Wireless Motion Bands

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ABSTRACT
In this paper, we present a wearable and wireless sensor device prototype called Motion Band. It can be easily strapped to any body part to provide accurate motion and orientation information. With a single Motion Band we can recognize a motion trajectory of an individual body part, whereas multiple Motion Bands enable accurate tracking of full body poses and gestures. Real-time feedback to the user during an exercise opens a number of new promising applications, e.g. an interactive personal tai chi coach, active gaming with real physical user interaction or a re-animation of an athlete's performance for a detailed analysis. We suggest Motion Band as a device capable of introducing inventive ways to build interfaces motivating users towards physical fitness. Finally we discuss future research needs on the topic.

Categories and Subject Descriptors
B.4.2 **Input/Output Devices**

General Terms
Algorithms, Measurement, Experimentation

Keywords
Sensors, wireless accessory, Bluetooth device, body motion tracking, physical fitness, ubiquitous computing, motivating interface

1. INTRODUCTION
Current wrist computers for hikers and sportsmen utilize various sensing solutions including pedometers, speedometers, milometers, heart rate monitors, thermometers, altimeters, barometers, compasses and global positioning system (GPS). The most simple and common application for these sensing solutions has been just to show the sensor values to the user. A navigation system [1] and a personal running trainer [2] are examples of more advanced applications.

Measuring quantities that change quite slowly is a common restriction with the current fitness sensing solutions. During an exercise wrist computers are dominantly used by either relying on alerts or by watching the device display every now and then. After the exercise, data is often transferred to a computer for analysis. From the user experience and interaction point of view, solutions capable of providing an immediate response based on a real-time analysis of rapid user movement are missing. Applications can now estimate e.g. how many calories a user consumes during a tennis session, but cannot tell whether user currently hits topspin or slice.

Advances in miniaturization, mechanics as well as new sensor and radio technologies are enabling unseen wirelessly connected wearable fitness device prototypes. We have developed research prototypes, called Motion Bands, which are able to perform real-time body motion tracking. Motion Bands bring two main benefits. First of all, the devices extend the application scope of current wrist computers to cover the use of instantaneous body poses and gestures. One can easily e.g. create an interactive aerobics coach application, which is aware of user's movement in detail. In addition, Motion Bands can increase user's motivation to exercise by introducing interactivity and instant feedback. Depending on the application, the user may wear one or more Motion Bands on selected body parts.

2. PROTOTYPE DEVICE
Motion Band is a compact wireless sensor module that can be attached to different parts of the user's body. Motion Band measures human body movements using accelerometers, magnetometers and gyroscopes. Sensor data is transmitted wirelessly to a central unit that collects data from various Motion Bands and processes the data for further use. A mobile phone has been chosen to be the central unit in our experiments.

Motion Band is based on ultra low power microcontroller unit (MCU). MCU continuously collects data from the sensors, preprocesses the data and sends it to the main unit over wireless Bluetooth connection. See **Figure 1** for details.

A tri-axis linear accelerometer is used for acceleration measurements. The device includes a sensing element and an IC interface that is able to take the information from the sensing element and send the measured acceleration signals to the MCU via a serial interface.

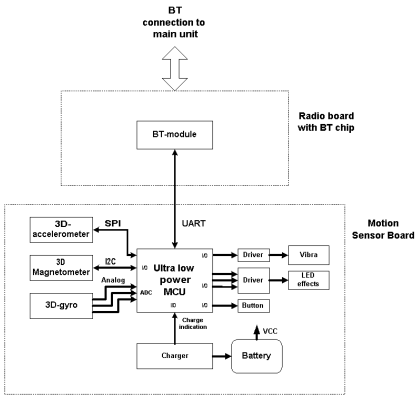

Figure 1 Motion Band Block Diagram

The magnetic measurement system consists of a 3-dimensional magnetic sensor and a measurement ASIC that interfaces sensors with the MCU. The magnetic measurement system is used to measure the magnetic field of the Earth. The system has been designed carefully to make sure that other components or the circuit board itself do not disturb the measurement. Ferromagnetic materials have been avoided or they have been placed as far as possible from the magnetic sensors. Also power and other high current tracks on the PWB have been wired so that magnetic field produced by the current does not distort the measurement.

A 3-dimensional gyroscope measurement system has been made using three 1-axis gyroscopes. XY-gyros are placed on small daughter PWB to get full 3D measurement system. Gyro sensors are used to detect the angular velocity of the device.

Measurement data is transmitted wirelessly to the main unit using Bluetooth connection. Standard Bluetooth solution enables Piconet of one master (mobile phone) and seven slaves (Motion Bands). High data rate and low latency makes Bluetooth suitable for real-time body motion tracking.

Motion Band can send motion data continuously to the main unit at 40Hz frequency. However, we have implemented the basic orientation calculation in the Motion Band MCU in order to reduce the workload in the main unit application processor. We have developed a custom protocol, which divides sensor data into appropriate packages. The protocol is running on top of Bluetooth RFCOMM protocol layer.

Motion Bands are designed to be comfortable to wear and thin enough to be used under clothes. Motion Band is attached to the user's body part with flexible straps. With two different length straps Motion Band can be attached anywhere on the body (e.g. wrist, arm, leg, chest…).

3. MOTION TRACKING

The orientation of any device is completely determined by two linearly independent vectors. Such two vectors can be obtained from the gravity and magnetic north. The sensor indicates these two vectors in its local coordinate system R, so that the measured acceleration can be assumed to be $a=Rg$, and the measured magnetic field $h=Rb$. In these two equations a, g, h and b are known and R is the unknown. With the further constraints, $det(R)=1$ and $R^T R = I$, R can be solved.

When the device experiences actual acceleration, the assumption $a=Rg$ is broken. It is impossible to separate gravity from acceleration without further assumptions, so the method cannot provide accurate orientation during motion. This problem is avoided by the use of gyroscopes. They can provide sufficiently accurate measurements of the angular velocity so that integration yields accurate orientation. The orientation from accelerometers and magnetometers is then used to compensate for the drift error in the integration. They are also necessary to determine the orientation at the beginning, since gyroscopes only offer information about the change of orientation.

A sensor can be used to track the orientation of a body part, such as the arm. If the orientation of two connected body parts is known, the angle between these body parts can be computed. The maximum number of joints that can be tracked with N sensors is N-1. The human body has over 200 bones, and over 230 movable or semi-movable joints [3]. It is not practical to wear more than about 10 sensors, so clearly it is impossible to track every nuance of the motion. When we talk about motion tracking, we mean tracking the angles of a few selected joints in time. Tracked joints need not be actual joints of the body. In fact, we have some model of the body, which has certain joints and we assume that the sensors are placed in certain positions relative to the joints. For example, the spine consists of multiple restricted joints, but is often modeled as a rigid staff and a single more flexible joint at the hip.

The angles of the joints indicate the pose of the model at any given time. The sensors, however, indicate the orientation of the bone they are attached to. If the orientation of the two bones on both sides of the joint are known it is trivial to compute the angle between these two vectors. If the main goal is visualization, however, it is unnecessary to compute the angles. One can simply start with a bone whose one end point is known. From that point, the bone can be drawn according to the orientation indicated by the sensor. The other end point of the bone then indicates the starting point of the bone connected to this bone by a joint. Iterating through the tree structure that is thus formed gives a complete visualization of the body model.

It is possible to automatically recognize certain poses of the body, such as tai chi forms. A more challenging task is to also categorize and automatically recognize the transitions between certain forms. We call these transitions, i.e. certain motion trajectories in space, gestures. Hidden Markov Models can be used to recognize gestures with just one sensor [4] and the method can easily be extended to the case of multiple sensors.

4. APPLICATIONS

Target population for the Motion Bands can be divided into two segments: consumers and professionals.

Consumer applications can be further divided into interactive training, expressive sports and active gaming categories. Training and fitness sessions can be made interactive by monitoring the user's activity. With Motion Bands we are able to monitor user's instantaneous poses, which allows the creation of timely and accurate personal feedback and coaching. For example, we can create a personal tai chi coach application, which can detect user's progress in the session, and which can decide to advance to the next form when the user has successfully done the previous form. As we can recognize also complex motion trajectories, we are able to identify on higher abstraction levels what user is doing. As an example, we can count how many times the user lifts weights, how many times the user raises her hands, how many sit-ups the user makes, and so on. All of this can be done also on the move, e.g. while jogging or exercising outside, which further increases the scope of possible applications

Partial or full body motion tracking data can be recorded in a main unit. This creates interesting use case extensions for Motion Bands. User can store an act, e.g. a ski run or a gymnastic exercise, and the movement can be re-animated on a main unit screen. This kind of accurate animation would be a replacement for a video photography team.

Active video gaming with Motion Bands has received positive feedback from our focus group. We have publicly demonstrated e.g. a snowboarding game in which the user is wearing a single sensor unit around her hip to control a 'virtual' snowboard. It has been especially encouraging to observe many non-gamers to say that this kind of direct motion control of a gaming character is something that they could actually do. In other words, a physical extension to the conventional gaming attracts new people into the world of gaming. It is also possible to create personalized 3D motion trajectories to be used e.g. in sports, fighting or expression games, as shown in **Figure 2**.

Recorded body motion tracking data could also be used in various ways in the professional user segment. An athlete's personal trainer would have a new tool for accurate analysis.

5. FUTURE WORK

The current system still has a noticeable setup phase where the user straps the Motion Bands on. This means that we are limited to applications where the user is really motivated, but even these applications have not been completely mapped yet.

There is lot of work to be done in optimizing the current technology so that it is as transparent to the user as possible. Our current research focuses on end user tests in the wellness, fitness and gaming domains. This research will help us to build completely transparent wearable sensor solutions and applications that people find inspiring. The end user tests will give us feedback about the mechanical design and material selections of Motion Bands, as well as the overall end use experience. We will also focus on experiments in which Motion Bands are used for long exercise sessions.

As sensor technology advances, we can move away from accessory sensor devices into sensors that are hidden into the clothes. This will open a whole new range of applications.

In gaming domain we will study the interoperability of Motion Bands and Wireless Game Pads, prototypes developed and published by Nokia Research Center [5]. The single hand operated game pads are also equipped with motion sensors, which enables us to develop unseen physical gaming interfaces.

6. ACKNOWLEDGMENTS

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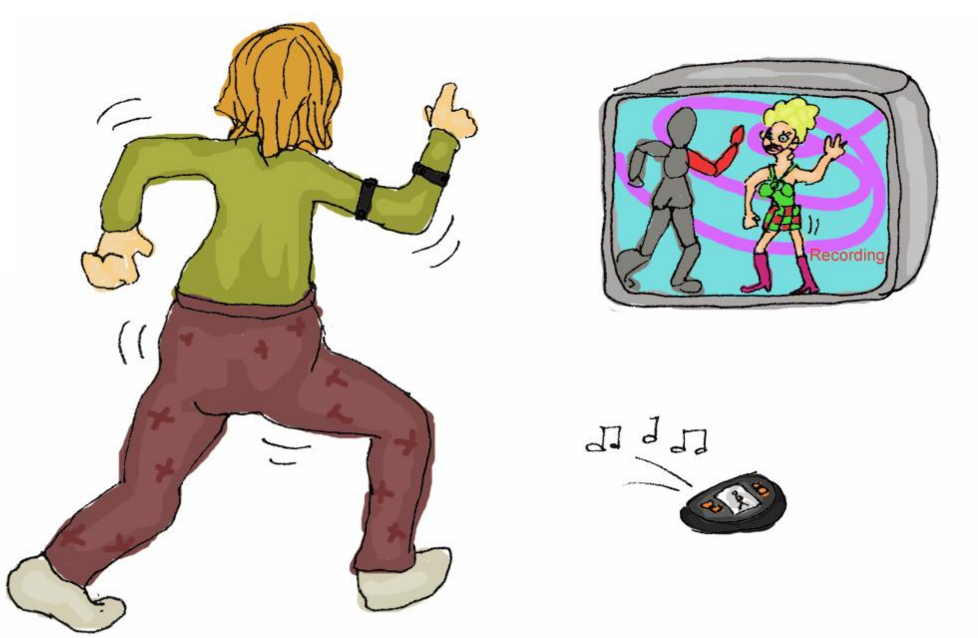

Figure 2: A user is recording his arm movement in a dancing game using two Motion Bands.