Wireless Digital/Analog Sensors for Music and Dance Performances

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ABSTRACT

We developed very small and light sensors, each equipped with 3-axes accelerometers, magnetometers and gyroscopes. Those MARG (Magnetic, Angular Rate, and Gravity) sensors allow for a drift-free attitude computation which in turn leads to the possibility of recovering the skeleton of body parts that are of interest for the performance, improving the results of gesture recognition and allowing to get relative position between the extremities of the limbs and the torso of the performer. This opens new possibilities in terms of mapping. We kept our previous approach developed at ARTeM [2]: wireless from the body to the host computer, but wired through a 4-wire digital bus on the body. By relieving the need for a transmitter on each sensing node, we could built very light and flat sensor nodes that can be made invisible under the clothes. Smaller sensors, coupled with flexible wires on the body, give more freedom of movement to dancers despite the need for cables on the body. And as the weight of each sensor node, box included, is only 5 grams (Figure 1), they can also be put on the upper and lower arm and hand of a violin or viola player, to retrieve the skeleton from the torso to the hand, without adding any weight that would disturb the performer. We used those sensors in several performances with a dancing viola player and in one where she was simultaneously controlling gas flames interactively. We are currently applying them to other types of musical performances.

Keywords

wireless MARG sensors

1. INTRODUCTION

There is growing need for improved devices to track the gestures and movements of musical performers and dancers on-stage, for various kinds of interactive performances. Systems that require only a light and fast setup, that are robust enough to take on tour and that don't modify the dancer's appearance. This often excludes the use of some well established technologies used in motion pictures or in the gaming industry, like putting visible markers on the body and using a large array of cameras, or demanding the dancer to wear a special and cumbersome suit fitted with arrays of sensors. And the price should remain affordable for artistic projects.

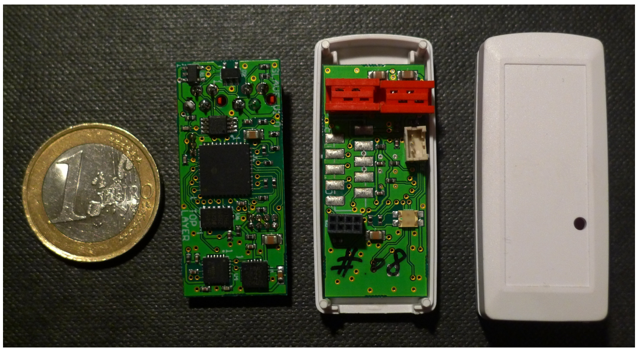

Figure 1: *The sensor nodes, from left to right: 1 Euro coin, top PCB view, bottom PCB view in the lower part of the box, showing red connectors for I2C Bus and power supply (empty pads can be used to solder up to 6 additional analog inputs directly on the PCB or with a micromatch connector), and box closed, with hole to see the bicolor LED.*

This design started as a part of a wider project to build hardware and software tools to enable interactive performances whereby a dancer controls music and fire in the form of software-controlled gas flame projectors. We also developed software for a stereoscopic camera to follow the dancer in a difficult environment with flames. We will come back to this in the application part of the paper.

When we started the project for the fire control in 2009, there were no affordable sensors on the market fulfilling our needs and we decided to build a new system, using the latest available sensing chips and low power wireless technologies to improve our previous designs, extending the capacities by combining 3-axes accelerometers, magnetometers and gyroscopes while reducing the size significantly.

We plan to make the sensors available commercially with a Max/MSP toolbox to communicate with the sensors, decode and analyze their signals. It takes care of bi-directional communication between the sensors and Max, allowing the user to tailor the sensor system to his needs and giving him tools to define his sensor name space. The received data is decoded and scaled and the value of each sensing axis is available using a simple Max receive object in physical units: g, Gauss and deg/s. Attitude information is given for each node in quaternion representation. The toolbox will include improved versions of the tools we developed for the *Dancing Viola* project [21]: hit detection, DTW-based gesture recognition [3] and mapping by interpolation[22].

2. SENSORS

All commercial wireless sensor interfaces designed for artists (Eowave [6] Eobody2 HF, Interface-Z [11] Wiwi or Mini-HF, Infusion System [10] I-cubeX, La Kitchen [13] Kroonde, ...)

have only analog inputs, limited to 16 channels and 10 or 12 bits ADCs. While they allow users to connect various sensors without any additional programming, they are all quite limiting in terms of the number of available channels and they imposes a heavy harness of wires. Indeed, as we wanted to fit each sensor node with 3-axes accelerometer, magnetometer, gyroscope and temperature sensor for calibration, it meant 10 channels plus ground and power, or 12 wires per sensor node. And we wanted a system capable of sampling 3 to 6 sensor nodes on a dancer at 100 Hz.

A system with sensor nodes of similar capacities had been described in [7], though with a different approach. There is an obvious trade-off between that system, truly wireless, even on the body, but with bigger nodes as each one carries its own emitter and battery, and our system with sensors connected through a digital bus on the body. We believe that our approach, with very flat sensors, invisible under the clothes, offers more freedom of movement to the dancer, particularly for movements on the ground, despite the need for cables on the body. Light-weight sensors have the additional advantage of having a small inertia than heavier sensors, which allows them to follow more closely the movements of the limbs of the dancer they are attached to.

Following the experience of the sensor system developed in 2006 at ARTeM [2] for the *Quartet Project* [16], *De deux points de vue* [5] and *Dancing Viola* [21, 4], we kept a master/sensor nodes architecture while reducing the form factor and adding sensing capabilities. They communicate through a 4 wire 400kHz I2C bus on the body: a bidirectional data (*SDA*) and a clock (*SCL*) link, a common ground (*GND*) and a power supply line (*VDD*). The global architecture is shown in Figure 2.

2.1 Sensor chips choices

We made an extensive search at the end of 2009 for our first prototype. There were obvious choices for 3-axes digital magnetometers (Honeywell [9] HMC5843) and accelerometers (STMicroelectronics [19] LIS302DLH or the Analog Device [1] ADXL345). We chose for the later both for its wider range, keeping a constant resolution of 4mg/LSB at all ranges, and for its additional functions. But 3-axes gyroscopes were not yet available and we had to chose a combination of an x/y-axes gyroscope and a z-axis one. Because of the amount of external components needed, we chose for the InvenSense [12] IDG-650 and ISZ-650 rather than for the STMicroelectronics [19] LPR550AL and LY550ALH gyroscopes. We used a PIC18F2423 for its 12-bit DACs, adding four times oversampling for better precision.

In our latest design, in 2010, we use the newly available Invensense ITG-3200 digital 3-axes Gyroscope and added 6 channels of ADC for optional additional sensors (pressure, flexion, light, ...), all on a 17x38 mm PCB that fits into a tiny USB key box (Figure 1). The boxes are 10 mm thick and if even flatter sensors are needed, it is possible to remove the connectors altogether, to solder the 4 I2C Bus and power wires directly on the PCB, and to enclose the sensor in resin, reaching less than 4mm thickness.

2.2 Wireless sensor system architecture

We tested several low power wireless transmission technologies to see how far we could reduce the size and weight of the battery: ZigBee, SimpliciTI, Bluetooth. But we found huge disparites between the announced data rates and the measured ones: ZigBee and SimpliciTI could not be used reliably with more than one or two sensor node. BlueTooth could handle three nodes at 100Hz, but only 50Hz gave a decent latency, as packet sizes increased with data rate. While a low power WiFi module [17] had no problem transmitting eight sensors nodes at 100Hz, with the added benefit of a smaller and constant latency thanks to the use of a match character to send data in a single IP packet. Despite higher transmission power, as the transmission time is reduced thanks to the high throughput, the average WiFi power consumption was similar to BlueTooth and was chosen as shown in Figure 2.

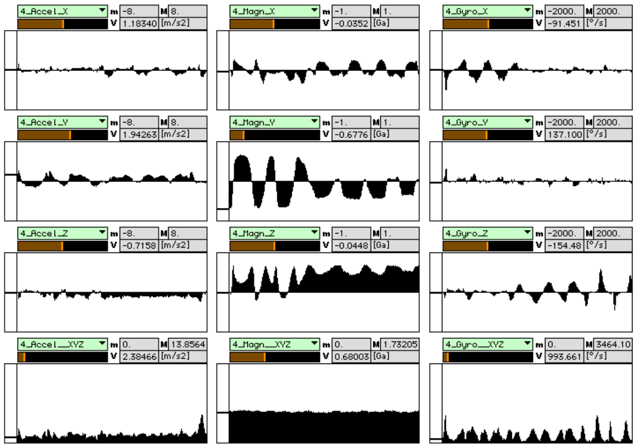

Figure 3: *Max/MSP Display of the 3 axes of the Accelerometer, magnetometer and gyroscope and total amplitude of each for one sensor node.*

2.3 Max Toolbox

Contrarily to most commercial systems, bi-directionnal communication allows the user to remotely and dynamically set up, directly from Max/MSP, the sampling period, which of the on-board sensors need to be transmitted by each node, including the number of ADC channels, allowing the user to tailor his system and to optimize bandwidth. Unused on-board sensors can be put to sleep in order to economize power. Various configuration parameters of the accelerometers, magnetometers or gyroscopes can also be modified in real-time: their range, their individual sampling frequency, the cut-off frequency of their low-pass filter, self-test of the accelerometer, degaussing the magnetometer, etc.

The received data is decoded by an external Max object. The user can define a name space for each sensor. The values are then scaled depending on gains and offsets. Those are either given by the user or automatically computed for the accelerometers and the magnetometers within the Max external after the user records the data in 6 different positions. A function to zero the offsets of the gyroscopes is also provided. And the value of each axis is made available using a simple Max receive object in meaningful units: g for the accelerometer, Gauss for the magnetometer and deg/s for the gyroscope. They can be displayed as in Figure 3.

2.4 Attitude computation and skeleton

MARG (Magnetic, Angular Rate, and Gravity) sensors allow for a drift-free attitude computation using Kalman filters with a quaternion representation of the angles [15] in order to avoid singularities associated to Euler angles. But we integrated in our external Max object a method by Madgwick [14] that gives good results even at low sampling rates. At 100Hz, using dynamic values of gains β and ζ to avoid disturbing the quaternion computation when the total acceleration diverges from 1g, we obtain excellent results, even when shaking the sensors or performing hits. The method performs quite well even at 50Hz.

As the amount of sensor nodes we can connect to a master

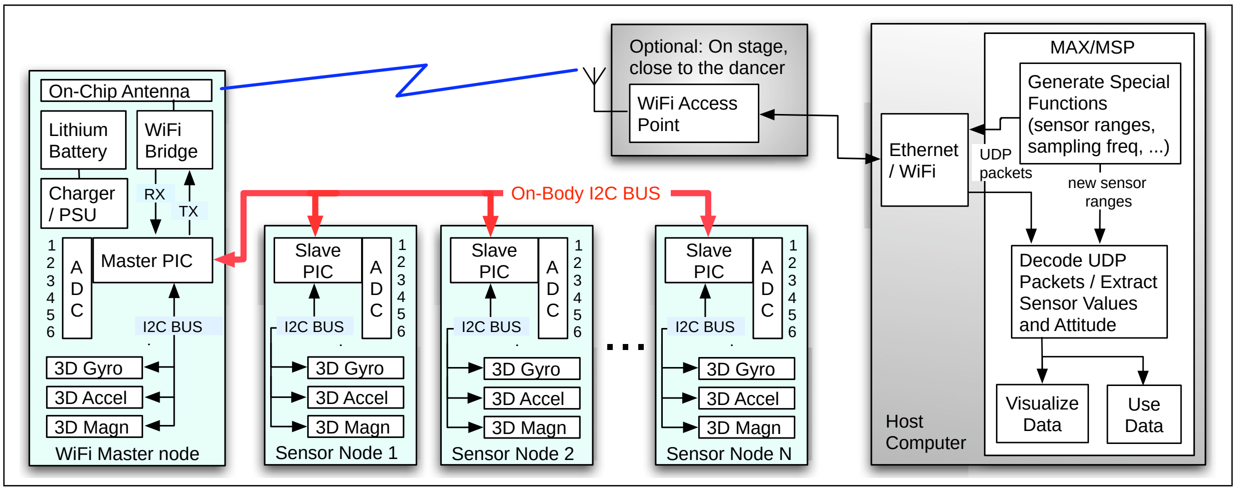

Figure 2: *Wireless sensor system global architecture, with all the bi-directionnal transmission paths (network, wireless, serial, local and on-body I2C) and analog inputs.*

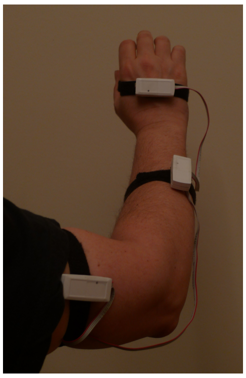

Figure 4: *Three sensor nodes attached to the arm and hand using velcro strips.*

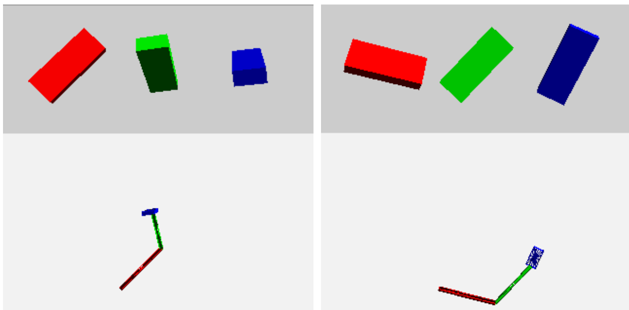

Figure 5: *Attitude of the upper arm (red), lower arm (green) and hand (blue) and reconstructed skeleton in Jitter.*

is limited by the bandwidth of the on-body I2C Bus, halving the sampling frequency allows to double the amount of nodes. Tests showed that our system could sample 3 sensors (master included) at 200 Hz, 8 sensors at 100 Hz and we may extrapolate to at least 16 sensors at 50Hz (we are waiting for a new batch of sensor nodes to get the real value).

If enough sensors are placed on a limb, for instance upper and lower arm plus hand as in Figure 4, a skeleton can be animated in jitter and the position of the hand in regard to the shoulder can be computed (Figure 5), We can thus get the skeleton of upper body at 100 Hz with 8 sensors or the complete body skeleton at 50 Hz with 16 sensors.

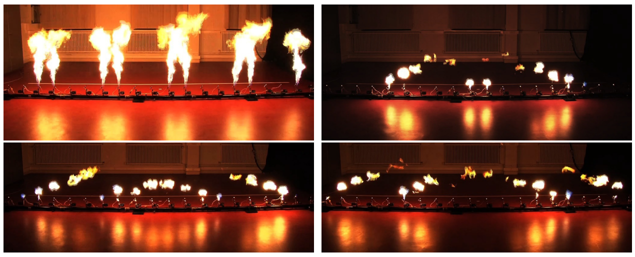

Figure 6: *On the fire ramp, each flame is individually controlled and short bursts of gas can generate fire balls.*

3. APPLICATION: CONTROLLING MUSIC AND FIRE

The sensors were used on the project *FireTraSe* [8] with pyrotechnician Pierre D'haenens who built a patent pending ramp of 20 flames projectors at ShowFlamme [18].

The height of each flame of the ramp can be independently controlled by software and we designed several pattern generators driven by the combination of the sensors signals, video analysis with a stereoscopic camera and sound analysis, using the mapping scheme described in [21]. The height of a gas flame depends on the opening of the corresponding valve, the amount of time that valve is kept open and the upstream gas pressure. Leaving the valve opened for a sufficient amount of time at a specific value will generate a flame of a corresponding specific height. If we modulate the opening of the valve in time, we can as well generate fire balls as shown on Figure 6. This phenomenon depends on the inertia and *time to live* of the projected material. We programmed pattern generators to generate sets of 20 control values varying over time. Though designed to control gas valves to produce flames, the software could drive any number of valves controlling any fluid, like smoke or water.

In that framework we also developed in our lab video analysis tools for a stereoscopic camera in order to track reliably the gestures, the position and height of a dancer despite the presence of the flames [20]. In short, we use the distance information from a Stereo-on-Chip Videre Design camera [23] to remove the image of the ground so that changes of light and shadows generated by the flame patterns don't interfere with the blob detection. Something that could not have been done with an IR camera or background subtraction techniques. The camera can be placed

Figure 7: *Dominica Eyckmans dancing while playing viola.*

in any position as we perform a coordinates transformation from pixel position and depth to stage coordinates (x,y,z).

As the camera reconstructs everything it sees, we define planes in front of the walls, the fire and over the ground. They serve as thresholds to suppress unwanted information, leaving only the dancer's 3D reconstruction. Blob tracking gives us a bounding box in stage coordinates, providing the (x,y) centre of the performer and his height.

The whole system worked within Max/MSP/Jitter, except for the video tracking, running on a separate Linux computer communicating through OSC.

In combination with the tools developed for the *Dancing Viola* project, we blended the three modalities: position tracking, gestures analysis and sound analysis. Figure 7 shows the performer playing the viola, controlling flames and sound transformations of her acoustical instruments as well as triggering and modulating pre-recorded sounds. The sensors were placed on her legs and torso. The attitude extraction, the interpolation tools [22] and the DTW gesture recognition [3] can be combined to give increased control.

4. CONCLUSIONS

We believe our sensors system is an improvement in size, capabilities and resolution over other systems in the same price range. The combination of high resolution digital 3-axes accelerometers, magnetometers and gyroscopes allows for a robust attitude computation and the choice of WiFi allows several performers to share the same wireless channel. Attitude extraction and skeleton reconstruction provide data that improves significantly DTW gesture recognition. Indeed, gestures measured only with accelerometers and gyroscope lack drift-free horizontal plane orientation that might help discriminate between different gestures. Another issue with acceleration and angular speed data is that they do change of value when a movement is performed faster or slower, inducing an increase of the DTW error when the execution speed diverges from the recorded reference gesture. Attitudes and positions don't suffer from that problem and are therefore more suitable for DTW.

We are working on better visualization tools to combine the attitude of each node, with the display of the smoothed and maximum values of the individual sensing axes, devising appropriate representations for accelerations, angular speeds and magnetic field. And we are investigating percussionist gestures, taking into account the preparation gesture before the hit to determine the sound being played.

5. ACKNOWLEDGMENTS

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