Using Gravity to Estimate Accelerometer Orientation

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Abstract

Several wearable computing or ubiquitous computing research projects have detected and distinguished user motion activities by attaching accelerometers in known positions and orientations on the user's body. This paper observes that the orientation constraint can probably be relaxed. An estimate of the constant gravity vector can be obtained by averaging accelerometer samples. This gravity vector estimate in turn enables estimation of the vertical component and the magnitude of the horizontal component of the user's motion, independently of how the three-axis accelerometer system is oriented.

1. Introduction

Most previous work on detecting or measuring user motion activities using body-worn accelerometers [1 – 7] attached the accelerometers to the body in a known position and orientation relative to the body. The research issue addressed in this work is the following: in the *absence* of information about how a device containing a three-axis accelerometer is being carried by the user, can we still make reliable inferences about the user's activities or actions?

2. Orientation-independent acceleration information

Our hardware configuration employed two Analog Devices, Inc. ADXL202 evaluation boards hot-glued together at a 90-degree angle to provide three orthogonal acceleration axes. We needed all three because of our assumption that the orientation of the device is not known. Acceleration measurements on each of the three axes were sampled at 100Hz and collected on an iPAQ, which experimental subjects could carry with them.

Our approach for obtaining orientation-independent acceleration information makes use of the fact that MEMS accelerometers measure gravitational ("static") acceleration as well as ("dynamic") acclerations caused by the wearer's motion. The pull of gravity downward along some accelerometer axis manifests itself in the accelerometer output as an acceleration in the opposite direction along that same axis.

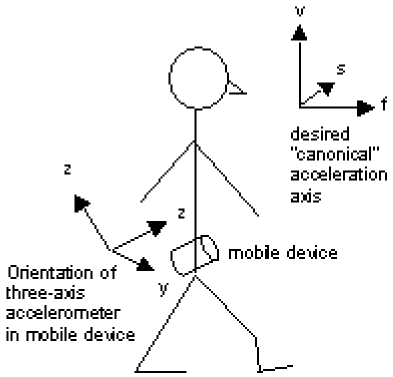

Fig. 1. Relevant coordinate systems

There are two relevant coordinate systems, as shown in Figure 1. The three-axis accelerometer configuration is in some arbitrary orientation on the wearer's body. The three accelerometer axes are denoted in the figure as x, y, and z. Ideally, we would like to know acceleration information in terms of a coordinate system oriented to the user and his forward motion. In the figure, these axes are denoted v (for vertical), f (for the direction of horizontal forward motion), and s is a (usually of less interest) horizontal axis orthogonal to the direction of motion.

The algorithm works as follows: for a chosen sampling interval, typically a few seconds, obtain an estimate of the gravity component on each axis by averaging all the readings in the interval on that axis. That is, we are estimating the vertical acceleration vector **v** corresponding to gravity as $\mathbf{v} = (v_x, v_y, v_z)$, where v_x, v_y and v_z are averages of all the measurements on those respective axes for the sampling interval.

Let $\mathbf{a} = (a_x, a_y, a_z)$ be the vector made up of the three acceleration measurements taken at a given point in the sampling interval. We assume for the sake of simplicity that the three measurements are taken simultaneously. We set $\mathbf{d} = (a_x - v_x, a_y - v_y, a_z - v_z)$ to represent the dynamic component of **a**, that caused by the user's motion rather than gravity. Then, using vector dot products, we can compute the projection **p** of **d** upon the vertical axis **v** as $\mathbf{p} = \left(\frac{\mathbf{d} \bullet \mathbf{v}}{\mathbf{v} \bullet \mathbf{v}}\right)\mathbf{v}$. In other words, **p** is the vertical component of the dynamic acceleration vector **d**. Next, since a 3D vector is the sum of its vertical and horizontal components, we can compute the horizontal component of the dynamic acceleration by vector subtraction, as $\mathbf{h} = \mathbf{d} - \mathbf{p}$.

However, as opposed to the vertical case, we don't know the orientation of **h** relative to f, the horizontal axis we'd like to have it projected upon. Furthermore, it appears impossible to detect. There is no dominating static acceleration as there is in the vertical case. Accordingly, we simply compute the magnitude of the horizontal component of the dynamic accelerations, concluding that that is the best we can expect to do.

The result of the algorithm performed across a sampling interval is a pair of waveforms, estimates of the vertical components and the magnitude of the horizontal components of the dynamic accelerations, each of which is independent of the orientation of the mobile device containing the accelerometers.

3. Conclusions

Our results indicate that a three-axis MEMS accelerometer system might be useful in detecting and distinguishing several user motion activities, such as walking, running, climbing or descending stairs, or riding in a vehicle – in spite of the fact that the position and orientation of the device are not known. We conjecture that the vertical acceleration component is sufficient information for most such activity detection.

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