Ambient Health Monitoring: The Smartphone as a Body Sensor Network Component

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Abstract

Inertial measurement units used in commercial body sensor networks (e.g. animation suits) are inefficient, difficult to use and expensive when adapted for movement science applications concerning medical and sports science. However, due to advances in micro-electro mechanical sensors, these inertial sensors have become ubiquitous in mobile computing technologies such as smartphones. Smartphones generally use inertial sensors to enhance the interface usability. This paper investigates the use of a smartphone's inertial sensing capability as a component in body sensor networks. It discusses several topics centered on inertial sensing: body sensor networks, smartphone networks and a prototype framework for integrating these and other heterogeneous devices. The proposed solution is a smartphone application that gathers, processes and filters sensor data for the purpose of tracking physical activity. All networking functionality is achieved by Skeletrix, a framework for gathering and organizing motion data in online repositories that are conveniently accessible to researchers, healthcare professionals and medical care workers.

1. Background

Motion capture is the act of reconstructing physical movements in virtual space as character animations, quantifiable graphs or tables. Inertial and optical motion capture technologies play a significant role in medicine and healthcare research, particularly in patient condition monitoring and rehabilitation tracking. Many research projects in this field employ highly expensive motion capture systems that often involve re-purposing animation suits to track the particularities of human comportments. With advances in inertial microelectronics, which are primarily driven by mobile computing technologies, inertial hardware is becoming more robust, affordable and ubiquitous.

In the context of medical science, motion sensing is an underexploited application area due to the cost and complexity of inertial hardware. Motion capture technologies can be used as tools for monitoring movement and measuring rehabilitation. In many scenarios, a patient has to be monitored for extended periods of time. Wearing a cumbersome motion capture suit during day-to-day activities is unfeasible from a usability perspective. As an alternative, this paper investigates the relevance of smartphone sensing to the field of medicine by providing a framework that gathers and makes motion data accessible to movement science researchers, healthcare professionals and medical care workers.

2. Body Sensor Networks

Inertial motion capture systems are body sensor networks containing both inertial measurement units and hardware for interconnecting nodes. A typical wired motion capture suit will contain a multiplexer, a central node acting as a gateway between the network's nodes. A typical wireless suit will use a router as a hub for transmitting data wirelessly to and from network nodes.

As with inertial measurement units, modern smartphones contain low-power accelerometers, magnetometers and gyroscopes to measure orientation. This sensor combination has made its way into mobile computing technologies to enhance the user experience. For example, users can play smartphone games or rotate the onscreen interface by simply tilting or shaking the device. The data originating from the three sensors is combined through sensor fusion algorithms. Sensor fusion is a multi-stage computation for unifying three streams of sensor readings to produce highly accurate estimations of orientation.

Specific human movements and gesticulations can be examined to diagnose health-related problems or measure treatment responses. The human motor-function system provides skeletal information through posture, balance and coordination. Motion capture has potential in treating musculoskeletal dysfunctions such as Idiopathic Scoliosis [1] or Parkinson's disease [2]. Although optical systems are pre-eminent in medical science, inertial motion capture is more practical because it can be used outdoors, outside of the comfort of a recording studio, medical or research laboratory [3]. For example, inertial motion capture systems can be utilized during clinical procedures concerned with treating degenerative joint diseases. Wearing individual sensors is one approach for measuring physical activity. Smartphones can be used to measure activity and lifestyle properties such as steps taken [4], calories burnt and weight lost.

To summarize, smartphones utilize the same hardware, software and firmware used by much more expensive motion capture technologies. Smartphones could potentially offer a much more affordable and flexible solution for specific movement science applications (e.g. medical science, sports science, patient rehabilitation [5]), particularly when combined with other patient data such as blood pressure, EEG/ECG, etc.

3. Skeletrix Framework

Skeletrix is our prototype framework for developing and researching inertial motion capture. It starts with sensing motion through microelectronics, continues by reconstructing visualizations of motion and finishes with uploading data into online storage. As highlighted in Figure 1, this paper focuses on a smartphone application entitled Skeletrix Mobile.
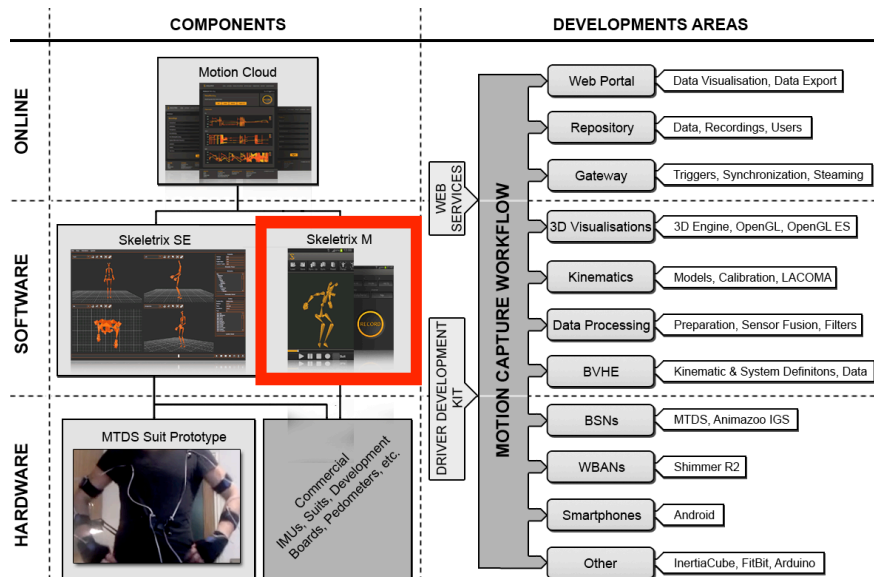

Figure 1: Skeletrix Framework

Skeletrix Mobile originated from our motion capture software environment [6] and features a kinematic engine, networking functionality, calibration and sensor fusion algorithms. In effect, Skeletrix Mobile turns an appropriate smartphone (e.g. a Samsung Galaxy S3 or S4) into an inertial measurement unit. To form a body sensor network out of these smartphones, several of them can be interconnected in two ways. First, several smartphones can be worn by one individual and share one skeletal rig. Smartphones running instances of the application can intercommunicate by transmitting motion capture data to the cloud. The cloud receives several sets of data, synchronizes the streams and echoes the processed result back to the smartphones. Second, several smartphones can be used independently of each other by separate individuals whereby all data can be stored by one centralized repository. In both scenarios, the data is made accessible to medical professionals through a web interface in easily accessible graphical or tabular formats. Both approaches will produce omnidirectional body sensor networks.

Data streaming to the server is achieved in real-time using variable-sized I/O buffers. This approach was chosen to accommodate situations where Internet connectivity may be problematic. Figure 2 (a) illustrates the mechanism for connecting and synchronizing three Android devices over Wi-Fi and 3G. Figure 2 (b) illustrates three interconnected devices. The middle device only has Wi-Fi enabled while the one on the right only has 3G enabled. The white device is tapped and the other two begin recording after a short pause. In situations where Internet connectivity is a problem, the smartphone will record data into local storage until it reconnects to the Internet.
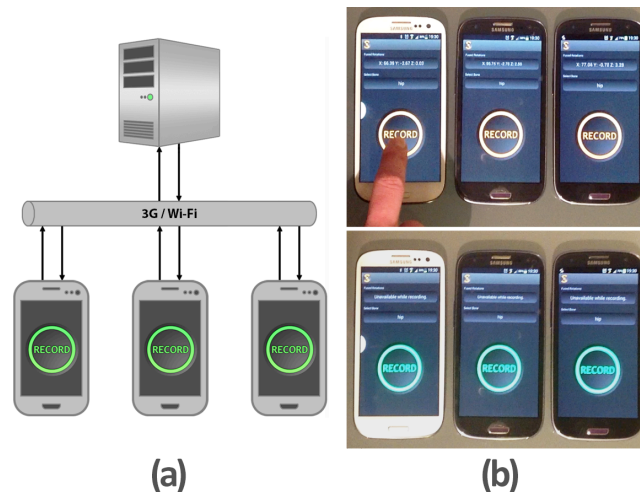

Figure 2: Network communication across the Samsung Galaxy S3 smartphone sensor network through Wi-Fi and 3G.

The above smartphones can record motion accurately for frequencies up to 120 frames per second, which corresponds to the recording frame-rates of inertial motion capture suits. Higher frame rates will cause duplicate angular readings to appear in the motion data. Additionally, a higher frame-rate will put more pressure on the application-to-cloud communications. To demonstrate the accuracy of the sensors we performed a short animation with the goal of animating a character rig. Skeletal rig animation is very demanding in terms of sensor accuracy and calibration. Figure 3 illustrates the gesture of moving two

smartphones across a flat surface to articulate a hand wave motion. This animation can also be recorded by physically wearing the devices on the body. The white smartphone is used to play the resulting animation.
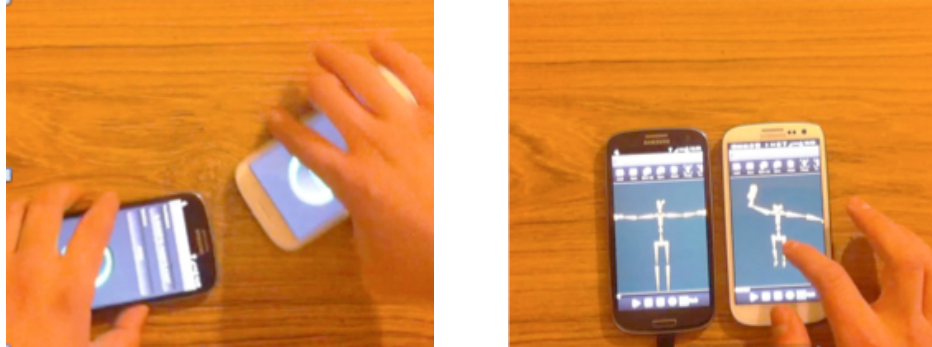

Figure 3: Animating character rigs using two networked smartphones.

4. Conclusions and Future Work

This paper demonstrates a prototype smartphone-based BSN for tracking physical activity that could be used as a component in a motion capture suit. While motion capture suits are accurate yet costly, our smartphone approach is an inexpensive solution for tracking motion useful in several real-life scenarios. Our system can be used to rapidly prototype activity tracking solutions. For example, a patient can carry one or several smartphones on their person while streaming health-related data to cloud-based storage, for downstream analysis. The resulting motion data stored can be made available to healthcare professionals in real-time. Similarly, a patient can also record data locally on their smartphone for self-assessment. Although using smartphones for character animation is unfeasible, animation is a good scenario for demonstrating the performance of smartphone sensors. Our future plans are to benchmark the smartphone approach against typical motion capture suits, inertial sensors with evaluation boards and other sensors that are available commercially.

5. References

[1] Zabjek, K.F. et al. Evaluation of segmental postural characteristics during quiet standing in control and Idiopathic Scoliosis patients, Clinical Biomechanics, Vol 20:5, pp. 483-490 (2005)

[2] Das, S. et al. Quantitative measurement of motor symptoms in Parkinson's disease: A study with full-body motion capture data, 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 6789-6792 (2011)

[3] Aminian, K., Najafi, B. Capturing human motion using body-fixed sensors: outdoor measurement and clinical applications, Computer Animation and Virtual Worlds, Vol 15:2, pp. 79-94 (2004)

[4] Tomlein, M., Bielik, P., Kratky, P., Mitrk, S., Barla, M., Bielikova, M. Advanced Pedometer for Smartphone-Based Activity Tracking, Proc. of the International Conference on Health Informatics, SciTe Press, pp. 401-404 (2012)

[5] Tseng, Y. et al. A Wireless Human Motion Capturing System for Home Rehabilitation, 10th International Conference on Mobile Data Management Systems Services and Middleware, pp. 359-360 (2009)

[6] T.Pascu, Patoli, Z., White, M. Unifying Software and Hardware-Centric Inertial Measurement Units in Body Sensor Networks. Proc. of Computer Graphics and Imaging, ACTA Press (2013)