Wearable Computers for Quantification for Lower Back Disorders

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INTERFACE CONTROL DOCUMENT

REVISION – Draft
2 March 2016

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FOR
Wearable Computers for Quantification of Lower Back Disorders

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Change Record

Rev.	Date	Originator	Approvals	Description
-	3/2/2016	Team		Draft Release

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1. Overview

Low back disorders (LBD) are very common disorders where the muscles and the bones of the back are involved. It affects about 40% of people at some point in their lives, which results in a substantial cost to society in terms of healing the patients. Although society knows about this common problem, in general, there has been little to no progress in the control of LBDs. This is because many assessment tools of low back disorders are subjective. As a result, usage of a wearable device which will quantify the level of LBD within patients to allow physicians to make more accurate diagnosis of LBD is being investigated.

In this document, the subsystems and interfaces for our wearable electronic device will be defined. This will include the general purpose of each subsystem, as well as its inputs and outputs to allow for interconnection and communication between the entire system. While defining our inputs and outputs, we will denote the specific connection types, standards, and other specifications required to start defining how our entire system will operate.

2. References and Definitions

2.1. References

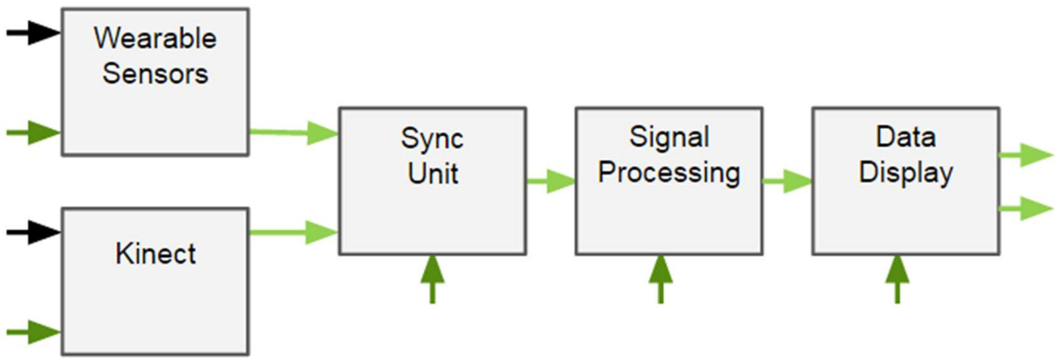
- **MPU-9150 Product Specification Sheet, Revision 4.0**
  14 May 2012
- **Blue Creation BC127 Datasheet**
  29 November 2013
- **Openkinect Protocol Documentation**
  7 March 2012

2.2. Definitions

mA	Milliamp
mAh	Milliampere-hours
mW	Milliwatt
kHz	Kilohertz (1,000 Hz)
MHz	Megahertz (1,000,000 Hz)
TBD	To Be Determined
bpp	Bits Per Pixels
fps	Frames Per Second
MSI	Motion Sensor Interface
lbs	Pounds
PCB	Printed Circuit Board
V	Volt
LBD	Lower Back Disorders
SPU	Signal Processing Unit
SU	Synchronization Unit
GBPS	Gigabytes per Second
ms	Milliseconds

3. System Interface

Figure 1: Overall System Interface



- Physical data: Angular motion captured
- Intermediary Signals: Bluetooth, USB, and other wired connections
- Output Signal: Simple readable display with numerical results

3.1. Physical Interface

3.1.1. Weight

There are multiple components of the overall system, but all must follow some basic guidelines. Anything wearable must be able to be worn comfortably, meaning all wearable pieces should be lightweight (less than 3 pounds). This system should also be reasonably portable. Thus, all other components should be reasonably able to be carried around (all modules less than 30 pounds). Specific details concerning the weight of the various subsystems may be found in their respective appendices.

3.1.2. Dimension

The components of the system vary in size but overall will fit easily into a relatively small patient room in a doctor's office. Each physical component will be relatively small in size, but the standing room required for the patient to use the Kinect will consume the most space by far. Specific details regarding the dimensions of individual subsystems is located in their respective appendices.

3.1.3. Mounting locations

The overall system will be placed in a patient room in a physician's office, which consists of having a relatively open, but small room with the purpose of giving the patient the freedom to perform the test without any obstructions. Additionally, this will allow the Kinect to perform better without any hindrances. The system will be set up with a patient, wearing the wearable sensors, facing a television screen and Kinect, spaced around 6 feet away from the screen. There will be a laptop which will function as the synchronization unit, signal processing unit, and results data display unit in close proximity to the Kinect as that requires a wired USB connection. Further information about the location of subsystems relative to one another may be found in the appendices.

3.2. Electrical/Communications Interface

3.2.1. Primary Input Power

The system will be powered via a standard 120V AC wall socket at 60 Hz. This power input will provide energy for the Kinect, technician monitor, patient monitor, and computer run sub systems. The wearable electronic devices are powered by 3.7V, 400 mAh batteries. These batteries can be charged via a USB to micro-USB cable.

3.2.2. Signal Interfaces

The input signals will come from three places in the system. The physical inputs of the patient will be converted to digital signals by the sensor modules and the visual representation of that data captured by the Kinect and digitized. The final signal input will be the keypresses and mouse clicks of the technician operating the system. These will also be converted to their digital streams and interpreted by the technician control interface.

3.2.3. User Control Interface

3.2.3.1. Patient Interface

From the patient perspective, the patient will wear two pieces which will contain the wearable sensors in order to gather data. In addition, the patient will stand in front of the Kinect approximately 2 feet away. Afterwards, the patient will perform a series of test according to the software provided by the GUI, which will guide the patient in every step of the way to successfully complete it.

3.2.3.2. Technician Interface

The technician will utilize a standard computer interface in order to interact with the system. This includes a keyboard, mouse, and LCD screen monitor. Physical input will be provided to the mouse or keyboard concerning which test to be implemented and for what duration. Any errors during the testing process will also be displayed to the technician for rectification.

4. Communications/Device Interface Protocols

4.1. Wireless Communications

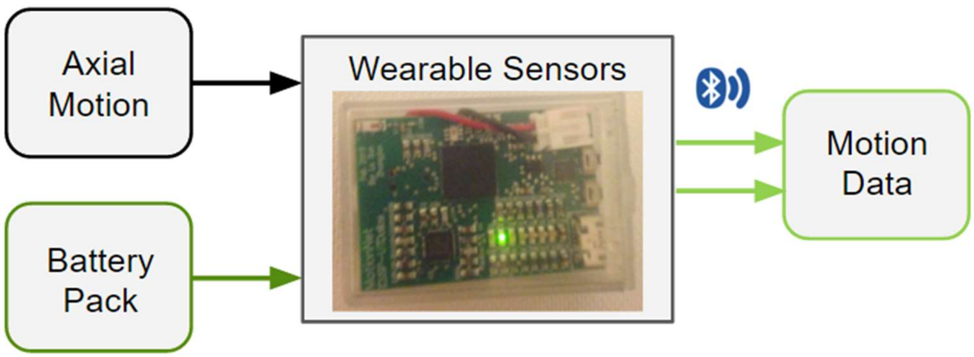
- IEEE 802.15.1: WPAN / Bluetooth

- IEEE 802.11a: OFDM Waveform

5. Appendix: Subsystems Interfaces

5.1. Wearable Sensors Interface

Figure 2: Wearable Sensors Interface



- Axial Motion: At various angles, must maintain posture.
- Battery Pack: One wired system to power all wearables.
- Motion Data: Bluetooth signal of raw motion data.

5.1.1. Physical Housing Interface

5.1.1.1. Weight

The sensors will be housed in two separate pieces, thorax housing and waist housing. The thorax housing needs to be made of lightweight, cushioned material for comfort of the user, but also have a rigid brace to keep the sensor steady. The unit should weight around 2 pounds. The waist housing has similar requirements: lightweight, comfortable, but must maintain the integrity of the sensor. The waist unit should weigh around 5 ounces.

5.1.1.2. Dimensions

The thorax housing will measure approximately 12 inches in height by 16 inches in length by 8 inches in depth in total volume. The unit must fit a reasonable wide amount of body types with a reasonable amount of comfort. The waist housing will be annular in shape, adjustable in a range of 32 inches in circumference to 40 inches in circumference. The unit will be 1.5 inches tall and, at its thickest point, 1 inch in thickness.

5.1.1.3. Mounting Locations

The thorax unit will be worn like a harness around the chest of the patient. The waist unit will be worn in the fashion of a belt.

5.1.2. Physical Sensor Interface

5.1.2.1. Weight

There will be two MotionNet sensors in total. Each MotionNet sensor is comprised of an accelerometer, gyroscope, and magnetometer on a PCB with Bluetooth communications, connected to a battery, inside of a 3D printed box. Each unit weighs 1.5 ounces.

5.1.2.2. Dimensions

Each 3D printed box, which houses the sensors, measures 0.71 inches in height by 1.13 inches in width by 1.60 inches in length, on the outside. The inside measures 0.61 inches in height by 1.05 inches in width by 1.57 inches in length.

5.1.2.3. Mounting Locations

One sensor will be mounted on both of the physical housing modules. Both sensors will be mounted on the back of their respective modules, along the spine, in the center.

5.1.3. Electrical/Communications Interface

5.1.3.1. Primary Input Power

The power input will be a small rectangular battery that is capable of fitting the inside the 3D printed box. The battery will supply 3.7 V and have a span of 400 mAh.

5.1.3.2. Signal Interfaces

The inputs of the sensors will be the raw physical data captured by the accelerometers and gyroscopes. Most importantly, the angular displacement and acceleration as measured between the two sensor units. This information will also be used to derive the angular velocity and jerk between points. The raw data is captured in the x, y, and z planes relative to the sensor. Each data point captures 16 bits of data and is captured at a rate of 1.024 kHz. So in total, per MotionNet sensor, the output is 6 16 bit 1.024 kHz digital I^2C signals.

5.1.3.3. User Control Interface

The MotionNet sensors do require some way for the developer to access and change their logic. This is done through a mini-USB connection that is mounted on the PCB and is accessible by opening the 3D printed box. The code governing the logic of the MotionNet sensor is C#, a graphical higher level of C.

5.1.3.4. Wireless Communications

To communicate the raw data acquired to the signal processing unit, a Bluetooth 4.0 unit is attached to the PCB of the MotionNet sensor.

5.2. Motion Sensor Interface

Figure 3: Motion Sensor Interface

- Joint Motion: Front view of Body.
- USB Power Supply: Wired system to power the Kinect.
- Motion Data: USB 3.0 to transmit skeletal raw data.

5.2.1. Physical Interface

5.2.1.1. Weight

The motion sensor interface (MSI) will be a Microsoft Kinect that will be run in conjunction with a computer. Therefore, the weight of this subsystem is approximately 4.5 pounds, depending on the accessories that will include for the proper function of the Kinect.

5.2.1.2. Dimensions

As mentioned, this subsystem will be the Kinect, which means that the dimensions are 5.46 x 14.2 x 6.48 inches.

5.2.1.3. Mounting Locations

The motion sensor interface will be planned to be mounted in the physician's office. As a result, the Kinect will require a tripod, or be mounted over a monitor for it to be sufficiently stable. In addition, we will have to make sure that the front of the sensor is not obstructed by power cords, computer cables, or other solid objects, as well as, make sure the Kinect sensor is in a well-ventilated space for it to properly function.

5.2.2. Electrical/Communications Interface

5.2.2.1. Primary Input Power

The input power will a special adapter made by Microsoft, which takes a normal wall socket connection (~120V, 15A) and supply power to the Kinect via USB 3.0.

5.2.2.2. Signal Interfaces

The MSI will receive the movement of the patient as an input, which will be focused on the Joint movement, and the depth of where the patient is. This will be handled internally in the Kinect and will be sent via USB 3.0 to the computer, which afterwards, it will be analyzed by a special software made for the Kinect that process the data by outputting the skeletal raw data and analyze 26 joint points from the body. Finally, it will go into the next subsystem for synchronization.

5.2.2.3. User Control Interface

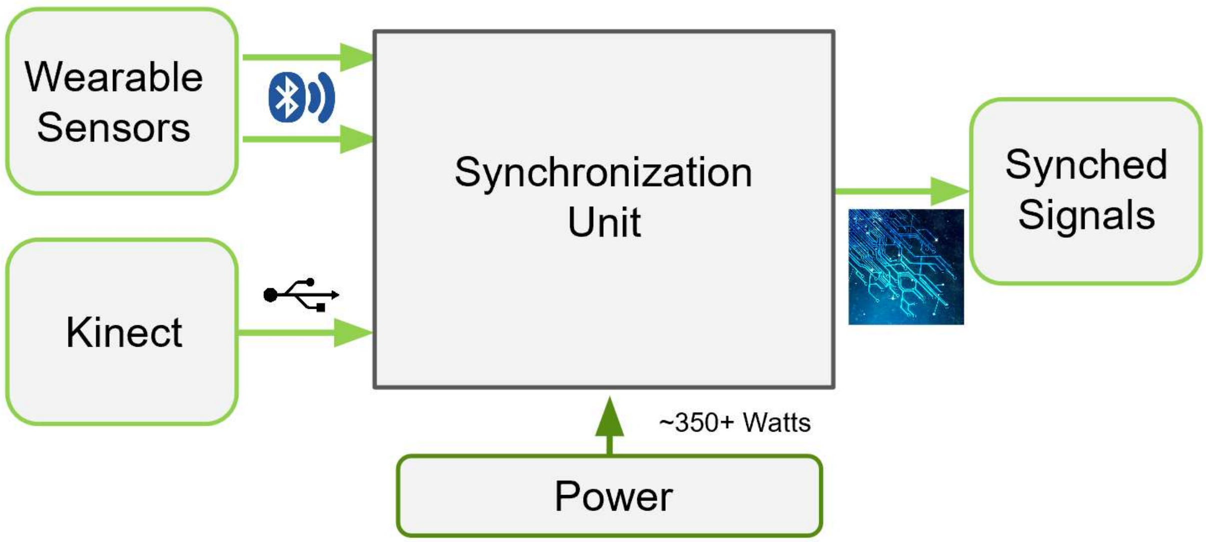
The MSI will require a basic setup, which it consists on opening the main software for the Kinect to start gathering data and sending it over to the computer. This will run in real-time and does not require anything else, besides the movement of the patient to start the test.

5.2.2.4. Wired Communications

As mentioned before, the data transfer will be handled via USB 3.0, which will be expecting a data transfer of at least 2 GBPS. This will consist of three different bitstreams, which are color, depth and infrared. The color stream will be our main data, which takes 1920 x 1080 x 16 bpp at 30 fps, the depth stream will take 512 x 424 x 16 bpp with a 13-bit depth, and the infrared stream will take 512 x 424 bpp with an 11-bit dynamic range. In addition, this will send a control packet structure of 8-bytes, which consist of RequestType (1 byte), Request (1 byte), Value (2 bytes), Index (2 bytes) and Length (2 bytes). As a result, this will be used to read accelerometer values, set Motor/LED status and camera registers that is integrated in the Kinect. Thus, we will be expecting a latency of approximately 60-80 ms by tracking this information.

5.3. Synchronization Unit Interface

Figure 4: Synchronization Unit Interface



5.3.1. Physical Interface

5.3.1.1. Weight

The Synchronization Unit (SU) will interface via a computer, running as MATLAB code. This therefore will not factor into the physical weight aside from the necessity of a computer to run the MATLAB program and receive the input signals. Therefore the required weight for the SU will be wrapped into the computer weight at an aim of approximately 25 lbs.

5.3.1.2. Dimensions

The dimensions for the SU will follow those of the computer that will be running the MATLAB code. The physical dimensions will therefore be less than 20'' x 20'' x 10''.

5.3.1.3. Mounting Locations

The mounting location for the SU will coincide with the location of the computer running the MATLAB program. This unit is an integral bridge between both sensor units and the signal processing unit, so the computer must be within Kinect cable range and Bluetooth 4.0 range.

5.3.2. Electrical/Communications Interface

5.3.2.1. Primary Input Power

Due to the SU being run from within a computer, the required input power for the unit to function is supplied via the computer power supply. This power requirement is approximated at 200W and with a current draw of no more than 15A.

5.3.2.2. Signal Interfaces

The SU must be capable to receive multiple input streams from the sensor devices. Therefore it must read in data streams from the wearable sensors at 16 bps via Bluetooth 4.0 as described above in section 5.1.3.2. The expected latency for the Bluetooth module is approximately 3 milliseconds. The Kinect signal interface is through USB 3.0 cable as also described above in section 5.2.2.4, and will experience a latency of approximately 60-80 milliseconds. The Bluetooth interface signals will then be delayed in this module and two output signals will be produced. These signals will follow their previous standards as described, but will each timestamp will coincide with the same global instant.

5.3.2.3. User Control Interface

This unit will not contain any user control, as established latencies from the system should be universal across use. Should alternate technologies be used in the sensor systems, adjustment of raw MATLAB code should be performed by a qualified technician.

5.3.2.4. Wireless Communications

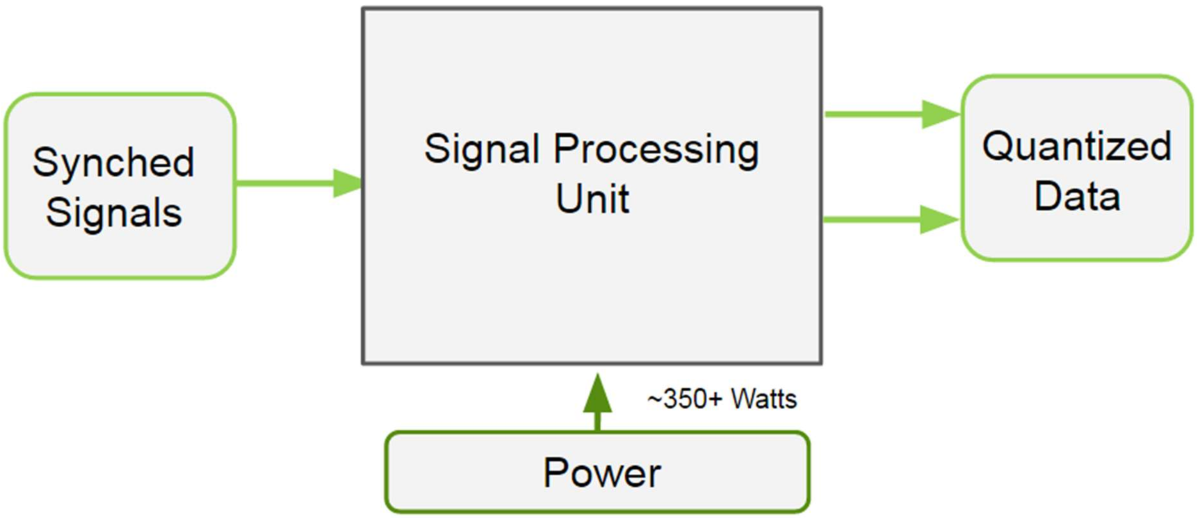
There will only be one wireless communications signal incoming to this module, which will follow Bluetooth 4.0 standards.

5.3.2.5. Wired Communications

There will be one wired communication signal coming into this module, which will follow USB 3.0 standards. The output of this module will be stored into memory, directed by the computer's operating system. This memory will then be accessed by the Signal Processing Unit to provide real time signal analysis.

5.4. Signal Processing Unit Interface

Figure 5: Signal Processing Unit Interface



5.4.1. Physical Interface

5.4.1.1. Weight

The Signal Processing Unit (SPU) will be a program that is run on a computer. As a result, the weight of this subsystem will be the weight of the computer which will be mounted in a physician's office. As a result, the aim is to have this subsystem weigh less than approximately 25 lbs.

5.4.1.2. Dimensions

As mentioned, this subsystem will be the desktop computer which means the dimensions desired will be less than 20" x 20" x 10".

5.4.1.3. Mounting Locations

The computer will be required to also implement the Data Display subsystem which will output required data to the physician. As a result, the SPU will also be mounted in the physician's office.

5.4.2. Electrical/Communications Interface

5.4.2.1. Primary Input Power

Since the SPU is interfaced internally in the computer, the input power will simply be a standard PC Power Supply (power depends on PC's power supply) connected to a standard wall socket (~120Vac, 15A).

5.4.2.2. Signal Interfaces

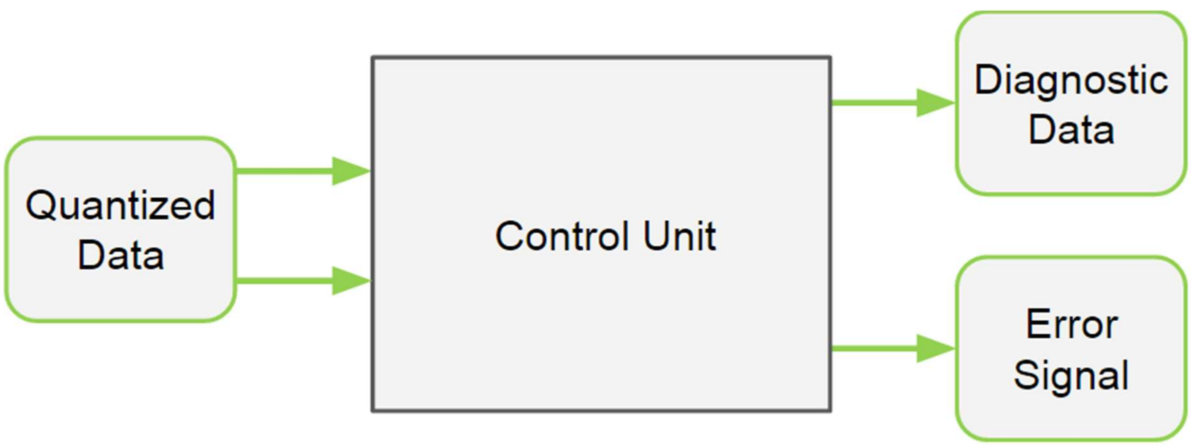
The SPU will receive a set of synchronized signals from the synchronization unit which will contain a comprehensive set of sensor data. This will be handled internally in the computer and sent through a process which will return a stream of data in the form of the corresponding sensor data according to their specific APIs mentioned above with timestamps attached. The SPU will then collect this data into a data structure and begin to analyze and correct the data and output a quantified LBD level within the patient which we will aim to make a number on a scale of approximately 1-10 (decimal values will be allowed to give a more accurate analysis rather than an attempt at rounding). It will proceed to directly send the data it received and analyzed which supports its quantified result, the result itself, and any notifications of serious errors during analysis to the Data Display Interface.

5.4.2.3. User Control Interface

The SPU will not be user accessible and will run in the background processing the data received from the synchronization unit to quantify LBD so all of the user control will be done through the Data Display Interface.

5.5. Data Display Interface

Figure 6: Data Display Interface



5.5.1. Physical Interface

5.5.1.1. Weight

The Data Display Interface (DDI) will be another computer program which creates a GUI on the computer monitor (LCD). As a result, the subsystem will be the weight of the computer as mentioned above plus the monitor itself (a typical monitor weighs approximately 10 lbs).

5.5.1.2. Dimensions

Once again, the DDI will be the dimensions of the computer mentioned above as well as the monitor which will be less than 24in x 24in.

5.5.1.3. Mounting Locations

Since the computer is mounted in the physician's office, the monitor will be mounted as well in the physician's office in order to allow for easy connection.

5.5.2. Electrical/Communications Interface

5.5.2.1. Primary Input Power

The computer will be powered by the power supply mentioned above, and the monitor itself will be powered via a normal wall socket connection (~120Vac, 15A).

5.5.2.2. Signal Interfaces

The DDI will receive the set of supporting data, error signals, and quantified level of LBD mentioned as input from the SPU. Once again, this will be done internally by the computer through software which will receive the set of supporting sensor data as a reference to the data structure containing a comprehensive list, an integer value for the quantified level of LBD, and some simple integer values which will be parsed to specify the error values and figure out what the value corresponds to. This data will be displayed to the monitor using a GUI built using a GUI builder such as Windows Forms available for C# and Windows C# API.

5.5.2.3. User Control Interface

The DDI will be required to receive user input from the mouse and keyboard in order to allow the physician to search and filter the supporting data received and hide or expand other features. As a result, we will be receiving inputs through standard I/O interfaces through the Windows API for C#.