was the first to identified the mechanism of formation of blood clot inside a blood vessel and its complication, which is also known as Thromboembolism (Schillar, 1970, Furie and Furie, 2008, Handin, 2005).

2.3   Causes of Stroke

As described briefly in the previous topic, we can conclude that there are two main types of stroke, which is ischemic stroke and haemorrhagic stroke.

An ischemic stroke as shown in Figure 2.1, is caused by blood clot formed in an artery or blood vessel in human brain which considers as most common type of stroke (Furie, 2008, Handin, 2005). Parts of the brain will suffer a change in the blood flows due to the blood clot. Because of this, infact (tissue death) due to lacking of oxygen can occur to those locations of the brain which are not delivered with blood. In detail, the occurrence of ischemic stroke can be determined by two different ways: The first is due to thrombotic stroke which is the result of blood fat, cholesterol or calcium which blocked the blood vessel resulting to narrow the pathway of blood vessels. It causes clumsiness and weakness which also serve as

early warning sign of major stroke. The second way is through embolic stroke, which can occurs when blood clot is formed not in the brain, but at the other part in the body and travels in the body to the brain. This will give an immediate physical and neurological effect due to the restriction of the flow of blood to the cerebral artery in the brain.
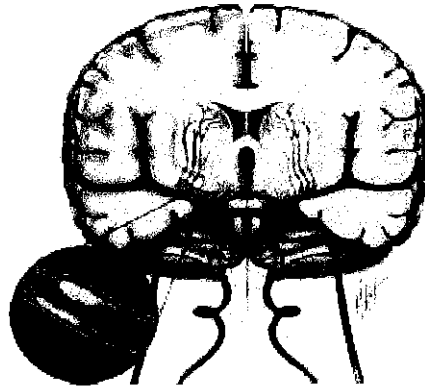

Figure 2.1: Ischemic stroke (Fitzhenry, 2009).

Haemorrhagic stroke is the second type which is not a commonly occurred stroke. This type of stroke occurs when a burst of artery in the brain causing blood to spread on the brain tissue which not only lead to infarction (loss of blood supply) but also intoxicated the affected brain tissue (Handin, 2005). There are also two types of haemorrhagic stroke. The first type is a subarachnoid haemorrhage, when a blood vessel on the surface of the brain bursts. This may result with blood leaking into the area between the brain and the skull (subarachnoid space). The second type is an intra-cerebral haemorrhage which is due to the bleeding of the brain tissue which usually causes by high blood pressure.

Aside from Ischemic stroke and haemorrhagic stroke, stroke also can be caused by aneurysm. Aneursym occurs on the wall of a blood vessel in the form of a ballon-like swelling which is filled with blood (Fitzhenry, 2009). The force generated by heart's blood pumping activity can affected a weak spot on a blood vessel, where over a period of time, a balloon shape or swelling will be formed on this weak spot. At the end, the wall will be ruptured due to its weak condition.
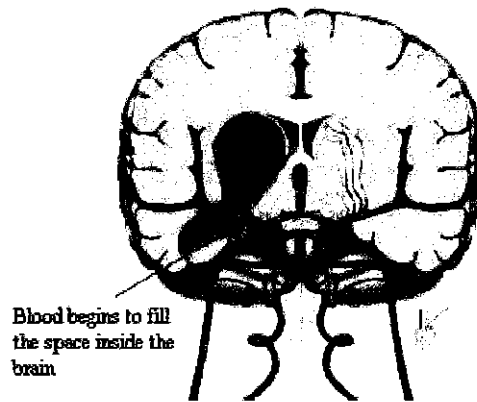
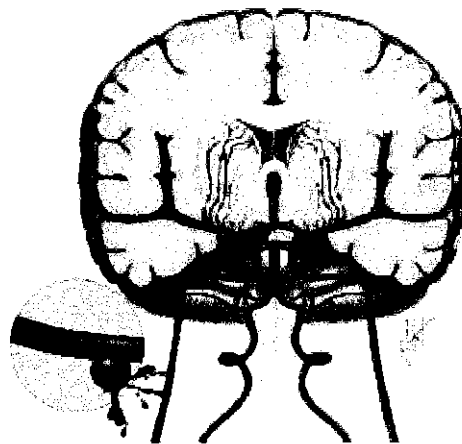Figure 2.2: Intra-cerebral Haemorrhage (Fitzhenry, 2009).

Figure 2.3: Aneurysm (Fitzhenry, 2009).

2.4 Effects of Stroke

Stroke is well-known to cause several forms of disability, maybe minor or even long term disabilities and even death. As shown on Figure 2.4, the various forms of disability may include paralysis, visual and perceptual deficits, language deficits, emotional changes, swallowing dysfunction, and blower and bladder problems (Mauk, 2009). Basically, the effects of stroke can be different for each patient. As described in previous sub-chapter, it may depend on which part and to what extent does the stroke affected the brain. The patients that suffer from stroke do not only need frequent medical treatments, but it also gave a significant impact not only to the patients individually, but also care-givers and even surrounding communities.

2.4.1. Effects of Hemiplegia and Hemiparesis.

Hemiplegia is a complete paralysis on one side of the body which is a common effect of stroke (Fitzhenry, 2009). This can occur due to the left side of the brain controls the right side of the body and vice versa as shown on Figure 2.4. In other word, when stroke occurred, hemiplegia will affect the opposite side of body.
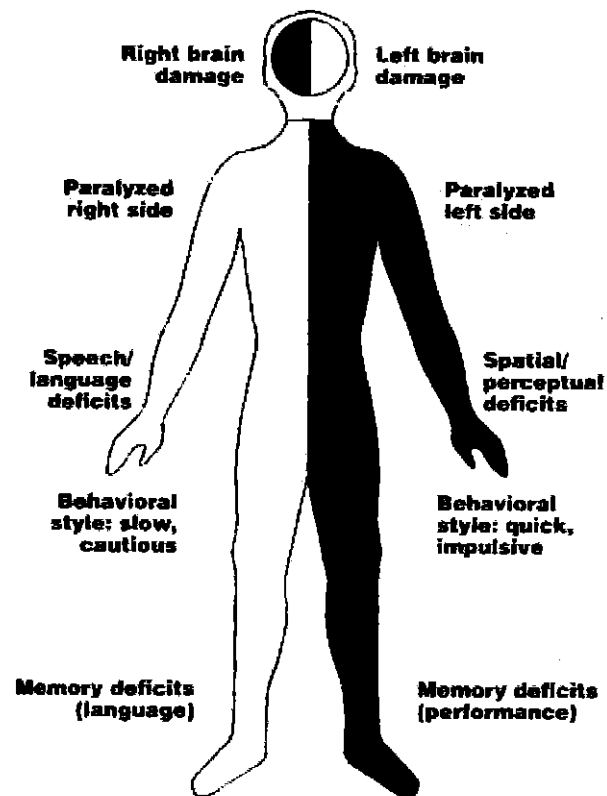

Figure 2.4: Common problems due to the effect of stroke. Adapted from
(http://www.nasam.org, 2011)

Hemiparesis is a disability which is not as chronic as hemiplegia which may result in paralysis. Patients that suffer from hemiparesis may feel weakness on one side of body. According to Mohr et al. (2004), the patient is able to move the impaired side of the body but with reduced muscular strength. Similar to the effect of hemiplegia, hemiparesis will occur on a side of the body which is opposite the side of the brain affected by the stroke. Mohr et al. emphasized that the most common pattern of hemiparesis is weakness of the hand, shoulder, foot and hip. Patient with hemiparesis or hemiplegia may experience the below physical difficulties:

- Poor coordination and walking ability
- Abnormal posture and balance
- Speaking, reading and writing
- Chewing and swallowing (dysphagia)
- Loss of sensation
- Partial loss of vision

2.4.2. Effects due to Cognitive Deficits

In some cases of stroke, the patient may suffer from a syndrome where the patient has no knowledge of one side of the body, or the visual field and even unaware of the deficits. This is a syndrome called neglect syndrome. Usually, stroke may also cause cognitive ability problems such as

- Ability to think
- Poor concentration in learning new skills
- Inability to understand speech

2.4.3. Effects due to Psychological Deficits

Other than a visible affects of stroke, patient may also be affected with long term and short term psychological changes which can lead to intense emotional problems. The patient may suffers from

- Difficulty to control emotion
- May express inappropriate emotions in certain situations
- Sadness or depression resulting from stroke
- Incline to commit suicide

Long term effects of stroke can be described as the result of injury to the area of the brain which control the emotional functions, resulting to :

- Loss of memory
- Problem in solving logical problem
- Change of personality

- Loss of motivation to live
- Total depression

While the short term psychological effects may be the result of reaction to personal loss.

2.5   Overview of Rehabilitation

The main reason of rehabilitation is to assist patients whose suffers from strokes or other injuries to return as much as possible to their previous normal condition through the process of relearning and redefining the knowledge of everyday living activities. Moreover, rehabilitation also involves the support from family members which plays an important role in improving the process of rehabilitation. With the help of family members, home-based rehabilitation can promote early initiation of rehabilitation which can promote fast recovery. Early initiation of rehabilitation is necessary in order to prevent secondary complications such as contractures and de-conditioning (DeLisa et al., 2004). With the help of rehabilitation, patients will learn to understand the difficulties and try to adapt it in their daily lives.

Figure 2.5: A common scene inside a rehabilitation center. Adapted from
(http://www.tenaweek.org, 2011).

Usually in government or private hospitals, a group of people comprises of staff with different skills working hand by hand to assist patients on developing and monitoring rehabilitation process is called multidisciplinary team. These could be a group of specialist physicians from various medical specialties such as occupational therapists, psychiatrist, geriatrics, pharmacology, nursing staff, physiotherapists, occupational therapy, speech and language therapy, and usually a physician trained in rehabilitation medicine (Norrefalk, 2003). Figure 2.5 shows a common scene inside a rehabilitation center which usually occupied by elderly receiving rehabilitation treatment.

It is important for patients which suffer from limbs injuries and stroke to start rehabilitation as quickly as possible. Usually rehabilitation is completed within a year with the most early improvement can be seen from few days to over more than a year. But usually, many patients can feel improvement in daily activity in the first few months of rehabilitation. Most return of function is seen in the first months. In some cases on stoke patients, motor function may return as late as 6 months after stroke. Sensory deficits or swallowing problems may improve later (Cassel, 2003). Even with all of these improvements, it proves that rehabilitation efforts following stroke are cost-effective and lead to higher functional levels (Schonewetter et al., 1993). A meta-analysis of rehabilitation research determined that the average person in treatment functioned better than 66% of the participants in the control group. Activity of daily living (ADL) performance and visual-perceptual function improved the most consistently. Although younger patients fared better than older, but gains were seen among the older subjects (Patrick et al., 1994). However, studies done by Pearlman et al. (1993) et al shows that age, by itself, does not affect rehabilitation outcome.

It is important to stress the important of daily rehabilitation exercises. It should continue to be part of the stroke patient's routine. Although in some cases, a complete recovery from paralyzed condition is unusual, but it is not impossible and most patients will improve to some extent : proper diet and exercise are known to help the brain to recover (Cassel, 2003).

2.6 Home-based and Hospital-based Rehabilitation

As described in previous chapter, rehabilitation process is based on clinical assessment tools which can be executed by self-report (home-based) and observer-rated (hospital-based) (Roy et al., 2009).

In term of hospital-based rehabilitation, it is generally agreed that it is a must to have a multidisciplinary team containing experts in assisting patients with stroke illness. This is one of the reason why in government or private hospital have stroke wards which usually incorporate such team. Another approach which can be suggests is to involve such a team with the patient wherever he is, even at homes.

A coordinated team of physiotherapist, occupational therapist, speech therapist, nurse and social worker was the subject of another controlled trial which investigated the value of an additional service for patients at home (Wade and Langton, 1985, Vinken et al., 1989). Care for patients admitted to hospital was unaltered, and many patients in the control group received some home care and support albeit less than in the trial group. The 233 surviving patients in the trial group did not make a better recovery than the 199 control group patients seen at six months in terms of ADL function, depression, non-ADL activities or stress on the caregiver. Other analysis showed that admission to hospital per se conferred no benefit on the patient (Wade and Langton, 1985, Vinken et al., 1989).

The effect of setting up a hospital-based multidisciplinary team including medical, nursing and therapy staff has been investigated in previous studies. Wood-Dauphinee et al. compared 64 patients randomly allocated to Team care (multidisciplinary team) with 62 given traditional care (Wood-Daupnee et al., 1984, Vinken et al., 1989). According to the paper, a randomized controlled trial was conducted to examine the effects of multidisciplinary team care on acute hospitalized stroke patients. After obtaining baseline information on 42 stroke victims receiving conventional care in a general hospital, 130 stroke patients were stratified and randomly assigned either to Traditional or Team care.

There are similarities as well as differences in the approaches to the treatment of each care groups. While medical management was almost equivalent and both groups received specialized services, the Team approach was designed to provide an early and aggressive program of care and specifically oriented to the care of stroke patients. The process of family involvement was an important component of the

Team care plan and they found that this relationship was fostered. Finally, the interactions of the Team members and their deliberations about each patient make this treatment distinct from Traditional care.

Assessments by independent evaluators permitted comparisons between Team and Traditional groups with reference to patient survival, motor performance and functional abilities. Data obtained prospectively from charts and treatment logs allowed the care process across groups to be compared. Results described in the paper demonstrated Team and Traditional patients fared similarly in survival. However there was an unexpected difference in survival (not dead) depending upon sex. For motor performance, male survivors performed better with Team care and female survivors with the Traditional method. In terms of functional abilities, male patients receiving Team care again performed better than their traditional counterparts, whereas in women there was no difference between the treatment groups. From this study, there was no consistent benefit attributable to the Team or Traditional towards hospital-based rehabilitation, though statistical analysis of small sub-groups (using analysis of covariance) suggested some benefit to men in terms of activities of daily living – this cannot be considered reliable in view of the small number of cases entered into a complex statistical analysis. This study was relatively small, had only a short follow-up period of five weeks, and so may have failed to detect some minor immediate or major long-term benefits of hospital-based rehabilitation.

A comparative study to determine the effectiveness of home-based cardiac rehabilitation programmes between (i) usual care and (ii) supervised hospital-based rehabilitation was carried out by Jolly et al. (2006). In the study, a systematic review and meta-analysis of randomized controlled trials were developed concentrating on the outcome of several measures: mortality, smoking cessation, exercise capacity, systolic blood pressure, total cholesterol, psychological status and health related quality of life. 18 included trials for home versus usual rehabilitation and 6 trials of home versus supervised hospital-based rehabilitation were identified. The home-based interventions were clinically heterogeneous, trials often small, with quality poorly reported. Compared with usual care, home-based cardiac rehabilitation had greater reduction in systolic blood pressure, and a reduced relative risk of being a smoker at follow-up. Differences in exercise capacity, total cholesterol, anxiety and depression were all in favor of the home-based group. In patients post-myocardial

infarction exercise capacity was significantly improved in the home rehabilitation group compared to usual care. The comparison of home-based with supervised centre-based cardiac rehabilitation revealed no significant differences in exercise capacity, systolic blood pressure and total cholesterol. The study shows that home-based cardiac rehabilitation does not show significant inferiority to hospital-based rehabilitation. This prove that home-based rehabilitation have the capabilities to gave if not more but at least the same result as hospital-based rehabilitation. By increasing the numbers of patients and trials, it may contribute to the debate on the acceptability, effectiveness and cost-effectiveness of home-based rehabilitation which we predict can give significant inferiority than hospital-based rehabilitation.

Dalal et al. (2007) produced a research study which concluded that home-based cardiac rehabilitation was as effective as hospital based rehabilitation for patients after myocardial infarction. They also proved that by choosing a rehabilitation program did not significantly affect clinical outcomes.

There are several more studies which produce the same results which proved that home-based rehabilitation program does not permit loss of improvement compared to supervised hospital-based rehabilitation. Throughout the literature review which had been carried out prior to the completion of this paper, there are very few studies concentrating solely on arm rehabilitation processes. This is the main motivation for the completion of this paper which hopefully can contribute on this area.

2.7 Physiotherapy

Usually at rehabilitation centers, there are physiotherapists which will assist patients to perform the movement needed to enable the recovery of upper and lower limbs function. This function is called sensorimotor function which is a combination of sensation feedback and muscle control effect (Fitzhenry, 2009). The physiotherapists not only assist on physical movements, but also respiratory and musculoskeletal related problems. There are three major type of exercise in a rehabilitation process in order to train motor and sensory skills, which is

- Passive Range of Motion (PROM) exercises
- Active Range of Motion (AROM) exercise

- Active Assisted Range of Motion (AAROM) exercises

2.7.1 Passive Range of Motion Exercises

In order to permits patients to return home and living a normal life, patients need to do the necessary exercises which include the need to move the body or limbs through a specific range of motion. For passive range of motion exercises (PROM), the exercises will be assisted by a therapist, where the therapist will assist the movement of the patient's body part through the full range of motion (Fitzhenry, 2009).
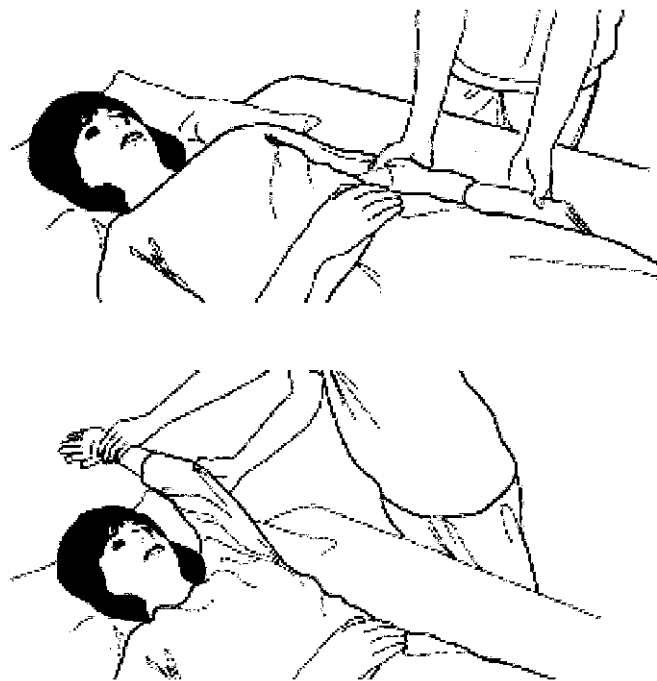
Figure 2.6: Passive range of motion exercises for the arm.

Adapted from www.als-mda.org, 2011).

The therapists need to make sure that the workouts are not stretching the joint past its normal limits. It is also important for the patient to participate as fully as possible in order to get the maximum benefit of the workout. Figure 2.6 shows a typical passive range of motion exercise involves a patient's left arm. The therapists or caregivers will help the patient lie comfortably on a bed. Then therapists will place the patient's arm on his or her side. Then therapists need to pick the arm up, and

move it over the head to a position behind the ear by supporting the patient's elbow and wrist. Finally, therapists return the arm to the initial position (patient's side). These exercises can be repeated for several times, usually about 10 to 15 times a session.

2.7.2 Active Range of Motion Exercises

A bit different with PROM, for active range of motion (AROM), the patient performs the full range of motion of the exercise voluntarily without any assistance from the therapists and no resistance applied to the patient (Fitzhenry, 2009, Houglum, 2010, Marcus, 2008).
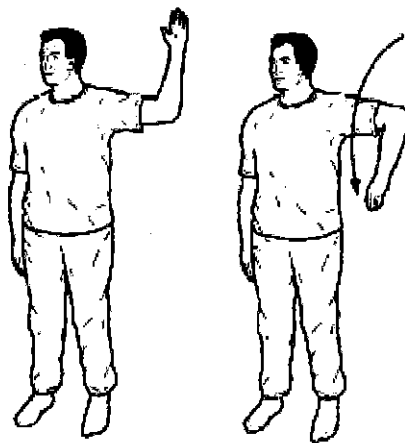

Figure 2.7: Active range of motion exercise for the arm (Fitzhenry, 2009).

The therapists can assist after some time, and he can record the performance of the patients throughout the extent of the exercise. These exercise needed for the patient to maintain or increase the limit of motion, also help to reduce deterioration of the muscles involved in the motion (Houglum, 2010). Figure 2.7 shows a typical exercise performed on a patient's arm involving AROM exercise. This exercise aimed at improving patient's shoulder and elbow movement. It can be performed either in the standing position or sitting with his or her elbow bent. The patient needs to rotate the shoulder joint by lowering the hands towards the floor. AROM exercises are good at improving sensorimotor skills but restricted to patient that has enough strength to do it without any assistance.

2.7.3 Active Assisted Range of Motion Exercises

Active assisted range of motion (AAROM) exercises are performed by the patient using the muscles surrounding the joint with the help from the therapists or assistive device. AAROM can be done by patients that have sensorimotor function but do not have enough strength to support the affected limbs.
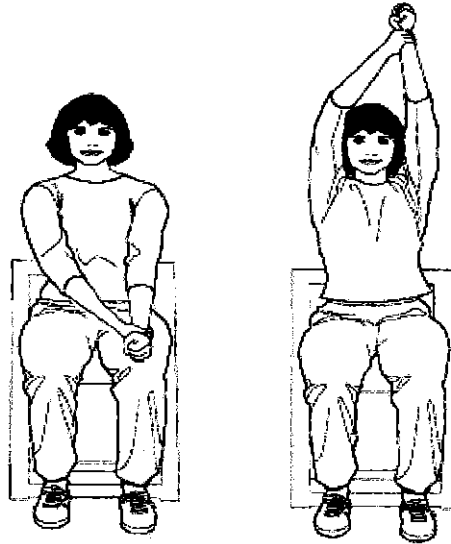

Figure 2.8: Active assisted range of motion exercise for the arm (Fitzhenry, 2009).

Figure 2.8 shows a type of AAROM exercise, the patient initial position can be done either sitting, standing or lying on a bed. This exercise can also be performed if he or she has one healthy or stronger arm than the other. Using his or her healthy arm, the patient needs to grasp the weaker wrist using his or her stronger healthy hand. The patient needs to use as much energy as he or she can on the weaker arm, with the little assist from the supporting stronger arm. This kind of exercise is very vital to help prevent pain and deformity of muscles.

2.7.4 Other Types of Exercises

There are other types of exercises such as resistive exercises which can be performed by the patient by pulling or pushing against an opposing force. This type of exercises are called resisted range of motion (RROM) which is a dynamic type of exercises which concentrating on strengthening the muscles (Houglum, 2010).

Other types of exercises include aerobic exercises such as swimming and isometric exercise (Houglum, 2010, Hughey, 2011). Isometric exercises can be done by the patient by contracting and relaxing muscles while keeping the targeted part of body in a fixed position. This is suitable to maintain the muscle strength when a joint is active (Hughey, 2011).
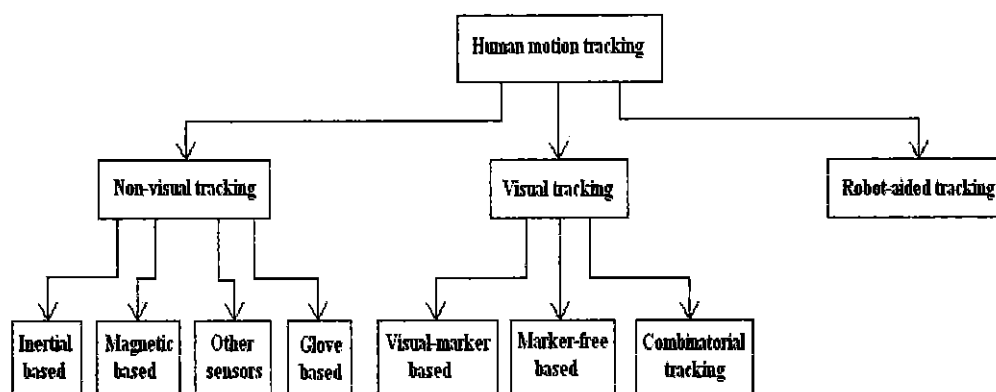
2.8 Technology in Rehabilitation

Figure 2.9: Classification of sensor technologies for human motion tracking (Zhou and Hu, 2008).

In order to permits patients to return home and living a normal life, patients need to undergo rehabilitation procedures and achieve a level of physical and psychological which allows them. Because of this, for each individual patient, specialized rehabilitation exercises is designed to match their goals based on their maximum abilities. As previously described, patients which requires rehabilitation can only found it in rehabilitation centers or hospitals. The patients need to attend rehabilitations frequently for about once or twice every week and can continue for several months (Khokhar et al., 2009, Zhou and Hu, 2008). Studies also proved that traditional rehabilitation methods lack the assessment in term of quantitative results towards patient's performance (Riener, 2005). Moreover, the movement of patient during rehabilitation process needs to be continuously monitored and verified in order to get a correct body motion. Because of these reasons, tracking and analyzing the human movement are vital and important in designing a home-based rehabilitation system (Zhou and Hu, 2004). Until today, many efforts to designed and

develop rehabilitation devices that incorporated advanced electronic and computer-based technology are actively being carried out by researchers throughout the world focused on the application of position sensors, such as goniometry, pressure sensors, resistive sensors, magnetometers and inertial sensors (e.g. accelerometers and gyroscopes). Sensory technologies for rehabilitation can be non-visual, visual based or can be a combination of both (Zhou and Hu, 2008). Figure 2.9 shows, the classification of available sensor technologies.

2.8.1 Non-Visual Based Tracking System

For non-visual tracking system, the patient will be attached with motion sensors in order to extract movement information. Usually, the sensors can be an inertial sensors, mechanical sensors, force sensitive sensors, magnetic based sensors, resistor based sensors or microwave based sensors.

Amft et al. (2006) described that some of these sensors can be very small and lightweight, for example force sensitive resistor sensors (FSRs), which can detect even a small movement such as individual muscle activity. They demonstrated the usage of FSRs to detect the contractions of arm muscles. They compared the extracted data from FSRs with data collected from an established EMG detection device. The results proved that FSRs can be used to monitor individual muscles.

Accelerometer is an inertial sensor which measures acceleration indirectly through inertial force. These can be converted into analog/digital voltage signals. Due to this ability, accelerometers have been used to track motion of human (Hall, 2005, Sakaguchi et al., 1996, Naghshineh et al., 2009). Allison L. Hall (2005) developed methods for using accelerometers to monitor and quantify the amount of motion in the arm for the application of monitoring limb recovery to be used by stroke patients outside therapy sessions. In her studies, it was found that the acceleration values can be processed to monitor and quantify arm motions. But the study was not performed using accelerometers, only to show the possibility for the developed method based on acceleration can be applied to accelerometer data. Sakaguchi et al. (1996) proposed a new measurement method for recognizing human arm gesture using accelerometers and gyroscopes. They focused on the merits of demerits of integrating both sensors. They came to a conclusion that their method

enables them to measure and recognize the motion of human arms in real time without the influence of occlusion and magnetic circumstances. But, for a patients which requires home-based rehabilitation device, real-time monitoring through PC could be a burden.

Another sensor which is widely implemented in studying human motion researchers are flex sensor. Gentile et al. (1992) patented a sensor design for detecting angular displacement of an object. This sensor soon afterwards known as flex sensor. The sensor comprises a substrate for attachment to the object whose angular displacement is to be sensed and a sensing means attached to the substrate and connectable into an electric circuit. The electric circuit measures the resistance of the sensing means, which changes as a function of the angular displacement. Chapman et al. (1999) used flex sensor along with nitinol wires (usually known as muscle wire or Flexinol), attached on a straw as a new design alternative to motor-driven artificial limbs. It is referred as "Strawbotic", refer Fig.10. This option implies structures that are relatively small, cheap, light, continuous, adaptable, available and easily controlled. The muscle wire acts as actuators, where it will contracts to a maximum of 8% of its length when warmed with an electrical current signal provided by an external controllable source. While flex sensor is being used for sensing the position of a limb, where the sensor's resistance depends on the degree of bending. The more it bends, the greater the resistance of the sensor.
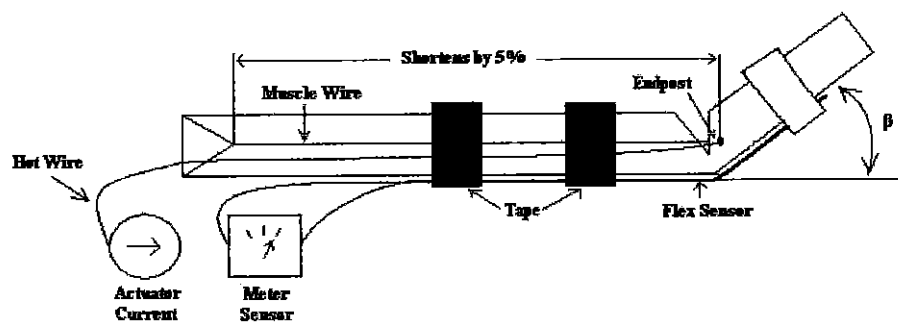

Figure 2.10: Schematic of a straw limb showing the bend angle beta

(Chapman et al., 1999).

L. K. Simone et al. (2004) used flex sensors contained in Lycra/Nylon sleeves to collect real-time flexion data of finger flexion over extended period of time (refer Figure 2.11). The individual sensor sleeves are securely attached to the back of each

finger. They demonstrated that data can be collected comfortably over an extended period of time while individuals perform daily activities away from the clinical site.

Jae-Myung Yoo et al. (2006) used flex sensor as a part of sensing system for artificial arm's control research. It can measure how flexed the muscle is based on flex sensor. Flex sensors was attached to the biceps brachii muscle and triceps brachii muscle in order to get flexion signal. The two signals that output from the sensors are passed to the amplification and Low Pass Filter where arm's movement is classified into 4 motions – flexion and extension, pronation and supination by the sensing system. The proposed system was verified and tested on a small artificial arm of 2 degrees of freedom (D.O.F) as shown on figure 2.12. It is consists of two actuators and two potentiometers. They found that the moving speed of the artificial arm was the same with that of the actual human arm though some position error occurred during tests.

Figure 2.11: Sensor within sensor sleeve attached to the finger using toupee (Simone et al., 2004).

Figure 2.12: Overview of the artificial arm (Jae-Myun Yoo et al., 2006).

Borges et al. (2009) produced two versions of Flex Sensor Belts where the main objective is counting the movement of the foetus from a pregnant woman. It is a part of a project called Smart Clothing for Health Monitoring and Sport Applications (Smart-Clothing). The monitoring process is done in the last weeks of pregnancy through wearable solutions where flex sensors are integrated. Wireless monitoring solutions have been explored whose purpose is to allow for freedom of movements at home or in the hospital. To accomplish this, a system was created by

using a belt with several flex sensors connected to the pregnant woman. It detects the foetal movement based on the bending of the sensor, and sends the information online through Wireless Sensor Networks (WSNs).

2.8.2 Visual Based Tracking System

For visual tracking system, the patient will be attached with identifiers as a visual marker with cameras being used to get more accurate position estimation. Visual marker based tracking system is reliable to solve problems regarding the exact position of a marker due to lighting and scattered scenes (Zhou and Hu, 2004). There are several types of visual tracking marker system such as ELITE, OPTOTRAK and VICON, which can provide accurate position data for human motion analysis.

A study by Peter Barnes et al. (2007) on the performance of an OPTOTRAK Certus system in term of position and timing produced a results which shows that it's positional accuracy is very high, around 20μ at a distance of 2.8 m. They found that the timing performance through Ethernet or SCSI communication channel to host computer is not very reliable below roughly a 5% accuracy level. But this can be improved by custom software codes which can give very accurate timestamps to data frames

Lai et al. (2008) described a prototype design of a wireless device which can monitor vertical toe clearance. The study focused on detection of tripping gait patterns among elderly by demonstrating that minimum toe clearance (MTC) is a sensitive aspect as a falls risk predictor. The wireless device was attached on subject's shoes, incorporating sensors such as tri-axis accelerometer and dual-axis gyroscope. Information collected from the sensors was compared against the measurements made by OPTOTRAK motion system. Their device's toe clearance measurements were found to follow the OPTOTRAK measurement trend. This is an example of a research which utilizes 3D motion measurement system as a current gold standard in gait analysis (Lai et al., 2008). Another application Broeks et al. (1999) shows that by using 3D camera motion analysis, the trajectories of arm function of stroke patients can be characterized. This study shows increased movement variability, increased motion segmentation, and by spatial and temporal coordination in comparison with healthy people. They concluded that there is a need

to develop effective treatment methods for hemiplegic arm (paralysis affecting only one side of the arm) function.

There are disadvantages using this system, is that the system is highly expensive. Moreover, rotated joints and overlapped body parts cannot be detected, thus, 3D rendering is not possible (Broeks et al., 1999).

2.8.3 Robot-Aided Tracking System

Robot-aided tracking system is possibly the most popular research regarding rehabilitation systems. As a system which combines the technologies of electro-mechanical or electromagnetic tracking abilities, couples with various sensory technologies, is proved to be an important platforms for neuro-rehabilitation for human limbs following stroke (Lai et al., 2008, Hillman, 2003, Speich and Rosen, 2004).

There are various studies on robot-aided rehabilitation Nef et al. (2005) designed a novel arm rehabilitation robot which constructed with a semi-exoskeleton structure. The robot is called ARMin which has six degree of freedom and equipped with position and force sensors. Figure 2.13 shows the complex structure of the robot which consists of a mechanical structure, sensors and motors which being implemented in the design of the robot. However, due to its heavy and complex structure, it is only suitable for daily living in clinics
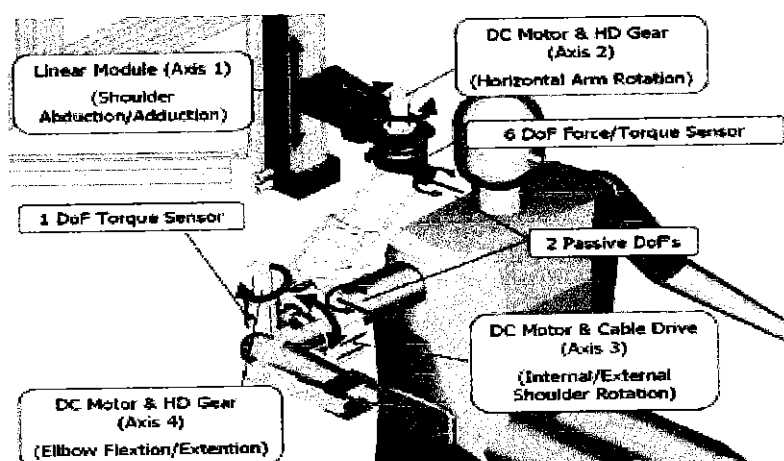

Figure 2.13: The mechanical structure, sensors and motors of ARMin robot (Nef et al., 2005).