Celeritas: Wearable Wireless System

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ABSTRACT
In this paper, we describe a new wearable wireless sensor system for solo or group dance performances. The system consists of a number of 25mm Wireless Inertial Measurement Unit (WIMU) nodes designed at the Tyndall National Institute. Each sensor node has two dual-axis accelerometers, three single axis gyroscopes and two dual axis magnetometers, providing 6 Degrees of Freedom (DOF) movement tracking. All sensors transmit data wirelessly to a basestation at a frequency band and power that does not require licensing. The interface process has been developed at the Interaction Design Center of the University of Limerick (Ireland). The data are acquired and manipulated in well-know real-time software like *pd* and *Max/MSP*. This paper presents the new system, describes the interface design and outlines the main achievements of this collaborative research, which has been named *'Celeritas'*.

Keywords
Inertial Measurement Unit, IMU, Position Tracking, Interactive Dance Performance, Graphical Object, Mapping.

1. INTRODUCTION
Many different wearable wireless sensors for interactive dance performance have been developed in the last couple of decades. For the purpose of motion tracking, many of those systems have tried to offer a valid alternative to camera-based systems such as Very Nervous System [19] and Eyes Web [10]. Although earlier systems like DIEM [12] and Troika Ranch [11] were commonly classified as wireless they required a lot of wired technology on the body of the dancer, hence limiting his/her movements. As new developments of such technology could be applied in 3D computer graphics with systems like Shape Wrap [18], new entirely wireless systems have been specifically designed for dance performances such as Footwear [15], Pair and Wisear [17] and the more recent Eco [16] and Sensemble [8]. Some of these systems are designed for solo performances while others only for group performances. In this paper we present a new wearable wireless system that enables both solo and group performances. We also report some ideas for mapping with our new system.

Celeritas is an artistic/scientific collaboration between the Interaction Design Centre in Limerick, the Tyndall National Institute in Cork, The Fashion Department at the Limerick School of Art and Design, Cindy Cummings (Dance Artist, Cork) and Todd Winkler (Composer and Digital Artist, Brown University, USA). Research teams at Tyndall have developed wireless sensor network nodes, also known as *motes*, and associated miniaturized sensors. Motes can be applied in many different domains, ranging from medical and environmental monitoring to everyday applications in ubiquitous computing. This project aimed to apply Tyndall's sensor system, creating a low-cost wireless dance costume for audio/visual performance using inertial sensor technology.

2. HARDWARE
The system is designed around the Tyndall's 25mm WIMU, which is a wireless 6-DOF Inertial Measurement Unit (IMU). The system has of up to eight WIMUs that communicate with a base station using a customized Master/Slave protocol.

2.1 25mm WIMU
The 25mm WIMU is an array of sensors connected to a high resolution Analog to Digital converter (ADC). The array has three single-axis gyroscopes, ADXRS150 [2], two dual axis accelerometers, ADXL202 [3], both from Analog Devices (the latter soon to be replaced by a single three axis accelerometer), and two dual axis magnetometers, HMC1052L [5] from Honeywell. The ADC is a 12-bit AD7490 [4] from Analog Device. The ADC converter has a Serial Peripheral Interface (SPI) that connects to an ATMEL microcontroller.

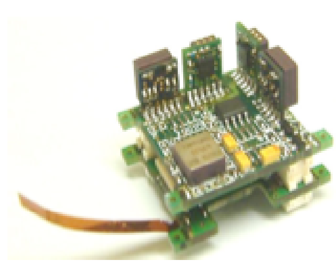

Figure 1. 25mm WIMU module

To facilitate the relevant 6-DOF, a motherboard/daughterboard configuration was used. This means a series of slots were machined in the motherboard to accept the daughterboard at exactly 90°. All the sensors were placed in such a way to allow for the retrieval of acceleration and rotation along and around the three orthogonal axes x, y and z. More precisely, to retrieve the three possible rotational movements the three single axis gyroscopes were set along the motherboard as shown in Figure 2.

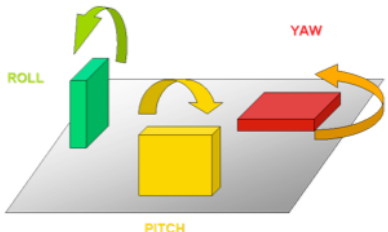

Figure 2. Gyroscopes placement

The software was designed to omit the z-axis values from one of the accelerometers, as its data is, in principle, a copy of the data from the other.

2.2 Measurements

Each WIMU module has its own power supply, a rechargeable lithium-ion battery pack. The weight of the node including battery is ~ 30g and its dimensions are 25 x 25 x 50mm (Figure 3). The battery-life is approximately 3 hours, which is well within the average duration of a performance.

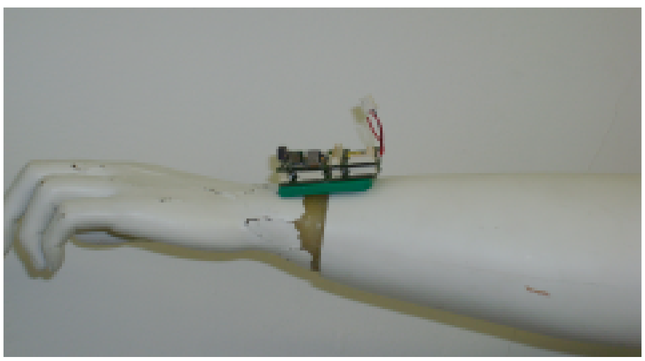

Figure 3. WIMU module (Battery and sensor)

2.3 Radio Unit

The wireless communication system is based on an nRF2401 single-chip 2.4GHz transceiver from Nordic [13]. The transceiver can be controlled both by external hardware (direct mode) and by its own internal hardware (shock-burst mode), which can help improve power saving. As a result the transceiver uses an on chip FIFO to clock in data at low rate but transmitting at a high rate, utilizing the power-save features. The transmission speed is 1 Mbps using Gaussian Minimum Shift Keying Modulation and Demodulation. Another important characteristic is that the 2.4 GHz ISM radio band used makes of it viable as a worldwide portable product not requiring permission from the local telecoms authorities. The transmission range was found to be ~7 meters, with no packet-loss. In a real stage configuration this allows for a performance area of up to 14 meters diameter.

2.4 Communication Protocol

The wireless communication system is based on an address driven master/slave protocol. The slave sensors are placed on the dancer's body and each one identifiable by a node address. The basestation (master) has a transceiver with a serial port output to allow communication with a host computer via RS-232. On startup, the basestation sends a message to all slaves to check for faults, for instance, low-battery in some node. The working sensors reply with the most updated package of data available. The UART of the basestation operates at 115.2 kbps, 8 bits data, 1 start-bit, 1 stop-bit and no parity.

The total data packet per sensor and transmission is 20 bytes long made up of 18 bytes of data (9 two-byte packets in which the first 4 MSB of each pair is the ADC channel number, while the remaining 12 bits are the ADC values), and 2 bytes for synchronization (see Figure 4). Therefore, the overall transmission speed will be equal to 72 arrays/sec with eight sensors operating and with an overall system latency of about 14ms.

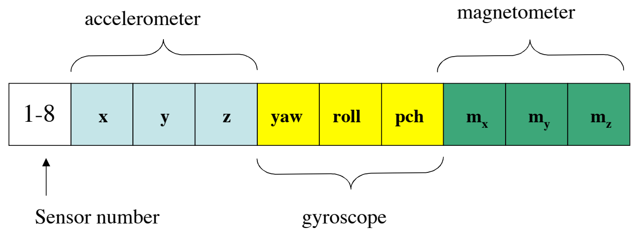

Figure 4. Sensor's Array

Currently, hardware latency depends on the number of sensors used. Considering that a single node has an internal system cycle of ~0.5ms, the total system latency could brought down to ~4 ms with eight nodes, or, ~8ms with 16 nodes for a group performance with only a single basestation connected to a host computer. Nevertheless, the hardware speed at the moment is ~9ms faster than the RS-232 actual speed of transmission. Future implementation with USB2.0 or Firewire could substantially improve performance.

Figure 5. Sensor Network

3. SOFTWARE

Pure Data and Max/MSP were the software platforms chosen for the real-time manipulation of the incoming data. The rationale for this was that these platforms are commonly used in computer music and video art, and therefore familiar to composers and choreographers working in this domain. We developed new pd and Max/MSP graphical objects called 'mote' to facilitate real-time operation of the system. See Figure 6 for system architecture.

3.1 Acquisition & processing

We designed a driver in C to process the stream of data from the basestation. As requests for data from the application is not synchronous with the data stream, the driver bridges this gap. In order to achieve this, a multi-threaded driver was designed. The first main thread handles reading from the serial port while the second thread handles the passing of data back to the application that is calling the function (the 'mote' graphical object). To make it easier to deal with a node going offline from the application level, the first thread loops constantly calling a function that starts by setting all the node data buffer to 0xFF, so that the application will get all –1's for non-working sensors.

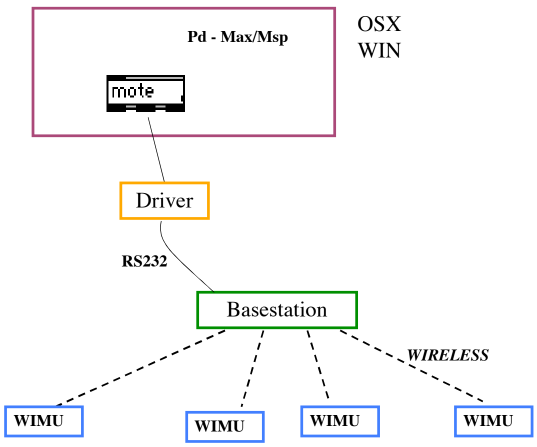

Figure 6. System architecture

3.2 'Mote' object

The new graphical object compiled for pd and Max/MSP is called *'mote'*. It has one inlet and three outlets. When the inlet receives the message '1' a function call to the above-mentioned 'reading thread' is made. If no synchronization error occurs, the leftmost outlet will send out the most update pack of data available with an array of eighty elements. The middle outlet sends out a *'bang'* message each time a new array is received, while the rightmost outlet provides the time interval between two subsequent arrays. To loop the reading process from the device it can be used with a *'metro'* object at high rate, or by *piping* the bang message coming out from the middle outlet to avoid stack overflow. To get the data flow run smoothly, the object has been implemented with a function that enables only new data packets, hence avoiding copies. Therefore it is sufficient to set the 'metro' or 'pipe' object to a speed faster than the actual transmission speed, found to be ~14 ms, to ensure that no copies of the same array are passed back to the program. The patch representing the input to the system is shown in Figure 7 (six nodes connected).

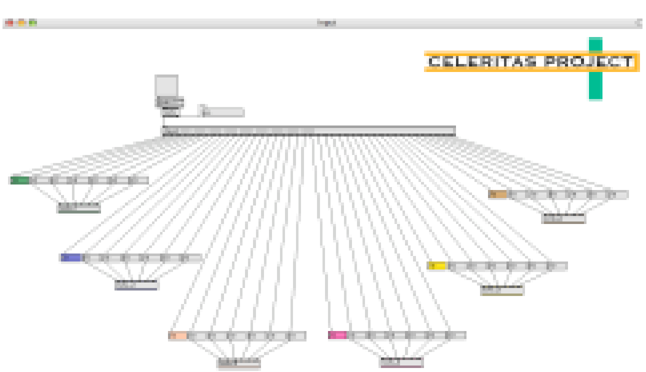

Figure 7. Input patch

The *mote* object has been compiled for both Apple OS X and Windows XP/2000 platforms running pd or Max/MSP.

4. INTERACTIVE SYSTEM DESIGN

The main objective of the system presented in this paper was to build a new interface for musical expression allowing solo or group dance performers to control the processing of audio and video signals in real-time. As sensor nodes are individually identified, it is possible for a composer or choreographer to use the mote objects as he or she desires. Using the 6-DOF from the sensors, we plan to design a 3-D virtual instrument around the body of the dancer. The virtual instrument is a virtual sphere with the center at the dancer's chest. The sphere's radius is the distance between the center of the chest and the tips of a performer's fingers or toes (see Figure 8).

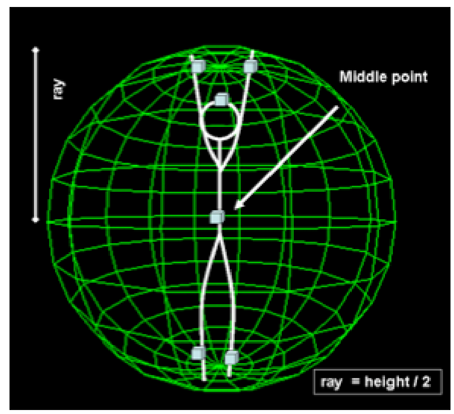

Figure 8. Virtual Sphere

From the sensor data we can calculate acceleration, orientation, speed and location of each sensor/limb – in real-time. The idea of the sphere is also important for containing the positioning data inside a virtual container facilitating an ego-centric mapping process and using it as a virtual instrument. With this design we can also segment the sphere in as many portions as desired to assign a specific function (sound or video-clip/process) to each location around the performer's body according to the scheme designed by the composer/choreographer. In the case of group performances, data coming from different dancers can be, for instance, used to retrieve proximity and area of intersection between spheres/dancers if absolute position is calculated (case in which Zigbee protocol would be necessary for accuracy over time), while an interesting comparative analysis can be conducted if relative position is instead retrieved. That is, synchronicity/asynchronicity identical/opposite directions of movements as well as proportional difference in speed between dancers represent only few examples of a formidable material available to the composer for mapping audio and video events in real time.

5. DRESSING UP

The Fashion Department at the School of Art and Design at the Limerick Institute of Technology designed and developed a protective envelope for the nodes. The design phase focused on three main aspects: wearability, strength and trouble-free sensor replacement. Figure 9 shows one example the results.

Figure 9. Protective Envelope (wrist)

6. CONCLUSION & FUTURE WORK

In this paper we have presented a new wearable wireless system for interactive solo or group dance performance. The system has an array of sensors with accelerometers, gyroscopes and magnetometers enabling 6-DOF operations. A new graphical object was developed to interface the sensor-nodes with Max/MSP and pd. A preliminary mapping strategy has been also proposed with a 3-D virtual sphere around the body of the dancer. So far, the system has proved to be a valid alternative to camera-based systems for motion tracking. The next generation WIMU designs are underway, bringing the size down to a 10mm cube per mote. We also anticipate that the next generation WIMUs will be more resistant to mechanical shocks. Furthermore, although the magnetometers have proven to be essential to increase accuracy, the platform still needs additional means to maintain accuracy over longer performances. We are also considering evaluating the possibility to implement the system with the Zigbee Communication Protocol (IEEE 802.15.4).

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