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Locomotors Rehabilitation System via Gait Analysis with Load cell, Gyroscope and Accelerometer Sensor

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Abstract: Locomotors Rehabilitation System (LRS) has a potential used with the advancement in electronic and computer. It requires sensors for a locomotion measurement and units to communicate between patients and the doctors. These promote a flexible and economical solution to a Gait analysis by develops units to differentiate the abnormal and normal patient different walking pattern. The LRS consist of a PIC microcontroller, RF transceiver, analogue multiplexer plus sensors for the compressive force, acceleration and angular velocity measurement. Later, these measurements are sent to the computer for further human locomotion analysis. The data transmission is optimized up to 250 meters line of sight with ±3 g acceleration, tilt angle at ± 0.1 ° and ≤ 150 Kg bodyweight measurement. The LRS is expected to offer more information than the Gait analysis and also the ability to improve the clinical and rehabilitation applications.

Keywords: Gait analysis, Locomotors Rehabilitation System, Embedded System, Load cell, Accelerometer, Gyroscope

1. Introduction

Human gait is an important indicator of health, with an applications ranging from diagnosis, monitoring, and rehabilitation. In practice the use of the Gait analysis has been limited and its widespread application in biomedical engineering began with the availability of video camera systems [1-5]. Either it becomes very expensive, intrusive, or requires well-controlled environments such as clinic or a laboratory [6]. Some of it happen to be impractical due to lots of sensor had been used [7].

A Locomotor Rehabilitation System (LRS) via Gait Analysis is a recovery intervention from neurologic injury or diseases such as spinal cord injury and stroke disorder. The study of human locomotion in the Fig. 1 is a continuum from standing, walking to running. It involves starting, stopping, changing directions and altering speed [8].

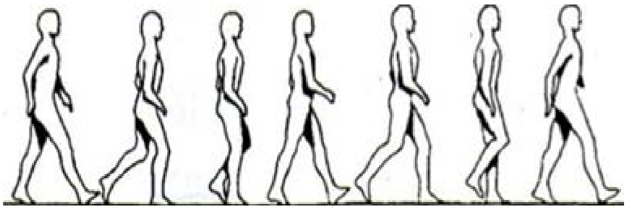

Fig. 1 Standing/walking/ running human locomotion

Most of the gait analysis deals with high technology camera for measuring retro-reflective markers positions [9-14]. Failures to place markers accurately and soft tissue artifact affect the measurements accuracy [15].

A calibrated intelligent sensors were installed under floor to monitor and assess fall risk. However due to its cost with sophisticated instrumentation and specialized personnel, makes it difficult to be applied [16].

Similar works was made via a wearable sensor. It was uncomfortable since too many sensor to hook up at exact position that were subjected to a gravity, noise and signal drift [17].

Other related contributions are the O'Donovan et al and Choquette et al developed a scientific monitoring limb's motion and measures of heart rate using Body Area Network (BAN) [18][19]. It was cumbersome due to its numbers of devices and the tedious task of getting dressed with them.

The paper is expected to attract interest because it is non-invasive and does not require the subject's cooperation on a walking pattern identification [20]. The objective of this work is to develop software and hardware for measuring locomotion force via load cell, gyroscope and accelerometer to analyze normal and abnormal human gait.

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2. Materials and Methods

Fig. 2 shows the block diagram of the system development.

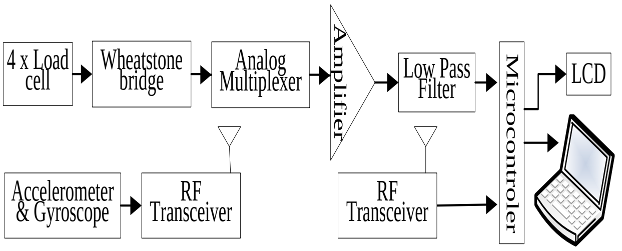


Fig. 2 Locomotor Rehabilitation System

Referring to the Fig. 3, locomotion force was measured via quadruple load cell and interface to the Wheatstone bridge in a ½ bridge configuration. Note that Rx is the 1k Ω resistor for balance the Δ Vout when ΔRx of the load cell is at a resting state.

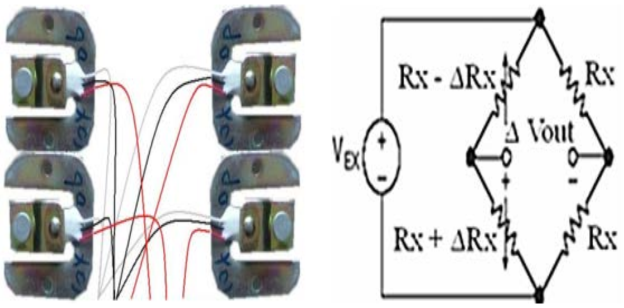


Fig. 3 Load cell and Wheatstone bridge

As illustrated in the Fig. 4, locomotion force at axis (X,Y) was measured by fitted each of the load cell under a2^2-feet plank at point A, B, C and D.

Fig. 4 Load cell placements

An economical system of single Instrumentation Amplifier (AD524) to amplify quadruple load cell was achieved in the Fig. 5 via a serial analogue multiplexer (MAX349). It was controlled by the three wire synchronous serial interface via time division switching technique. AD524 Instrumentation Amplifier (IA) is choosed as a perfect solution for amplifying noisy load cell's signal [21].

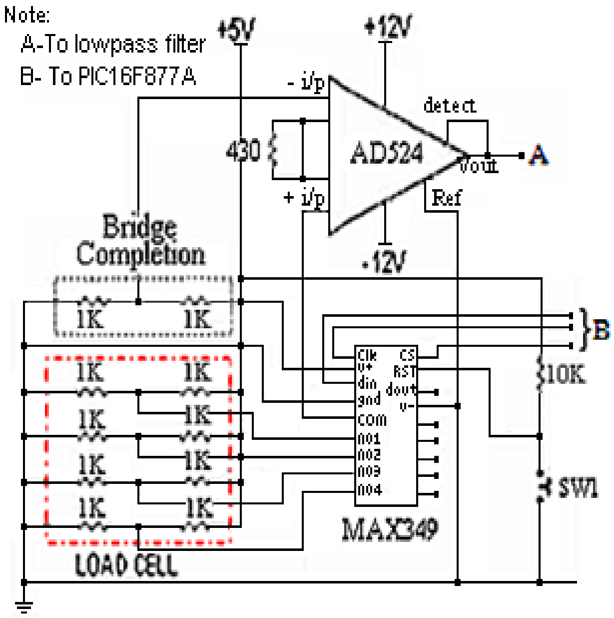


Fig. 5 Locomotion conditioning circuit

Referring to the Fig. 6, a 16 Hz passive low-pass filter with a voltage buffer (LM124) is cascaded to attenuate 50 Hz power line interference and noise such as artefact, environment and natural randomness.

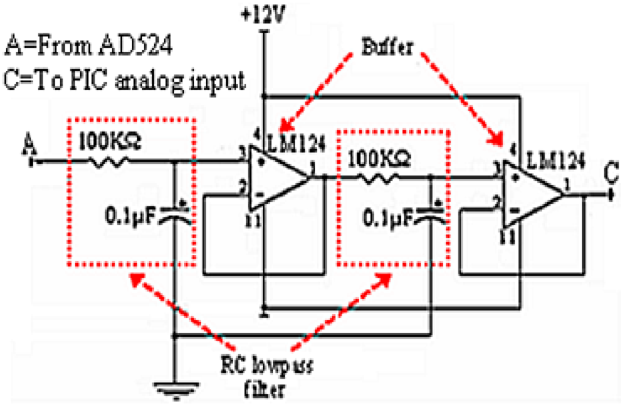


Fig. 6 Filtering and buffering circuit

The SN-IMU5D-LC in the Fig. 7 was placed to the subject feet or legs for measuring the motion status in the human gait. It is a simple breakout for the ADXL335 accelerometer and the ENC-03R gyro. The board comes with 5 degrees of freedom at degree per second gyro rate at and 3 dimensions acceleration (g's).

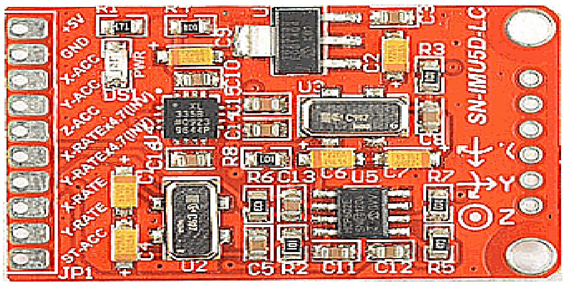


Fig. 7 Accelerometer and Gyro breakout board

A complementary filter algorithm was applied to handle drift and unstable performance of the Accelerometer and Gyro breakout board. In this study, the rehabilitation were done between Below Knee Injuries (BKI) and Non-BKI subjects. In Fig. 8, the subject were tested on the LRS platform while fitted with the accelerometer and gyroscope.

Fig. 8 LRS experimental procedure

The experimental methods have been composed of an exercise which is a part of the rehabilitation procedure. The experiments are listed in the Table 1.

Table 1 Experimental Procedures

Exercise	**Experiments procedure**
Walking	The BKI and Non-BKI subjects is walking on the locomotion platform to allows load cell measures the locomotion force while SN-IMU5D-LC module measure 3-axis acceleration, orientation and angular velocity over a specified durations.

Each experiment need to be sampled at least at 500 times per milliseconds for the locomotion force, gyro and acceleration before calibrated, displayed and transmitted on air via RF transceiver module (ER900TRS). A dedicated PC software is written in a Visual Basic program for reading asynchronous serial data at 38.4 Kbps baud rate via RF transceiver module (ER900TRS). The data are configured in a packet to prevent data losses and corrupt. It includes bytes for start qualifier, force, acceleration, angular velocity and end qualifier.

3. Results and Discussion

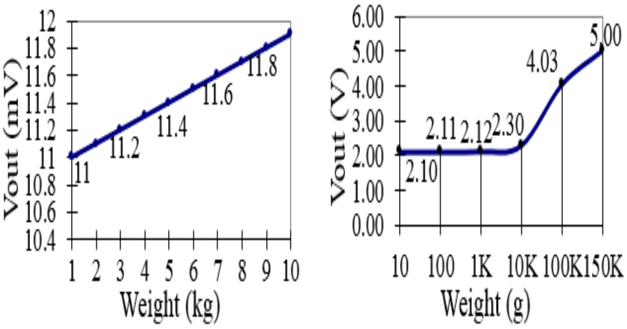
The load cell response in a compressive force had been conducted from a resting state until 10 Kg. A linear result in Fig. 9(a) was obtained and represented in the equation (1).

$$y = 0.1x + 10.9 \tag{1}$$

Therefore, given Weight(x)=150 Kg × 0.1 mV, Vout(y)=25.9 mV. As noted in the equation (2) when Amplifier Vout= 5 V, Amplifier Vin= 25.9 mV then Amplifier gain, AV=193.

$$AV = {}^{Vout}\!\!\diagup_{Vin} \tag{2}$$

Fig. 9(b) indicates an Instrumentation Amplifier (IA) voltage output from 10 g to 150 Kg of applied weight. A significant voltage output had change from 10 Kg onwards which is relevant to the adult bodyweight measurement.



(a) Load cell output (b) Amplified output

Fig. 9 Weight Vs Voltage

Referring to the Fig.3, a small change of the load cell (Δ *Rx*) will cause a tiny output voltage of Wheatstone bridge output (Δ *Vout*) as expressed in the equation (3) and derived in the equation (4).

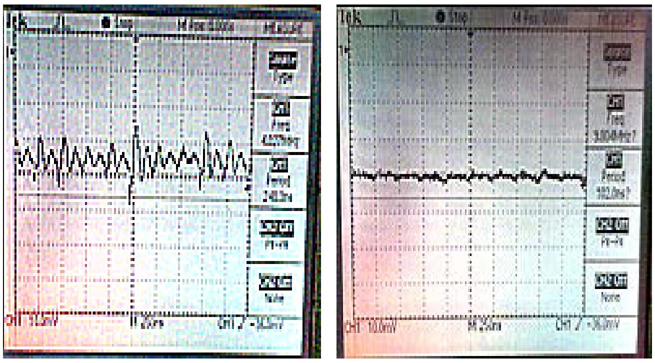
$$\Delta Vout = \left[\frac{Rx + \Delta Rx}{Rx - \Delta Rx + Rx + \Delta Rx} - \frac{Rx}{2Rx} \right] Vex \tag{3}$$

$$= \left[\frac{Rx}{2Rx} + \frac{\Delta Rx}{2Rx} - \frac{Rx}{2Rx} \right] Vex$$

$$= \left[\frac{\Delta Rx}{2Rx} \right] Vex$$

$$\Delta Rx = \frac{2(Rx)(\Delta Vout)}{Vex} \tag{4}$$

Therefore, given resistor *Rx*=1 kΩ, Δ*Vout*=0.1 mV and excitation voltage *Vex*=5 V the Δ*Rx*=0.04 Ω. Thus at every 1 kg, 1 kΩ load cell will change at 0.004 %. As a result, at 150 kg, Δ*Rx*=6 Ω and Δ*Vout*= 15 mV + 10.9 mV (load cell at resting state) is equal to 25.9 mV. Finally at 150 kg, the equation (1) and equation (4) will lead to the same result. The high frequency noise due to the natural randomness In Fig. 10(a) such as imbalance posture and human respiration was successfully smoothed out In the Fig. 10(b) via the low pass filter.



(a) (b)

Fig. 10 Low pass filter at 16 Hz cutoff frequency

In Fig. 11a to 11d shows the averaging result over fluctuation caused by the natural randomness. The lower LCD row represents the 200 samples of the 10-bit accumulative Analog Digital Converter (ADC) fluctuated result while the upper LCD row is its consistent average value. The averaging technique was successfully handle the measurement fluctuation by divide the accumulative ADC values by 200 samples to obtain stable ADC output at 56.

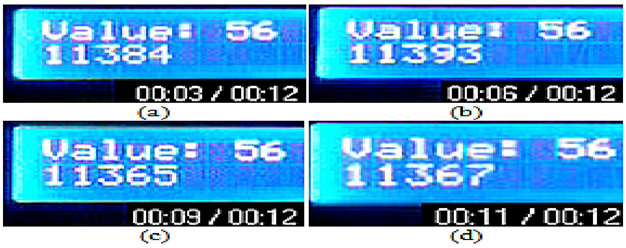
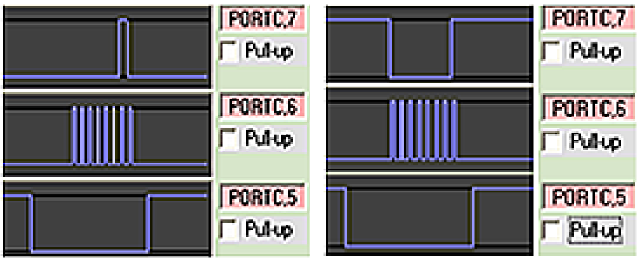


Fig. 11 The averaging result on LCD

The MAX349's analog switches for multiplexing four load cells to a single amplifier was successfully tested. It allows data (DIN/ PORTC.7) to be clocked-in synchronously with the rising edge of clock (SCLK/ PORTC.6) and finally updates the analog switch status via chip enable pin (CE/ PORTC.6) as shown in the Fig. 12(a) and Fig. 12(b).



(a) Switch 1 is closed (b) Switch 0 is closed

Fig. 12 Multiplexing the MAX349's analog switches

An acceptance test was conducted in Fig. 13 with the bodyweight result was displayed on the LCD before transmission to the master unit on air via the RF transceiver.

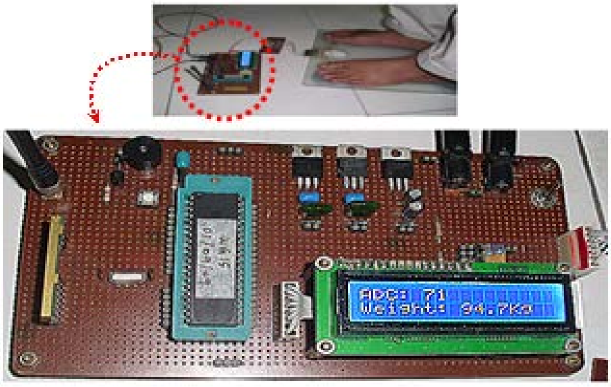


Fig. 13 Body force measurement system testing

Referring to the Fig. 14, a data packet consisting of a start qualifier 'A', ADC value and end qualifier 'Z' were send via the RF transeiver. The data packet assures the RF transmission is encrypted, secured and zero data losses.

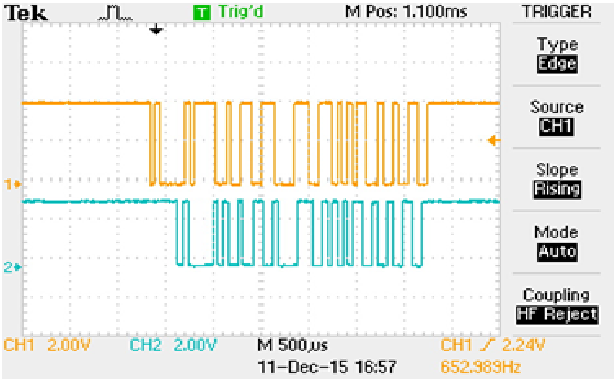
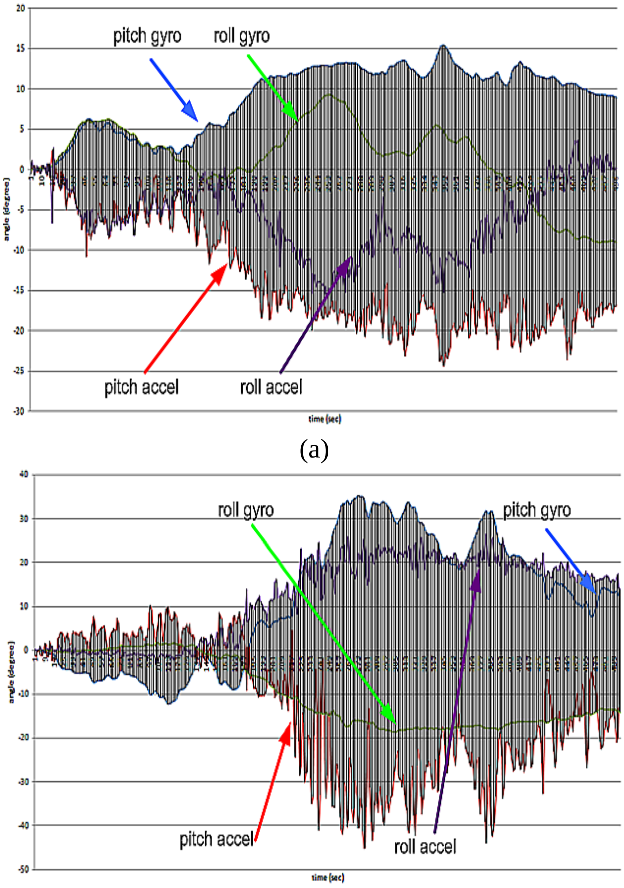


Fig. 14 RF data transmission

A SN-IMU5D-LC experimental result in Fig. 15 was initially tested for acceleration and angular velocity when BKI and Non-BKI subjects were walking on the LRS platform. Refer to Fig. 15(a), it can be seen that the Non-Below Knee Injuries subject is producing a Non-distorted waveform for all axes. While a Below Knee Injuries (BKI) subject indicates a distorted waveform as shown in Fig 15(b). This clearly shows the walking pattern for Non-BKI/ BKI subjects for abnormal/ normal walking ability.



(b)

Fig. 15 Acceleration Vs Angular velocity measurement for BKI and Non-BKI subjects

4. Summary

The potential of combining load cell, accelerometer and gyroscope sensor was effective for locomotors rehabilitation process via gait analysis. Based on the results, the load cell change (ΔRx) at 0.04 Ω/ 0.1 mV per Kg. As linear interpolation, ΔRx is equal to 6 Ω/ 25.9 mV at 150 Kg. The Instrumentation Amplifier voltage gain is set to 193 that measure range between 10 Kg ~ 150 Kg bodyweight. The low pass filter and averaging algorithm was effectively remove any high frequency noise prevalent in most environmental settings. The calculated tilt angle from the accelerometer data has slow response time, while the integrated tilt angle from the gyro data is subjected to drift over a period of time. A method to combine the data from the gyro and the accelerometer is by using the complementary filter. This will result in a drift free and fast responding estimated tilt angle. One of the future works of our system includes the use of a smart phone can be particularly helpful for the recognition and validation of the exercise's beginning and end. Moreover this new technology helps patients to wear the mobile device at home. In summary, our system improves the physician monitoring, guide patients on the rehabilitation process, and can reduce the problem of health care systems overcharge.

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