Bluetooth™ Enabled Accelerometer Tracking (BEAT) Technology for Leg Ulcer Patients

Aleksey Shaporev¹, Vladimir Reukov¹, Chengyi Tu¹, Mathew Gregoski², Frank Treiber², David Kwartowitz¹, Teresa Kelechi², Alexey Vertegel¹

¹Bioengineering Department, Clemson University, Clemson, SC;
²College of Nursing, Medical University of South Carolina, Charleston, SC

Our group is working on development of new mobile health devices/services in collaboration with physicians and nurses to improve patients’ quality of life
The problem:

- Overweight patients with diabetes often face a problem of “diabetic limb” caused by insufficient blood supply and chronic foot blood deoxygenation;
- This can lead to poor healing of even minor wounds and may eventually require amputation of toes or the entire foot due to development of gangrene;
- Physical activity (PA) is critical to improve the condition of their legs and promote wound healing;
- Unfortunately, these patients are unable to engage in guideline based PA programs;
- PA programs at home is the most economic way of these patients treatment, but those programs are often inefficient due to lack of compliance and patient’s motivation.

- So, patients remote monitoring is necessary to motivate them to have PA.
Requirements to PA remote monitoring system:

• **Small size** – sensor must small enough to be nested at foot or shoes;

• **Sensitivity** – sensor must be able to record small accelerations corresponding to exercise motions;

• **Power efficiency** – battery lifetime must be reasonably high;

• **Interactivity** – device must be able to analyze patient’s PA, perform statistical analysis, encourage him to perform exercises and warn patient (and his physician) if PA is insufficient;

• **Telecommunication capabilities** – device must be able to transmit data to physician, and retranslate doctor’s recommendations to the patient.

http://www.awaretechs.com/WirelessAccelerometer.html

What is BEAT? An accelerometer-based system for remote smart monitoring of overweight patients' physical activity

BEAT consists of 3 main parts:

**Hardware+ Firmware**: power-efficient components assembled into a sensor which measures patients' PA and communicates via Bluetooth with patient’s smartphone.

**Software** (smartphone’s program) receives data from the sensor, performs data analysis, performs patient feedback and sends processed data to the web-server.

**Netware** (internet-server and corresponding web-sites) collects data sent by phones and provides doctor an access to PA data and data analysis capabilities.

**BEAT features:**

- sensor is small enough so it can be affixed to patient’s foot or slipper;
- can monitor and record patient’s exercise for a prolonged period of time;
- smartphone analyzes PA and automatically transmits the recorded data to the health care providers office.
Sensor consists of **radiomodulus** (Bluetooth), **microprocessor**, **accelerometer** and a **battery** assembled on a single board that can be as small as quarter.
We developed BEAT application for Android OS with following functions:

- **Wireless connection to the sensor**;
- **Data analysis**: determines whether patient makes an exercise or no, distinguishes between exercises and calculates exercise duration and significant parameters (magnitude, frequency etc.);
- **Conversation to user/patient** (stimulate him to do required actions, inform him on analysis results and his progress – e.g. to motivate him);
- **Data transmission to server** (where doctor has and access to them and to statistics).
**Server:**

- Stores data;
- Provides access to the data to authorized users (physicians etc.);
- Performs statistical analysis of received data (and provides access to the statistics to authorized users);
- Performs feedback (to patient and/or physician).
**Validity/Reliability:**

**Why so important?** Because exercises include limited motions with relatively small accelerations, so accelerometer sensor must be both sensitive and reliable.

- Device reliability was checked in an experiment with 4 devices, coefficient of variation was found to be <1% - so assembled developed devices are reliable.

![Fig. 1. Schematic of exercises recommended to patients](image1)

![Fig. 2. Two device comparison data – reliability study.](image2)
**Validity/Reliability:**

- A software was designed to distinguish between different exercises that patients are supposed to do. Special decision-tree type data analysis algorithm (including PCA and FFT) was developed;
- Tests showed that application works well (fig. 1). As well it was found that software is able to recognize exercises done by different patients (fig. 2).

**Fig. 1.** Various exercises done by a volunteer distinguished by software.

**Fig. 2.** Level 2 Exercise 1 acceleration data for two volunteers.
BEAT system was developed, including:

- **BEAT sensor** was created;
- **Smartphone software paired with internet-based solution** was developed to provide remote monitoring of patient’s physical activity;
- Both sensor and software were tested for reliability and found to be reliable.