uWave: Accelerometer-based Personalized Gesture Recognition

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ABSTRACT

The proliferation of low power, low cost accelerometers on consumer electronics has brought an opportunity to personalize gesture-based interaction. We present uWave [8], an efficient personalized gesture recognizer based on a 3-D accelerometer. The core technical components of uWave include quantization of accelerometer readings, dynamic time warping and template adaptation. Unlike statistical methods, uWave requires a single training sample and allows users to employ personalized gestures. We demonstrate uWave with a media player on both PC and cell phone. In our demo, uWave is implemented on a Windows laptop PC and a Smartphone running media player. With uWave, users can control the media player by pre-defined gestures. More importantly, uWave allows users to define personalized gestures with a single sample. *The "gesture" can be any physical manipulation of the remote that yields a distinct time series of acceleration.*

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General terms: Design, Human Factors, Experimentation.

Keywords: gesture recognition, acceleration, dynamic time warping, personalized gesture

INTRODUCTION

Hand gesture is natural for human users to express themselves and interact with others. It has recently become attractive for spontaneous interaction with consumer electronics and mobile devices. However, there are multiple technical challenges to gesture-based interaction. Firstly, unlike many pattern recognition problems, e.g. speech and handwriting recognition, gesture recognition does not enjoy a standardized or widely accepted "vocabulary". Therefore, it is often desirable and necessary for users to create their own gestures, thus personalized gesture recognition. With personalized gestures, it is difficult to collect a large set of training samples which is necessary for established statistical methods, e.g., Hidden Markov Model (HMM) [1, 2, 3]. Moreover, spontaneous gesture-based interaction requires immediate engagement, i.e., the overhead of setting up the recognition instrumentation should be minimal. More importantly, the targeted application platforms for personalized gesture recognition are usually highly constrained in cost and system resources, including battery, computing power, and alternative interfaces, e.g. buttons. As a result, computer vision or "glove" based solutions are usually unsuitable.

GESTURE RECOGNITION ALGORITHM

In this demo, we present uWave, a gesture recognition system based on a single accelerometer, to address these challenges. Our goal is to support efficient personalized gesture recognition on a wide range of devices, in particular, on resource-constrained systems. Unlike statistical methods [1], uWave only requires a single training sample to start; unlike computer vision-based methods [4], uWave only employs a three-axis accelerometer that has already appeared in numerous consumer electronics, e.g. Nintendo Wii remote, and mobile device, e.g. Apple iPhone. uWave matches the accelerometer readings for an unknown gesture with those for a vocabulary of known gestures, or *templates*, based on dynamic time warping (DTW) [5]. Unlike [7], which employed DTW with XWand for user-independent gesture recognition yet achieved mild success (70% accuracy with 7 training samples), uWave focus on user-dependent and personalized gesture recognition with a much higher accuracy with a single training sample. uWave is efficient and thus amenable to implementation on resource-constrained platforms. We have implemented a prototype of uWave using the Nintendo Wii remote hardware [6] and an accelerometer-enhanced Smartphone (Moto Q 9h [9]), respectively. Our measurement shows that uWave recognizes a gesture from an eight-gesture vocabulary in 2ms on a modern laptop, 4ms on a Pocket PC, and 300ms on a 16-bit microcontroller, without optimization.

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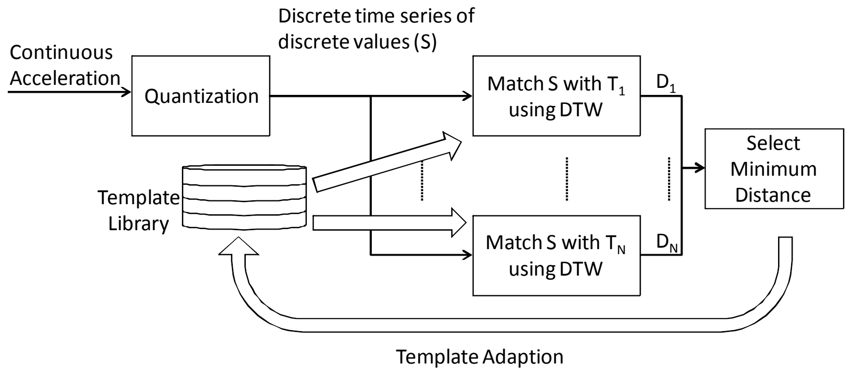

Figure 1: uWave is based on acceleration quantization, template matching with DTW, and template adaptation

For recognition, uWave leverages a *template library* that stores one or more time series of known identities for every vocabulary gesture, often input by the user. Figure 1 illustrates the recognition process. The input to uWave is a time series of acceleration provided by a three-axis accelerometer. Each time sample is a vector of three elements, corresponding to the acceleration along the three axes. uWave first quantizes acceleration data into a time series of discrete values. The same quantization applies to the templates too. It then employs DTW to match the input time series against the templates of the gesture vocabulary. It recognizes the gesture as the template that provides the best matching. The recognition results, confirmed by the user as correct or incorrect, can be used to adapt the existing templates to accommodate gesture variations over the time.

EVALUATION

We evaluated uWave with a pre-defined vocabulary of simple gestures reported in [1] and with a library of 4480 gestures collected from eight participants over multiple weeks. The study shows that uWave achieves accuracy of 98.6% with template adaptation and 93.5% without template adaptation for *user-dependent* gesture recognition. Such recognition accuracy is competitive with the results reported in [1] as 98.9% using HMM algorithm with 12 training samples.

If we treat all the samples in the database as from the same participant, in other word, in a *user-independent* way, the recognition accuracy will decrease to 75.4% compared with 98.6% for user-dependent recognition. To improve the accuracy of user-independent recognition, a large set of training samples and a statistical method are necessary.

CONCLUSION

The strength of uWave in user-dependent gesture recognition makes it ideal for personalized gesture-based interaction. With uWave, users can create simple personal gestures for frequent interaction. Its simplicity, efficiency, and minimal hardware requirement (a single accelerometer) has the potential to enable personalized gesture-based interaction with a broad range of devices.

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