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Mobile Motion Capture - MiMiC

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Abstract — **The low cost, simple, robust, mobile, and easy to use Mobile Motion Capture (MiMiC) system is presented and the constraints which guided the design of MiMiC are discussed. The MiMiC Android application allows motion data to be captured from kinematic modules such as Shimmer 2r sensors over Bluetooth. MiMiC is cost effective and can be used for an entire day in a person's daily routine without being intrusive. MiMiC is a flexible motion capture system which can be used for many applications including fall detection, detection of fatigue in industry workers, and analysis of individuals' work patterns in various environments.**

I. Introduction

The goal of the Mobile Motion Capture (MiMiC) system is to develop a human ergonomics data collection system that is easy to use, mobile, robust, accurate and cost effective. Video game controllers of today, like the Nintendo Wiimote, are inexpensive, but equipped with high precision sensors. These factors make them a viable option to be used for research [1]. Harbert et al. demonstrated the use of the Nintendo Wiimote to capture angular kinematic data of the knee, hip and back motion and determined that Nintendo WiiFit games may help prevent lower back injuries as well as improve the lifting techniques of industry workers [2], [3]. However, there were several problems with this Wiimote system that are being addressed by the MiMiC system: lack of absolute angular data due to sensor drift; insecure attachment of the Wiimotes; lack of readily available data recording and analysis software; and PC based data recording that was not mobile or easy to use by the average person.

Kinematic sensor modules typically contain accelerometers, gyros and/or a magnetic compass and as such have been used for motion capture in different research areas, including fall detection and prediction [4], analysis of walking and cycling activities [5], and monitoring the effect of medication in Parkinson's disease patients [6]. Although each of these systems is well-tailored to function in a specific application area, it would be more useful to have a flexible system that could be used in a variety of areas with little setup and customization.

The current MiMiC system uses 9DOF (Degree of Freedom) Shimmer 2r kinematic modules which have a 3 axis accelerometer, 3 axis gyro and 3 axis magnetometer [7]. These modules are ideal for research because they are highly configurable, small, have open source firmware code and provide a wide array of ways in which data can be captured and transmitted/stored [8].

With the advent of smart phones, mobile applications are now increasingly being developed and used for research in cases where a laptop/computer would have been used in the past. MiMiC is designed to be such a system with a mobile application that interfaces with sensors such as the Shimmer 2r modules. The purpose of this paper is to discuss the design constraints, capability and possible uses of the MiMiC system.

II. Design Constraints

The following design constraints served as guiding principles for the development of MiMiC:

1. *Mobile system.* MiMiC needs to be mobile so that it can be used in almost any setting for kinematic data capture.
2. *Capability to record an entire day's worth of data.* MiMiC may be used as part of worker safety assessment systems in different industries (e.g. poultry industry) and as such would need to be able to run for an entire work day.
3. *Non-intrusive.* As MiMiC will be used by people in different age groups and will be worn by workers in industry, it should be non-intrusive and comfortable so that the users wearing the kinematic modules are able to go about their normal routines.
4. *A secure method to attach the kinematic modules to the subjects.* In the previous study [2], [3] problems were experienced with the neoprene straps used to secure Wiimotes in place. The Wiimotes were large and the straps were not ideal, resulting in noisy data. Having better straps to ensure that the kinematic modules do not move during the experiment as well as having kinematic modules with a small form factor would help satisfy this constraint.
5. *Easy to use:* MiMiC should be easy to use so that even a non-tech-savvy person can use it. This is important if MiMiC is to be used in a broad array of applications in the future.

III. MiMiC System

The MiMiC system consists of the MiMiC Android application and the kinematic modules which are used for data collection.

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A. Android Application

MiMiC's Android application provides the capability to collect ergonomic data over Bluetooth from kinematic sensor modules, which currently include Shimmer 2r kinematic modules [7] and Sparkfun 6 DOF modules [9]. The current system connects to the kinematic modules and collects 3 axis accelerometer, 3 axis gyro and magnetometer data. MiMiC's structure is broadly separated into two parts; the MiMiC User Interface (UI) and the MiMiC background service (see Figure 1). The MiMiC UI allows the user to initiate a session and start the data collection. The background service runs during the data collection and is responsible for recording kinematic data. This service continues to collect data even when other applications are used on the smartphone. The MiMiC UI and the MiMiC service communicate with each other through a set of Android OS broadcast/receive protocol.

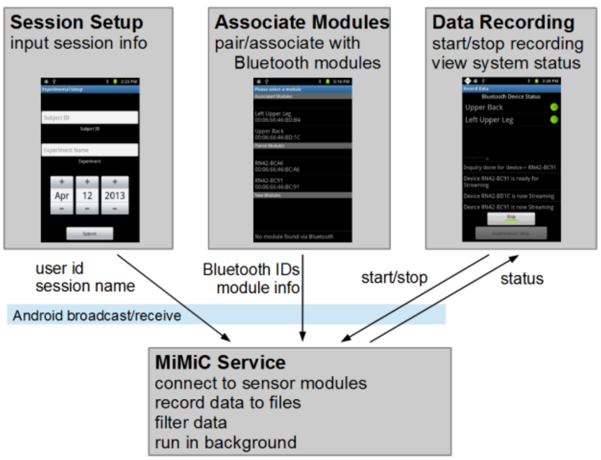

Figure 1. Interaction Between the MiMiC UI and the MiMiC Background Service

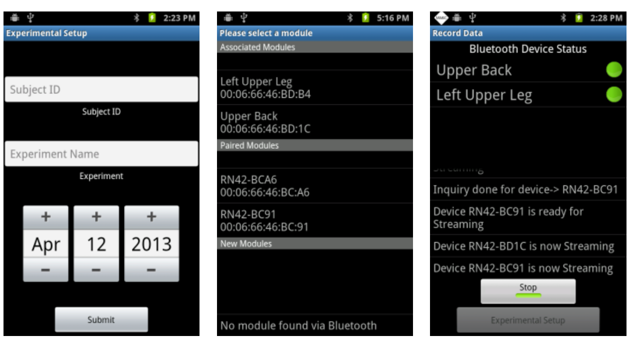

Figure 2. Screenshots of the MiMiC Android Application

The MiMiC UI consists of several Android activities (see Figure 2). Their functionalities are described below:

1. *Session Setup Activity:* This is the first activity which is started when MiMiC starts up. Through this screen the user can save the details of the session such as session name, date and unique personal identification number. Typically from here the user would proceed to the Data Recording Activity. In the case where no module is found to be associated when MiMiC starts up, the user is notified of this and is redirected to the Associate Modules Activity.

2. *Associate Modules Activity:* This activity allows the user to select kinematic modules which will be used for data collection. In the Associate Modules Activity the user can see associated, paired and unpaired kinematic modules. The user can then associate kinematic module(s) with MiMiC and rename them. This activity is started when there are no modules associated with MiMiC, or through the Session Setup Activity main menu.

3. *Data Recording Activity:* This activity allows the user to run the session. As soon as this activity starts, a Bluetooth connection is established with each of the associated kinematic modules. The current status of the kinematic modules is displayed on this screen via status indicators (gray (disconnected), blue (connected), green (recording) and red (error)). The user can start or stop the recording at any point in time.

4. *Settings Activity:* This activity allows the user to change the settings of the application.

The MiMiC background service handles the recording and saving of the sensor data. If the recording is underway and the user navigates away from the MiMiC UI, the background service continues to run and ensures that the data is being recorded. The user can access the UI at any time by starting the MiMiC application or by clicking on the MiMiC notification. The background service periodically checks the status of the kinematic modules and notifies the UI of any change.

MiMiC has 4 modes of service which are essential for maintaining synchronization between the UI and the service:

1. *MODE_OFF:* This is MiMiC's mode when modules are not connected or recording.

2. *MODE_BLUETOOTH:* When MiMiC enters this mode Bluetooth connections with the kinematic modules are established.

3. *MODE_RECORD:* MiMiC's mode when recording is started.

4. *MODE_STOP_RECORD:* MiMiC's mode when recording is stopped.

Both the MiMiC UI and the MiMiC service send broadcasts and have broadcast receivers that listen to each other's broadcasts. Whenever the UI requests a change in service mode it sends a broadcast to the service. The service carries out the change and responds with an acknowledgement broadcast. The MiMiC service also sends broadcasts to notify the UI of the current status of kinematic modules.

The MiMiC service adds an ongoing Android notification to indicate when recording is started. While the system is recording, the user can switch back from other applications to the MiMiC UI by clicking on this notification. Notifications are also added if there are any errors such as disconnection of a kinematic module, or write error due to insufficient space.

B. Posture Detection

In order to get the absolute orientation of the kinematic modules a posture detection algorithm was implemented using the raw data obtained from the MiMiC service. This algorithm uses Sebastian Madgwick's implementation of Mayhony's DCM filter to improve the accuracy of the orientation estimate and remove the effects of gyroscope drifting [10]. This is accomplished using the errors between the expected and observed direction of gravity and Earth's magnetic field. Madgwick also added magnetic distortion compensation to the algorithm to account for inferences and field inclination. The DCM filter uses quaternion algebra to calculate rotations of the device in order to make the algorithm more efficient and to avoid gimbal lock. FreeIMU [11], a 9 degree of freedom inertial measurement unit project, provides an open source implementation of the algorithm. By mounting the kinematic modules on a person and applying the posture detection algorithm, it is possible to monitor their absolute body and limb orientation in real time without the need for precise relative sensor positioning on the body.

Figure 3. Motion Capture in progress. Shown are the MiMiC Application, Shimmer Kinematic Modules and the Kinematic Module Attachments.

	Target Size (Inches)		Strap Size Used
	Min	Max	
Wrist	5	8	Small
Ankle	7	10	Small
Bicep	9	18	Medium
Calf	11	17	Medium
Thigh	19	30	Large
Chest	26	44	X-Large
Waist	25	43	X-Large
*Based off of 5th percentile female and 99th percentile male from 1988 U.S Army Anthropometry Study. Actual straps have been increased in size by 1-5" to allow for demographic changes in overall body mass.			

Table 1: Body Dimensions Relevant to Attachment Strap Sizing and Adjustability

C. Kinematic Module Attachment

To address design constraint 4, relating to kinematic module attachment, straps were developed with a pouch for the Shimmer kinematic modules (see Figure 3). These straps can be easily attached to different parts of the user's body and fit seamlessly beneath normal clothing, making them non-intrusive. The strap and pouch system holds the Shimmer devices firmly against the wearer's skin to ensure there is minimal extraneous movement of the Shimmer devices, a problem that was faced in earlier data collection with Wiimotes [2], [3]. The straps are made of nylon-coated neoprene rubber that wrap around the wearer's limb or torso and adjust via hook and loop fasteners. The neoprene straps do not irritate the skin, are comfortable to wear, and can be easily laundered for reuse. Table 1 shows the body dimensions targeted by the attachment straps.

D. Characteristics

Using MiMiC one can currently collect data from both Shimmer modules and Sparkfun 6 DOF modules [9]. MiMiC's UI is simple and intuitive, allowing the general population to use it easily for kinematic data collection.

MiMiC has been tested to collect accelerometer, gyro and magnetometer data. MiMiC has successfully collected data simultaneously from 4 Shimmer modules at a sampling rate of 102.4 Hz.

MiMiC is intended to be used for data collection over prolonged periods of time. Typically one should be able to collect data of an entire work day. MiMiC was tested and found able to collect data for over 8 hours using Shimmer kinematic modules and a 2009 Google Nexus One Android phone. The ability to collect data over long periods of time depends upon the battery life of the kinematic modules and the phone/tablet running MiMiC as well as the space constraints of the phone/tablet. It should be noted that phone/tablet batteries drain much faster when Bluetooth is being used. Recording data from 4 Shimmer modules at 102.4 Hz for 8 hours resulted in data files totaling approximately 1 GB in size. Using longer lasting batteries and ensuring that the phone/tablet has enough file storage space would correspondingly increase the time duration over which data can be recorded.

IV. DISCUSSION

There are other ready to use motion capture systems available on the market. Vicon [12] uses infrared cameras to track the motion of subjects. The ShapeTape [13] system by Measurand utilizes fiber optic based 3D flexible strips capable of measuring shape, position, orientation of an object or a person. Ascension technology offers two products, Flock of Birds [14] and trakStar [15], that use pulsed DC magnetic technology for six degrees-of-freedom tracking. These systems are very accurate but are not mobile and are also relatively expensive.

The use of an Android phone for data collection makes MiMiC a mobile system. MiMiC allows most Android devices to collect data from a number of kinematic sensor modules, making it a low cost option for motion capture. The batteries of the Shimmer 2r kinematic modules last sufficiently long to capture data for an entire work day. The straps developed for attaching Shimmer kinematic modules keeps them securely in place and are also comfortable to wear, making them non-intrusive. The UI of MiMiC Android application has also been kept simple, making it easy enough for an average person to use. These factors make MiMiC a good option for use in one's daily routine for kinematic data capture.

While most motion capture systems being used in research are designed for a specific application area, the MiMiC system can be used for a variety of different applications: studying walking or cycling patterns; monitoring and detecting fatigue in workers in industrial settings; studying learning patterns of workers, e.g. how workers learn to do cutting in the poultry industry; analyzing fall detection in homes etc. This illustrates how this simple and easy to use data collection system can be leveraged to achieve varied objectives. The algorithms for achieving specific goals can be either integrated into the system (e.g. on board fall detection) or can be developed separately and be fed the kinematic data collected through MiMiC (e.g. analyzing gait patterns). The MiMiC system has already been used to gather motion data in a research project analyzing the motion of workers performing a simulated poultry industry bird re-hang task [16].

Future work includes testing the robustness of MiMiC and its UI before moving onto a pilot study. The next steps will be to perform studies in real world environment, such as: evaluating worker safety in poultry plants; and gathering motion data through Georgia Tech's Home Lab [17], which is a test bed of 350 homes of older adults.

Additional features are planned for future versions of the applications. These include: the ability to select different parts of body on an image and associating modules with them to indicate which modules are collecting data for which body part; the ability to collect data from phone's sensors itself; implementing a server/client model for use in poultry industry by managers/workers for intervention; and the ability to connect to other kinematic modules having Bluetooth capability such as the Nintendo Wiimotes.

V. Conclusion

The development of such a flexible, low cost, mobile motion capture system will prove useful in many motion analysis research initiatives or in industrial ergonomic assessments.

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