An Inertial Measurement Unit for User Interfaces

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ABSTRACT
We have developed a compact, six degree-of-freedom inertial measurement unit for user interfaces. The system uses three axes each of gyroscopes and accelerometers for full 6-axis inertial sensing, and transmits data wirelessly to an external basestation, providing full state updates at 75 Hz. Circuitry for proximity sensing and ID transmission through capacitive coupling was also constructed. We used this system in the (void*) installation shown at SIGGRAPH '99, exploiting its compact size and wireless nature to construct a whimsical interface to a virtual world.

Keywords
inertial measurement, wireless sensing, motion capture

INTRODUCTION
Inertial measurement components, which sense translational acceleration and angular rate, are more frequently being embedded into common user interface devices. Such components hold a number of advantages over other sensing technologies such as vision systems and magnetic trackers: they are small and robust, and can also be made wireless using a lightweight radio-frequency link. We describe a system we constructed with all these properties and discuss a sample application.

PRIOR ART AND NEW DIRECTIONS
Inertial measurement devices have a very rich 20th century history[2], mostly driven by guidance systems for aircraft and missiles (dating to the V2 rocket). Because of the relatively large cost, size and power requirements of these systems, they were not appropriate for human computer interfaces and consumer applications. Recent advances microfabrication techniques, however, have led to lower cost, more compact devices.

Our system's direct lineage can be traced to the Expressive Footwear[3] project, where a small printed circuit card instrumented with inertial sensors (gyroscopes, accelerometers, magnetic compass), among a number of others (sonar, pressure, capacitive), was mounted on the side of a dance shoe to allow the capture of multi-modal information describing a dancer's movement. This hardware proved inappropriate for other interfaces because of its size and choice of sensor axes (which were suited to a dancer's movement).

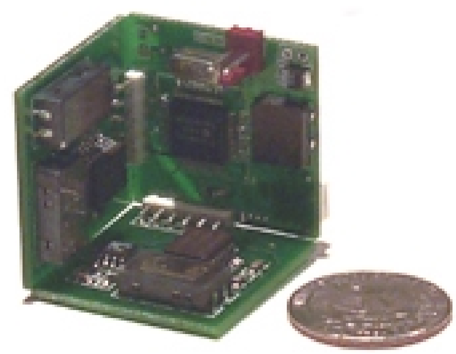

Figure 1: Inertial Measurement Unit

Therefore, we created a system that would contain primarily the sensors necessary for full six degree-of-freedom inertial measurement. The system had to be compact and wireless, to allow the greatest range of possible applications. While there are many 6-axis inertial measurement units on the market, most of them fail to meet our requirements. Many, such as the Crossbow Technologies DMU-6X and the Intersense IS600 (shown at SIGGRAPH98), are both far too large and far too expensive for our purposes. Other systems, such as the GyroMouse (a wireless 3D mouse), provide a limited sensor set (gyroscopes only) and offer very little access to the underlying hardware, which is of benefit to our research. We thus decided to construct our own system.

SENSOR HARDWARE
The final design of the inertial measurement unit (IMU) is a cube 1.25" on a side and is shown in Figure 1. The block diagram for this hardware is shown in Figure 2. Two sides of the cube contain the inertial sensors. Rotation is detected with three single axis Murata ENC03J piezoelectric gyroscopes[1]. Acceleration is measured with two two-axis

[1]Max. angular velocity 300°/sec. Sensitivity 0.67mV/°/sec.

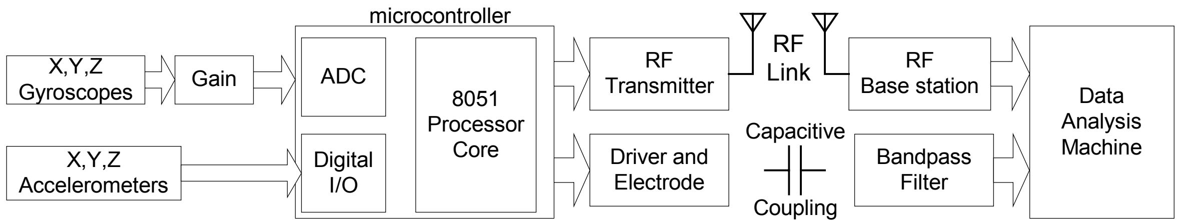

Figure 2: System Block Diagram

Analog Devices ADXL202 MEMS accelerometers[2]. The sensor data are input to an Analog Devices ADuC812 microcontroller with 12-bit analog-to-digital converter (ADC) and an 8051 microprocessor core. Gyroscope data is collected using the ADC, while the accelerometer data is collected via timing measurements. The raw sensor values are sent using a small RF Monolithics transmitter module to a separate base station, which connects to the data analysis machine via a serial link. These modules at available with 5 different frequencies; we are currently streaming data at 315.0 MHz and 916.5 MHz (we are now investigating channel-sharing protocols such as Bluetooth™). The device update rate is approximately 75 Hz.

In addition, a single 1” sq. mesh electrode and driving circuitry are provided for external, non-contact proximity signaling through capacitive coupling. A kHz-range waveform sourced off a processor pin will capacitively couple into a nearby electrode, with the magnitude of the signal depending on the inverse of the separation distance. Since the frequency of the driving signal is known, the received signal can be tightly bandpassed for very high signal to noise ratios. Likewise, different units are assigned different kHz frequencies to enable identification when they approach the receivers. An 8-input, two channel receiving board was constructed that connects to the data analysis machine via a serial link.

The complete system draws 23 mA while operational, and runs for about 50 hours on two Lithium Manganese batteries placed in parallel. These batteries are also small enough to fit inside of the cube formed by the hardware. A power monitor on the microcontroller is used to monitor the batteries for failure.

The total cost of the system, in prototype quantities, is approximately US$300.

SAMPLE APPLICATION

Our system was used in `(void*)`[1], an interactive exhibit created by the Synthetic Characters group at the MIT Media Lab and demonstrated at SIGGRAPH ’99. In this exhibit, a user could control one of three semi-autonomous virtual characters, causing them to dance. Drawing our inspiration from Charlie Chaplin’s famous “buns and forks” scene in *The Gold Rush*, we created an input device whose outer casing was two bread rolls, each with a fork stuck near the end, thereby mimicking a pair of legs. The IMU was placed inside the buns. A variety of gestures (kicks, twirls, etc) were recognized and used as inputs to the virtual characters. Also, a user could choose which character to control by placing the buns and forks in one of three designated positions, with presence detected using the capacitive coupling system.

The key design point for this interface is transparency. It is very important for user acceptance and immersion that the aesthetic of the interface not be broken. The IMU supported this goal in several ways. It fit completely within the 3” x 3” x 2” artificial roll used and was invisible to a cursory examination. The wireless interface helped maintain the illusion created by the buns and forks. Battery life also proved important, as anything that must be opened up to have its batteries replaced quickly loses its magic and becomes part of the computerized *other*. Finally, the robustness of inertial measurement (as opposed to vision) allowed the system to work virtually flawlessly in the somewhat hostile SIGGRAPH environment.

Response to the exhibit was very positive, and few people had trouble using the interface. Also, users appeared to form a bond with the characters they controlled, which we suggest would not have been possible with a less subtle interface.

CONCLUSIONS

We built a wireless six degree-of-freedom IMU, with three axes of accelerometers and gyroscopes, updating at 75 Hz. The system was successfully demonstrated as part of an exhibit at SIGGRAPH ’99. Future work on this system will concentrate on creating an analysis, gesture recognition and user-feedback framework for IMU applications in HCI.

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REFERENCES

1. Blumberg, B. et al. `(void*)`: A Cast of Characters, in Conference Abstracts and Applications, SIGGRAPH ’99, ACM Press, August 1999, pp. 169.
2. Mackenzie, D. *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*. MIT Press, Cambridge, 1993.
3. Paradiso J., Hsiao K and Hu E. Interactive Music for Instrumented Dancing Shoes. Proc. of the 1999 International Computer Music Conference, October 1999, pp. 234-237.

[2]Max. acceleration ±2g. Pulse width output, accuracy 12.5%/g