MEASUREMENT AND ANALYSIS SYSTEM OF THE ANKLE MOTION IN HEALTHY GAIT EVALUATION WITH DATA CLASSIFICATION

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Abstract—Ankle motion is a significant gait parameter for walking, which includes parameters such as angle of movement while walking and the average of the angle signal. This preliminary research is to study the ankle motion of the foot by creating an electronic measurement which measures the angle, measure the number of steps, and the experimental results were analyzed the signal of the ankle motion. This research prototype can measure for those who have problems the walking and normal subjects are compared to commercial gait equipment (Ultra-Flex measurement) [8]. The creating a prototype measurement to support medical device incorporates the passive sensors, the Arduino [7] as ADK R3 microcontroller board, storage unit, and display units. The experimental results show the measured parameters, we will analyze the results of walking signal that occurs at the ankle motion with initial behavior analysis of subjects. This research is used for testing with 36 subjects. The subjects were divided into those with less disabled subjects and normal subjects. After testing measurements with our prototype, we have analyzed the effects of ankle motion and using the classification of three groups, which results in a satisfactory level.

Keywords— ankle motion; gait system; data analysis; ankle rehabilitation; angle sensor; ADK R3 micro-controller board

I. INTRODUCTION

The researches have been explained on subjects walking [1], ankle motion [2][3][6][14], and gait analysis [4][5]. Therefore, this learning aims to create an ankle motion measurement during walking, first of all the significant clinical parameters for assessing subjects. This

Applied sensors; Sensor of this study is a passive electronic device that is used to measure physical properties of ankle motion. Sensor applications in term of healthcare are popular because they can measure and monitor the subject data immediately and continuously.

Rehabilitation; Angles of the ankle motion between the leg and foot which experts usually use such angle to measure the rehabilitation of ankle movement when a subject walks the normal behavior. This preliminary research evaluates a subject in gaits and tracks which can cause the changes in walking patterns (gait evaluation). Specifically, the range of motion and the ability to control the ankle is an important issue during the rehabilitation of the subjects. The ankle motion evaluation is usually measured in the sagittal plane.

Classical goniometer measurement; A classical goniometer is a manual tool and a value has depending on how the physician reads the static scale. The reading values must be calibrated before the measurement every time. Subject parameter cannot be recorded automatically.

Problem statement; Goniometer gives only static values per time. The gait tools are usually large and hard to move anywhere. The imported gait equipment is expensive. The number of measured static values is generally too small to be analyzed for meaningful results.

Objectives of this study; Preliminary research is to design and create the equipment that can track the movement of the ankle motion. The prototype is experimented on a small group of subjects with the approval of the university’s Ethic committee for conducting experiments on subjects. The prototype is implemented for portability, reliability, inexpensive, and effective use in a small health center. The prototype shown gait parameter in real time, and the gait data can be used for the walking analysis. The data collected from the measurement of subjects will be analyzed to see the differences of walking patterns in normal subjects and less disability subjects.

II. BACKGROUND

Ankle motion; Preliminary study refers to the range of motion that can explain walking behavior of subjects. The range of motion is the motion amount of each joint. Normal ankle motions are explained as follows: Extension part is the leg position that is straight standing as the minimum angle to increase angle value. Flexion part is the directional leg which is bending and means the maximum angle to decreasing angle value.

Gait analysis; Gait analysis shows subject behaviors, for example when walking, evaluation, and treatment planning. This study focuses on normal people and people with less disability.

Signals the movement of the ankle motion by describing in detail below.

• CP (Controlled plantar-flexion): After initial contact
• CD(Controlled dorsiflexion): As the lower leg progresses forward over the foot
• PP(Power plantar-flexion): During push-off
• SD(Dorsiflexion during swing): Assist foot clearance

The structure of the foot, there are three major parts
• Front feet consists of toe and metatarsal bones section.
• Foot includes the central part of the foot frame.
• The heel is the back foot

The physical structure of the foot muscles and tendons more than 100 pieces, which is responsible for controlling the posture and the movement of the ankle. Generally, humans have used many foot and ankle while walking by foot and ankle to 1.5 times the weight of the body as a walking distance of about 16,000 kilometers per year and gain weight while exercising at about 450 kg per hour. The point is that each year there are subjects who have problems with the ankle and foot by a number of researchers have studied the activity that caused the accident at the ankles, like walking, playing sports, and activities such as football, hockey, etc. The movement of the ankle is a significant issue and the parameters affecting the amount and human life or who have problems walking. As a result, quantitative measurements, such as the degrees of motion of the ankle. Measuring shocks that occur at the ankle or physical behavior that affects movement.

III. LITERATURE REVIEW

We have studied the substance and then summarize the interesting movement techniques used and the conclusions which we have categorized under major topics for study in depth research, innovative projects, for example: the human walking, the movement of the ankle, the gait analysis, and gait evaluation. According to the details as follows:

Human gait: Regular walking [9] The study went on to focus on the ankle by experimenting with shoes created for tripping joints to monitor the reaction of the floor and ankle in stroke patients. The ankle motion research [10] studied the motion of the ankle using surface electromyography sEMG sensors in the measurement and monitoring of human walking. The research [11] presented a structural component design movement marched to apply to robotic systems aim of this research is to increase the overall efficiency of the robot to walk more complex. Parkinson's disease [12] refers to subjects with Parkinson's disease, where subjects are unable to walk steadily, called freezing of gait in subjects can learn to use their voices heard rhythmic and jobs. Research has developed a system to support gait assist for rehabilitation walk in the primary. Developed sensors [13] in the article there had developed sensors worn for approximately torque together in gait analysis, especially wearing a portable sensor system to detect the ground reaction force using the unit of measuring force based on the modulation technique and the combination of the intensity of the light.

Ankle joint motion: Movement patterns of the ankle and foot [9] designed insole built using components of the sensor within 32 sensors and shoe size 10 model, which is an easy way to evaluate the walk. Ankle movement is measured to find the reaction force of the ground and the front and back of the ankle. All applications will be able to apply the sensor 32 of the reaction and the result is a progressive movement of the ankle in subjects who have to walk more normally. The movement of the ankle [10] found that the muscles of normal motion when the ankle is bent or stretched by such movements designed and processed with EMG sensor. The research [11] is learn the proper motion using a robot as a test system moves to the support structure and a sensor to recognize the leadership. Gait Assist [12] is supported portable personal or called Personalized wearable system for support walking by gait assist to detect the freezing of gait with ankle motion sensor and sends the data via blue-tooth to the mobile phone operating system, android In response, the system plays the sound rhythm. that adapts to the pace of a regular patient of research [13] describes the technique of animation using structural and optical properties, which have the advantage, as the signal used to detect the slightest mistake. The GRF (Ground Reaction Force) sensors can detect the plane has three-axis vector and light weight, ease of use and ease of movement.

Gait analysis and gait evaluation; For gait analysis [9] Stroke patients with impaired walking parts of the sensor that measures the number of 32 sensors monitoring the ground reaction force and motion of the ankle. The system can support the evaluation of the walk that is normal or abnormal. Analysis of the results [10] describes the process in the form of the signal caused by the passage by the results in signal sEMG during the motion of the ankle joint and can be the pathway for users to control the movement. the ankle in research [11] is an evaluation of a robotic test under the same environment by analyzing the use Intelligent robot system to support the movement to know the normal and abnormal walking in research [12] describes a system that can be used as a walking aid or support walking for fitness and rehabilitation research [13] in the analysis and assessment to detect motion. (IMU: Inertial Motion Unit) for capturing the movement of the camera and torque share of the ankle, knee and hip were calculated using the sensor system can provide results immediately (wearable sensor system) by value. Joint torques of ankle have been checked against the system, according to conventional sensors.

IV. RESEARCH METHODOLOGY

Principle research methodology: System architecture shown in Figure 1, which is a principle that can explain the steps: First step, research form the structure of the movement of the ankle by a focus on:
• To measure the motion of the ankle.
• Measuring the impact of the ankle while walking.
• Research from theory of human gait system.
Second step, the calculation is the introduction of computer systems, software and hardware to work caused by the assumption of input data formats and values that are different as follows:

- I2C bus system is used for interfacing of I/O part.
- Storage unit is used for recording the gait data analysis.
- Analog to digital convertor uses for real time calculation.
- Software and hardware are combined into process unit.

Third step, analysis of the results measured parameters by a specialist to determine whether expert was commissioning the effect of walking, however, any information that is scientifically significant and is information for gait evaluation.

**Process research methodology:** Figure 2 shows the flow process as follows:

- **Start:** Start Initial state the size and scale input parameter.
- **Input phase:** analog input material consists Angle and Impact force value.
- **Methodology phase:** getting the input data to adjust the linear movement again buffers and then send a digital signal to analog converter (ADC).

- **Data storage:** The storage memory and bring the results into data analysis techniques to identify data clustering results or abnormal gait.
- **Monitoring phase:** the display of information through a display unit such as Serial Peripheral Interface, lighting emitting diode screen, graphic liquid crystal display.

V. **Design and Implementation**

Figure 4 shows the marker sensor can detect when a subject starts walking and stops walking since it can mark a gait cycle from the rising point and falling point. This utility can specify the number of subject’s pace and determine the average value of angles in one gait cycle.

Figure 5 shows a multi-sensor combined with the two sensors. The sensor hardware is a section of the system architecture. The hardware design considers the ankle motion, detection, and markers. The configuration consists of the print circuit board, connectors, belts, and mechanical axis. The connection between multi-sensor and the processing board is a compatible board.
Figure 6 shows the practical prototype of this research. The ankle motion measurement is designed to measure angle and pace numbers. The technical specifications are as follows:

- To measure the ankle motion.
- To measure the angle values \(0^o \leq \text{angle} \leq 270^o\)
- To detect the step number while walking.
- To detect the position, standing or sitting.
- The gait parameters will record data into the SD card while the measurement is working and detecting.
- The power consumption equal to one watt.

```c
// An algorithm 1 the analysis the Angle sensor
// Calculation of an Angle sensor in the range of motion
sweep_angle = analogRead(sweep_a0); // PORTA0
a = ((float) sweep_angle/10); // reduced memory
b = ((float)263/10); // reduced quantity
c = (a*b)/(float)1023; // Analog (input 10 bits)
deg = (c*(float)100)-25; // converted to degree unit
```

Figure 7 Algorithm of the angle sensor

Marker algorithm in Figure 8 shows the marker program that applies mathematical equations to measure the number of paces when walking. The marker algorithm uses the function of digitalRead() from the assigned input port (IN_PIN). The IN_PIN will receive the logical status whether it is low or high. Then the marker algorithm will show a pace number.

```c
// An algorithm 2 the analysis the marker sensor
reading = digitalRead(IN_PIN); //read Digital pin0 or PD2
if (reading == LOW && previous == HIGH) // en/dis
{ delay(DEBOUNCE); // delay 10 mSec
  if(digitalRead(IN_PIN) == LOW)
  state_sw = !state_sw;
digitalWrite(OUT_PIN, state_sw); // OUT_PIN is Dig pin5
  interrupt();
  previous = reading;
```

Figure 8 Algorithm of the marker sensor

VI. GAIT ANALYSIS

A. Human gait

The normal ankle motion signal consists of the stance and swing phases. The range of the CP and CD is from the initial value to 50% approximately. The range of the PP and SD is from 50% to 100% approximately. The maximum swing is considered as the swing phase. The marker sensor marks the position of the start to stop signals. The marker sensor is useful because it can count the pace number. The vertical axis represents the angle value in degree and the horizontal axis represents the timing in second. Figure 9 shown the normal ankle motion signal.

```c
Figure 9 Normal ankle motion signal
```

VII. EXPERIMENTAL RESULTS

The experimental result can be grouped with similar signal of three groups as follows:

The behavior A is first group signal of movement over the ankle of subjects aged 20 to 40 years, while the vertical axis represents the degree units and the horizontal axis measures the size of the unit \(x 10^{-2}\) in seconds as shown in figure 10.
The behavior B is second group signal of movement over the ankle of subjects aged 41 to 50 years, while the vertical axis represents the degree units and the horizontal axis measures the size of the unit (x $10^{-2}$) in seconds as shown in figure 11.

The behavior C is third group signal of movement over the ankle of subjects aged 51 to 60 years, while the vertical axis represents the degree units and the horizontal axis measures the size of the unit (x $10^{-2}$) in seconds as shown in figure 12.

Comparison between the prototype and commercial product as shown in Figure 13, while the vertical axis represents the degree units and the horizontal axis measures the size of the unit (x $10^{-2}$) in seconds.

Future study: Hardware development such as the wireless module, the storage unit, and intelligent sensors should be extended. The software development bases on mobile application.

VIII. CONCLUSION

The results of our prototype to determine the ankle motion in the angle to show the gait data of subjects with a total of 18 subjects have information on walking or angle average value of ankle motion different, we can identify the gait waveform. The movement of the ankle, with similar pattern number in 3 groups.
- Behavior A is 20-40 years, 5 subjects
- Behavior B is 41-50 years, 7 subjects
- Behavior C is 51-60 years, 6 subjects

The findings of this research can be applied initially only apply to science and medicine to some degree by the results of such analysis needs to be supported by professionals with medical science. The research prototype engine is compared with commercial tools that are used the same way. We have a consistent measurement results, respectively.

REFERENCES


