Virtual Hooping: teaching a phone about hula-hooping for Fitness, Fun and Rehabilitation

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ABSTRACT

The paper demonstrates the feasibility of using mobile phones for fitness and rehabilitation purposes by training them to recognise a user's hula-hooping movements. It also proposes several parameters which can be used as a measure of rhythmic movement quality. Experimental measurements were achieved with two test subjects performing two sets of steady hula-hooping. The paper compares algorithm performance with accelerometer, gyroscope and magnetometer sensor readings. Analysis of the recorded data indicated that magnetometers had some advantages over accelerometers for reliable phase extraction. Hilbert transforms were used to extract the phase information, and a Dynamic Rhythmic Primitive Model was identified for the hula-hooping movement. Together these tools allow the creation of hula-hooping performance metrics which can be used in wellness, rehabilitation or entertainment applications for mobile devices. We outline open technical challenges and possible future research directions.

Categories and Subject Descriptors

H.5.1 [**Multimedia Information Systems**]: Evaluation/ Methodology; Artificial, augmented and virtual realities

General Terms

Algorithms, Measurement, Performance, Experimentation

Keywords

hula hoop, magnetometer, phase angle, fitness, Hilbert transform, dynamic movement primitives

1. INTRODUCTION

Fitness exercises are gaining importance everyday due to worsening obesity and health-related issues, especially in the younger population. Since classical exercises usually require a variety of equipment, are considered uninteresting and due to lack of encouragement, people often rapidly abandon fitness programs, so making the exercises fun and accessible everywhere is important. Hula-hooping is a good example of fun and mobile exercise which requires good balance and coordination affecting several muscle groups, but which requires the user to have access to a large and not easily portable hula-hoop. Recently, there have been several successful attempts of introducing hula-hooping (and exercise programs in general) into game based environments, with Wii Fit, using the floor-based pressure sensor, as a good example. Older users could potentially also benefit from such systems in their rehabilitation or exercises.

In this paper we examine the feasibility of a mobile fitness system for hula-hooping without the actual hoop (thus the name *Virtual Hooping*) and discuss possible application scenarios in fitness and in rehabilitation. In order to verify the feasibility of the approach, we carried out experimental measurements with inertial sensors on two test subjects with both successful and unsuccessful hooping attempts.

2. COMPUTER-BASED FITNESS SYSTEMS

A well-known example of an indoors computer-based fitness system is the *Wii Fit* from Nintendo and its newer version *Wii Fit Plus*, both of which use hula-hooping as a part of their aerobic exercises. They use the *Balance Board*, a force plate sensor, to measure the centre of balance and its trajectory, based on which conclusions are made about current posture and subject actions. The Wii Fit system provides encouragement during the exercise and provides incremental training and rewards in the form of unlocking new program features. It also keeps a log of user game activities. More recently, the system found application for rehabilitation and exercise for elderly users [5]. We note that center of balance measurements, while they might reflect the intention of the person hula-hooping, might not reflect body movement which could maintain stable oscillations of a physical hoop. This is due to the fact that several body (mass) configurations can result in the same center of balance measurement. The point is carried further in tests [4] which demonstrated that use of Wii Fit *Super Hula Hoop* application burnt 3.7kcal/min or 111 calories in 30 minute sessions, which according to authors is significantly lower than compared to the actual physical activity.

Apple's iPod music player has been linked with a wireless sensor to Nike training shoes to record running performance, and many Polar wrist watches are designed to support tracking of sports activities, and can link to wireless heart rate sensors. Nokia offers several mobile fitness based applications such as *Nokia Sports Tracker* [1] and *Step Counter* [2]. The *Nokia Sports Tracker* is a GPS based activity tracker for recording, monitoring, analyzing and sharing of outdoor sport activity information. It also provides features for real time sharing of exercise, training diaries and blogs. Recorded data can be visualized and analyzed in sev-

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eral ways. A similar approach to activity monitoring can be found in [7] where a mobile assistant for runners based on an auditory and graphical UI was designed. Emphasis was put on providing non-visual feedback on time or distance traveled, navigation and finish. The system provided encouragement through interactive notes left by other users along certain running routes and through competition with either the virtual rival or real opponent. Although both systems present a useful tools for fitness exercise planning and monitoring they do not provide feedback on quality of the exercise movements. *Nokia Step Counter* uses the phones' accelerometer to sense and infer user steps. Based on the measured data and data provided by the user (e.g. height and weight) it can estimate the distance covered, as well as energy expenditure. TripleBeat is a mobile phone based system that assists runners in achieving predefined exercise goals via musical feedback and two persuasive techniques: a glanceable interface for increased personal awareness and a virtual competition [6]. [13] present a multimodal conversational Companion system focused on motivating and supporting users in health and fitness activities, which has both a stationary and a mobile component. A number of systems have been developed using mobile technology to encourage joint physical activity even when participants are not co-located, e.g jogging over a distance [10], and [9] looked a range of collaborative systems to persuade teams of participants to improve their health using technologies such as location-aware mobile phones.

3. APPLICATION SCENARIO

The main requirements of the system are that a mobile phone or similar device should be able to correctly recognise hooping behaviour, and then be able to: 1. Track the length of time, and level of exertion involved, as part of an on-going wellness programme 2. Provide measures of quality of performance, to help the user monitor or improve their skills, or to provide diagnostic information to rehabilitation support staff. 3. Support and encourage the user in the hooping task by providing appropriate real-time feedback. This could be simple audio or vibrotactile feedback, or the user could be coupled into the music system, and would have to keep hooping to keep the music playing. Deterioration from optimal quality hooping could be coupled to deterioration in music quality, as if there was a bad radio connection.

4. METHOD

In order to verify the feasibility of our approach we carried out several measurement session involving two test subjects. Questions posed at the beginning of measurement were: 1. Which of the two sensors usually found in mobile phones (accelerometer and magnetometer) is more appropriate for the intended application? 2. Is there repeatability of measurement for a particular subject? 3. Can hula-hoop movement be adequately modelled with rhythmic dynamic movement primitives? 4. Can hula-hooping movement quality be monitored with the data that would be available on a modern mobile phone? Two female volunteers were recruited for experimental measurements. Both participants were occasional hula-hoop users and could maintain stable loop oscillations for longer periods of time (> 30 s). While we recognize the limitation of testing the proposed methodology on established hula-hoopers, this fact doesn't interfere with our primary goal which is to demonstrate the feasibility of *Virtual Hooping*. Test subjects were informed about measurement objectives and were instructed to maintain stable hoop oscillations for as long as possible with self selected hooping speed. Each test subject performed two successful hooping attempts. A Shake SK6 [14] sensor was attached to subject's hip by means of elastic band with a pouch as shown in Figure 1. The sensor was connected via Bluetooth to a laptop computer for data logging. The shake sensor pack has 3D accelerometer, gyroscope and magnetometer which enabled sensor performance comparison. A large sized hula-hoop with $R = 100$cm diameter was used for testing. The data received via Bluetooth was interpolated to a constant frequency (50Hz) in order to ensure valid filtering results. The interpolated data was filtered with FIR bandpass filter of length 52 with cut-off frequencies based on raw signal spectrum analysis. The filtered data was used for calculation of a Hilbert transform. In off-line analysis such as this, the Hilbert transform was used in analytical form (on batch data). For real-time application, this issue can be solved by the introduction of a 5th order IIR filter approximating the Hilbert transform calculation with the introduction of 0.1s delay. Phase angles of the rhythmic motion were calculated using the Hilbert transform of filtered data [11].

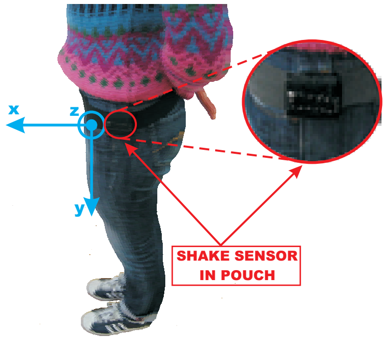

Figure 1: Sensor positioning on subject's body.

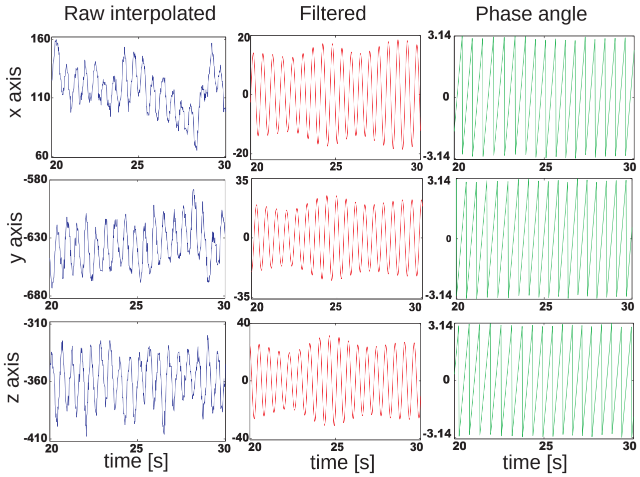

Figure 2: Magnetometer sample results for one test subject, showing the raw data, the filtered data and the inferred phase angle for the three axes.

5. RESULTS AND DISCUSSION

Examples of recorded magnetometer data for one test subject during a single measurement session are shown in Figure 2. In order to conclude which of the two sensors used was better suited for the fitness application we examined their respective signal spectrum, presented in Figure 3 (for y-axis) in which filtered data and calculated phase angles are also depicted. Closer examination of the figure reveals that the magnetometer spectrum has a single distinct peak between frequencies of 1.65 Hz and 1.95 Hz which is in accordance with the available literature [3]. The accelerometer spectrum, on the other hand, has several peaks, with the largest being between frequencies of 3.35 Hz and 3.75 Hz. Note that there also exists a small peak in accelerometer spectrum whose frequencies correspond to the peak in the magnetometer spectrum frequencies. If we bandpass filter the data, YZ phase plots can be obtained as depicted in Figure 3, indicating more consistent structure in the case of the magnetometer data. The quality of the phase angle signal is similar for both sensors. These observations, in conjunction with ever increasing availability of magnetometers in mobile phones (e.g. iPhone 3GS or Nokia N97 and E72) for use as a compass, led us to conclude that the magnetometer is a good choice for measurement sensor for hula-hooping motions. The gyroscope data were comparable to that of the magnetometer, but these are currently less widely used in mobile phones we did not consider them further.

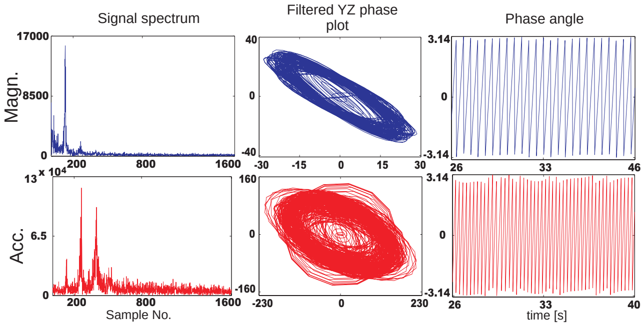

Figure 3: Comparison between accelerometer and magnetometer measurements.

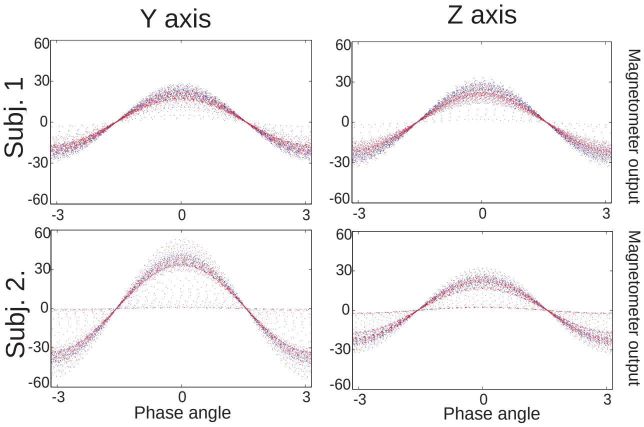

Figure 4: Distribution of magnetometer data for Y and Z axis (blue - Data set 1, red - Data set 2).

Next, we examined the repeatability of hula-hooping measurement by analysis of the magnetometer output as a function of phase angle, as depicted in Figure 4, where all four data sets are presented. These results indicate that even after 1 minute of constant unconstrained hula-hooping there exists a tight distribution of magnetometer outputs in relation to hooping movement indicating rhythmic movement (and measurement) repeatability. We expect to obtain slightly different distribution portraits for some subjects which might be indicative of their distinct hooping style. Also for the case of unstable hooping we expect dispersed distribution. The level of dispersion should indicate how far from a stable oscillation the current movement is thus presenting one way of quantifying movement quality. Another measure which can be considered as indicative of hooping quality is the variability in phase evolution depicted in first row of Figure 5 for one subject.

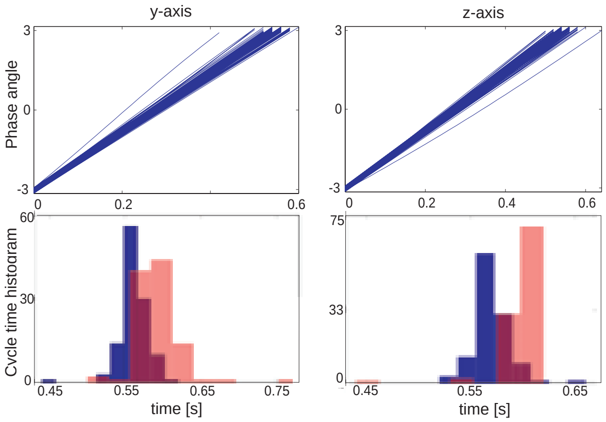

Figure 5: Phase variability for N=104 hula-hooping cycles (blue - Subject 1, red - Subject 2).

Again a tight distribution is present, indicating a low variability of steady (stable) hooping for particular subject (in both measurement runs). For comparison purposes histograms of cycle times for both subjects are presented in second row of Figure 5. In order to demonstrate modelling power and applicability of rhythmic dynamic movement primitives (RDMP) [12, 8] recorded data for y gyroscope axis is used. The modelling procedure was modified in comparison to ones found in the literature, in order to accommodate for changes in amplitude and frequency of rhythmic movements via the calculated Hilbert transform (i.e. instantaneous frequency and amplitude). There is a good match between the modelled (predicted) and recorded magnetometer signal and its derivate, as can be seen in Figure 6. There is also a good match between the measured and predicted control function driving the model. Again the properties of the control function can be used in applications as a metric for hooping style and quality.

To demonstrate the applicability of the developed model for a particular subject, we first trained the model using *Data set 1*. Next, we applied *Data set 2* to the previously developed model and used it to reconstruct the original data, the results of which demonstrated good matching between model predicted and measured data with reconstruction accuracies of same and different data sets being comparable. The control function of RDMP can be used to complement the other parameters for evaluation of hooping quality. If a

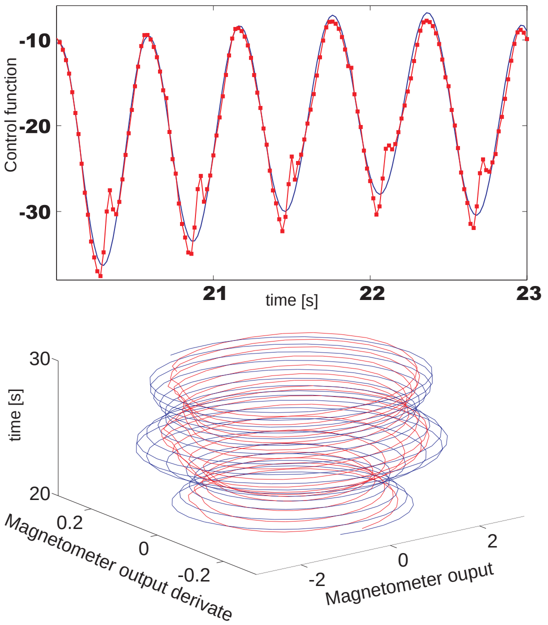

Figure 6: Rhythmic dynamic movement primitives for hula-hooping (blue - measured; red with dot markers- modeled/predicted)

histogram of control function amplitudes at instances when phase angle equals zero is calculated variability of spread of amplitude values depicted in Figure 7 is obtained linking model control function to quality of hula-hooping. The figure suggests smaller variability in amplitude for the y axis compared to the z axis. The results for amplitude variability are not as conclusive as the ones for phase variability but also indicate a long-tailed distribution which could be parametrised and used for estimation of movement quality. Overall, the obtained results demonstrate that a mobile device with currently available sensors can recognise hooping behaviour and can log and grade the quality of performance. The algorithms (detailed in Section 4) were written in Python, and are feasible for implementation for real-time processing on mobile devices, and the extraction of effective phase angles opens up a range of multimodal feedback possibilities for vibrotactile and audio feedback during hooping.

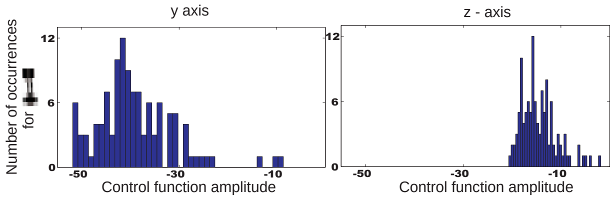

Figure 7: RDMP control function amplitude histogram at $\phi = 0$.

6. CONCLUSIONS

In the paper we described an experimental platform, where inertial measurements of subject's pelvic thrusts were recorded using a Shake inertial sensor pack. A modelling approach based on Dynamic Movement Primitives was tested, and found to be able to represent the hooping data well, and to be able to give measures of performance which could be used in sports, wellness or rehabilitation software.

The automatic extraction of phase information supports rich real-time multimodal feedback potential, and could also be coupled to music players on the device. The models were experimentally validated on data from two test subjects, demonstrating the feasibility of implementation of a proposed *Virtual hooping* fitness device. Further wide-ranging use in applications might be made by supporting joint rhythmic activities [11] with a remote or colocated partner via wireless communications, where synchronisation of joint phase angles could lead to appropriate feedback.

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