Smart Object for 3D Interaction

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Abstract. This paper reports on the creation of an interface for 3D virtual environments, computer-aided design applications or computer games. Standard computer interfaces are bound to 2D surfaces, e.g., computer mouses, keyboards, touch pads or touch screens. The Smart Object is intended to provide the user with a 3D interface by using sensors that register movement (inertial measurement unit), touch (touch screen) and voice (microphone). The design and development process as well as the tests and results are presented in this paper. The Smart Object was developed by a team of four third-year engineering students from diverse scientific backgrounds and nationalities during one semester.

1 Introduction

Progress in technology, especially in fields of embedded systems, communication and sensor systems, give rise to new types of applications and devices. The availability of low cost Micro-Electrical-Mechanical Systems (MEMS), which are very small electro-mechanical devices, allows on chip physical measurements such as acceleration or rotation. This has enlarged the scope of application domains and fostered the engineers ability to combine several sensor technologies to test new methods of human computer interactions.

This project was focused on the design and development of a Smart Object to be used as a 3D Personal Computer (PC) interface. Standard computer interfaces are bound to 2D surfaces, e.g., the computer mouse which gives allows movement in the *X* and *Y* axis. The goal of this project is to design a product that allows 3D movement and, moreover, that enables the user to turn, rotate, zoom in and out on a computer screen. This type of device can be useful in computer games with 3D

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graphics, on which often there is the need to simultaneously translate and rotate the virtual world, but can also be of extremely utility in professional Computer Aided Design / Computer Aided Manufacturing / Computer Aided Engineering (CAD / CAM / CAE) applications. Very often, the users of these professional applications need to translate, rotate, zoom in and out the view of the products that they design in CAD applications (such as, just as an example, SolidWorks™ [1]) and the virtual equipment's to manufacture these products, that are modelled virtually in applications such as ABB RobotStudio (an application for robot simulation and off line programming from ABB [2]) or, even, computer applications for layout design (such as QUEST, from DELMIA [3]). The fast and simultaneous translation, rotation and zooming of the virtual worlds in these types of applications is often difficult to realize and even gives rise to some difficulties that could be surpassed by using and Human-Computer interface such as the Smart Object herein described.

This paper is structured in five sections. The introduction (Section 1) presents the general problem, motivation and objectives and is followed by the description of related three-dimensional PC interfaces (Section 2). Section 3 introduces the support technologies adopted. Section 4 addresses the design and construction of the device, the control software, the data connection and the representation of the object in a virtual 3D environment. Finally, Section 5 discusses the results and presents the conclusions.

2 3D Interactive Objects

The 3D mouse from 3Dconnexions is a family of devices with identical functionalities. The company 3Dconnexions, which has launched the first product in 2009, has five different products that can be used for the same purpose, but with diverse segmentation [4]. They differ in size and functionalities, e.g., the products with higher dimensions have a built-in liquid crystal display (LCD), have more functions and are more expensive. The smallest device has just a Controller Cap and two interface buttons. The 3D mouse device from 3Dconnexions, that is identical to the Smart Object, resembles a joystick and allows the user to rotate, zoom, turn and pan the object. The manufacturer describes this 3D mouse as having "a level of control that is simply not possible with a traditional mouse and keyboard" [4].

A cube, equipped with an Arduino based development board, various sensors and an XBee wireless interface was developed by [5]. This cube was tested as an input controller for several computer games and the software was released under an open source license.

3 Support Technologies

The technologies that support this project are standards in modern electronic devices and are mass produced.

3.1 Microcontroller

The Arduino is a popular open source single-board microcontroller designed to make the process of using electronics in multidisciplinary projects more accessible [6]. The hardware consists of simple open hardware design for the Arduino board with an Atmel AVR processor (it is a single chip microcontroller which was developed by Atmel in 1996) and on-board input/output support [7]. The software consists of a standard programming language compiler and the boot loader that runs on the board.

3.2 Sensors

An inertial measurement unit (IMU) is an electronic device that measures and reports the velocity, orientation and gravitational forces applied to a craft and uses a combination of accelerometers and gyroscopes. Typically, they are used to maneuver aircraft, including unmanned aerial vehicles (UAV), and spacecraft, including shuttles, satellites and landers. The IMU is also the main component of the navigation systems used in aircrafts, spacecrafts, watercrafts and guided missiles. In this capacity, the data collected from the IMU sensors allows tracking a craft. This project uses an IMU to sense movement.

The touch screen is an electronic visual display that detects the presence and location of a touch within the display area. Although the term generally refers to touching the display of the device with a finger or hand, it can also sense other passive objects such as a stylus. In this project the touch screen is intended to detect the touch of the user's finger.

A microphone is an acoustic-to-electric transducer or a sensor that converts sound into an electrical signal. In this project the microphone is intended to detect and convert the user voice into an electrical signal.

3.3 Power Supply

To power such a device it is possible to use solar panels or rechargeable batteries since the remaining options are too difficult, expensive or complex to implement.

Solar panels are a packaged, connected assembly of photovoltaic cells. The solar panel can be used as a component of a larger photovoltaic system to generate and supply electricity for commercial and residential applications. A photovoltaic system typically includes an array of solar panels, an inverter and, sometimes, a battery and/or solar tracker. Solar panels are expensive when compared with batteries. Besides, since the Smart Object is intended to be held by the user, it should not be too large. Additionally, the solar panels would often be obstructed by the user hands and, in contact with human skin, would require frequent cleaning.

Lithium Polymer (LiPo) batteries are rechargeable batteries composed of several identical secondary cells in parallel to increase the discharge current capability. They are compact and ideal for small cordless devices. This project uses a LiPo battery as power source.

3.4 Wireless Data Connection

Wi-Fi is a technology that allows an electronic device to exchange data wirelessly over a data network, including high-speed Internet connection. There are a lot of devices that can use Wi-Fi, such as PC, video game consoles, smartphones, tablets or digital audio players. All of these can connect to a network resource such as the Internet via a wireless network access point. Indoors the range is about 20 m and outdoors is greater. Access point coverage, also called hotspots, can comprise an area as small as a single room with walls that block radio waves or as large as many square miles - this is achieved by using multiple overlapping access points [8].

ZigBee is intended to be simpler and less expensive than other wireless personal area network (WPAN) such as Bluetooth [9]. It is targeted at radio-frequency applications that require low data rate, long battery life and secure networking. ZigBee is best suited for periodic or intermittent data or single transmission from a single transmission from a sensor or input device [10].

Bluetooth is a widely spread wireless connection option [11]. It can be found on PC, smartphones, laptops and other devices. It is used for exchanging data over short distances from both fixed and mobile devices. Bluetooth creates personal area networks (PAN) with high levels of security [12].

Bluetooth was selected for the wireless data link because it is present in most laptops, tablets and smartphones platforms. ZigBee was contemplated as an alternative wireless technology, but was not adopted because requires acquiring a receiver for the user platform. Finally, Wi-Fi was discarded since it is, among the wireless technologies, the biggest consumer of energy.

4 Project Development

The system is made of the Smart Object, the wireless data link and the PC application. On the Smart Object side, the Arduino microcontroller, that is connected to the sensing system, is responsible for collecting and transmitting all measurement data over the wireless data link to the PC application. The sensing system includes an IMU, that provides a full six degree of freedom measurement of the position of the object, an accelerometer, a microphone and a touch pad. On the PC-side, the object is modelled and displayed in a virtual environment using Java programming language.

4.1 System Components

All components were selected considering price, ease of use, flexibility and energy consumption. The Smart Object includes:

- **Arduino BT** – a microcontroller board based on the ATmega328 and the Bluegiga WT11 Bluetooth module. Its main features are the wireless serial communication over Bluetooth, 14 digital input/output pins, 6 analog inputs, a 16 MHz crystal oscillator, a 32 kB Flash Memory and 2 kB SRAM [13].
- **IMU Digital Combo Board ITG3200/ADXL345** – a six degrees of freedom measurement with an I^2C interface containing:
  - ITG-3200 Integrated Triple-Axis Digital-Output Gyroscope is a single-chip, digital-output, 3-axis MEMS gyro optimized for gaming, 3D mice and motion-based remote control applications. It features three 16-bit analog-to-digital converters (ADC) for digitizing the gyro outputs and a Fast-Mode I^2C (400 kHz) interface. The Digital-output X, Y and Z axis angular rate sensors have a sensitivity of 14 LSB/°/s and a full-scale range of ± 2000°/s [14].
  - ADXL345 Accelerometer – a small and ultra low power 3-axis accelerometer. It measures the static acceleration of gravity as well as the dynamic acceleration resulting from motion or shock. The measurement is performed with a high resolution (13-bit) at up to ± 16 g. The data is formatted as 16-bit two's complement and is accessible through a I^2C digital interface. The resolution of 3.9 mg/LSB enables measurement of inclination changes less than 1.0°[15].
- **ADMP401 MEMS Microphone** – an analog omnidirectional microphone [16].
- **Nintendo DS Touch Screen LCD-08977** – a 4-wire analog touch screen manufactured by Hantouch USA originally for the Nintendo DS [17].

4.2 Data Flow

The Smart Object detects movement, sound and touch sensing and communicates all perceived changes to the PC application via the wireless data link – Fig. 1.

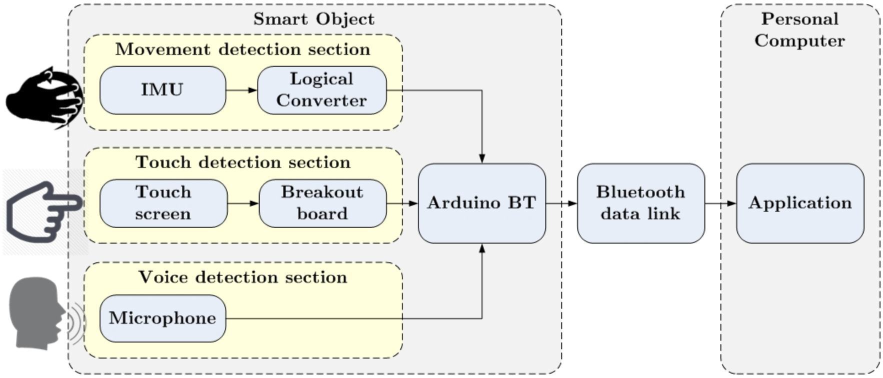

Fig. 1 Data flow

The IMU, microphone and touch pad are continuously measuring and sending the detected user inputs to the Arduino: (*i*) the IMU senses and reports the movement-related data to the Arduino via a logical level converter; (*ii*) the microphone registers and sends directly the voice input to the Arduino; and (*iii*) the touch pad detects the user input (touch) and sends it via a breakout board to the Arduino.

4.3 Software Modules

The Smart Object programming was divided in two sections. On the device side, the Arduino program was written in C and, on the PC side, was coded in Java. To get powerful graphical functions the PC-side application uses a Java OpenGL engine called "jmonkeyengine" [18]. Eclipse was use for the Java programming development. Figure 2 gives an overview of the software architecture. The Java application is composed of three threads: (*i*) the data management thread for the Bluetooth data link; (*ii*) the sensor data plotting thread; and (*iii*) the 3D-environment visualization thread.

4.3.1 Arduino Application

The Arduino application is structured in a setup and a loop functions. In the setup, the serial connection is established, all digital and analog ports, which are connected to the sensors, are defined and an array of double values to hold the sensor values

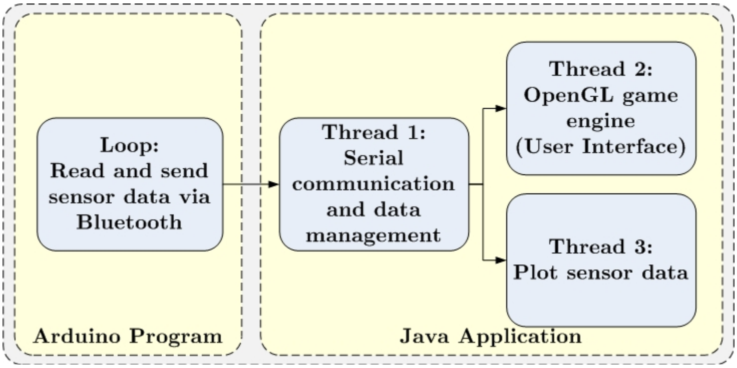

Fig. 2 Software architecture

is declared. After the execution of the setup, the infinite control loop starts. If a wireless connection with the PC exists, the Arduino reads all sensor data. In the case of the IMU, an open source library called "FreeIMU" [19] was used. The gyro values and acceleration values are fused together to calculate a more stable position. As a result, it is possible to obtain directly the Euler Angles from the IMU. The touch pad is directly connected to an analog port and requires a special pin configuration to allow reading the X and Y position simultaneously. Finally, the microphone analog output is read.

4.3.2 PC Application

The PC application is responsible for establishing the wireless data link (Data Management Thread), plotting all measurement data (Plot Thread) and, finally, displaying the Smart Object in the 3D virtual environment (Game Engine Thread).

Data Management Thread

The data management thread establishes the connection between the PC application and the Smart Object. The Bluetooth profile used is a serial connection. If the Bluetooth connection is established, all incoming data is stored in three different First In First Out (FIFO) queues. These FIFO are declared as public. The implemented data structure is thread safe in order to avoid data crashes since multiple threads access the incoming data.

Plot Thread

The plot thread plots incoming sensor data in real time. The thread associates a time stamp to each incoming value as soon as it is added to the data management thread FIFO and refreshes the corresponding plot. All plots are accessible via a tabbed pane in the Java application, allowing the user to switch between the different sensor data plots and the 3D environment - Fig. 3.

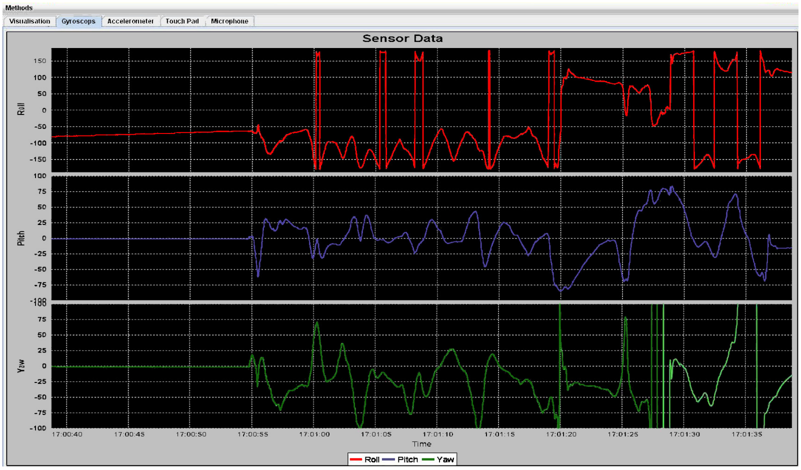

Fig. 3 Plot thread visualisations

Game Engine Thread

The Game Engine Thread implements the OpenGL game engine. After setting up the 3D virtual environment and displaying the cube, the thread tries to get data from the data management thread. If data is available, a loop is started to permanently update the visualization. Figure 4 shows the flowchart of this thread. To detect the zoom, the touch pad data is analysed in a separate function. If the values are decreasing or increasing the zoom value is calculated accordingly. By analysing the acceleration data for big changes in a short time period, a shake of the object can be detected. With this information two modes are implemented. The first mode rotates the cube and the second mode rotates the camera around the cube. For both modes the three Euler angles from the IMU are used to change the rotation of the cube or camera.

Figure 5 shows the 3D virtual representation of the Smart Object.

4.4 Building and Assembly

Finally, the project development involved building the external cubical container and the assembly of the components.

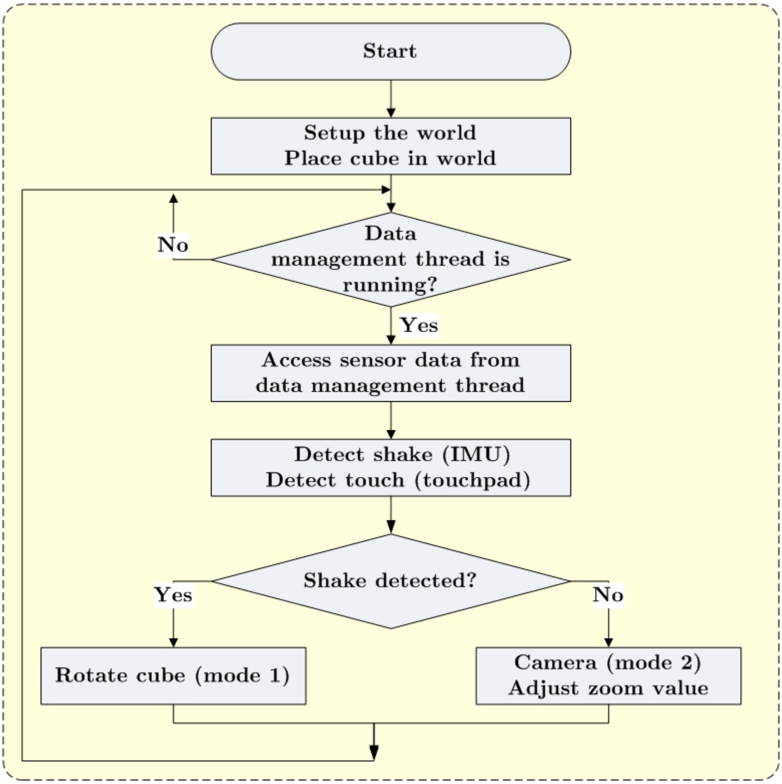

Fig. 4 Game engine thread

Fig. 5 3D Virtual environment

4.4.1 Angle Brackets

All Smart Object components, except the touch screen, are stored inside the container. The outer shell is made from acrylic glass that was machined and bent to the needed shape. The angle brackets were made from an aluminium alloy L-profile. The L-profile had to be cut in 20 mm wide pieces and then two holes had to be drilled into each angle bracket for the screws. The first hole drilled was 2 mm in diameter and the second one was in 3 mm in diameter. Rasps were used to make the edges surfaces smoother, because a metal saw was used for the cutting. Angle brackets for the bottom part had to be smaller from the 2 mm hole side so that the Arduino could be taken out if needed. Thus, the angle brackets were grinded to size.

4.4.2 Bending the Acrylic

Before bending the acrylic, the container parts were cut to size and small incisions of 0.3 mm to 0.5 mm deep were made along the bending lines. These incisions were performed on the inner side of the bent in order to relieve stress that the bending causes. A voltage regulator was used to heat up a wire that was fastened between two clamps. The wire was placed 3 mm from the piece of acrylic sheet and was heated to approximately 400 °C (the voltage regulator was adjusted to 3.1 V and 11.8 A). This temperature was best suited for the 3 mm thick acrylic glass sheet used.

4.4.3 Machining the Acrylic

The holes for the screws were drilled after bending the acrylic parts. Chamfers were made so that the screw heads would be at the same level as the acrylic. A drilling machine was used for this purpose. Additional holes were made for the touch screen connector and for the USB cable to charge the assembled device. The top and bottom parts were cut into size, the sides and corners were grinded and filed. Finally, the holes for the screws were drilled. Chamfers were also made to hide the screw heads.

4.4.4 Assembly

To assemble all parts different screws, washers and nuts were used. The angle brackets hold together 4 acrylic glass parts that form the shell. Two types of screws are used to fasten the angle brackets to the acrylic: metal screws and M3 screws. The metal screw is screwed straightly in the angle bracket's 2 mm diameter hole. The M3 screw goes through the 3 mm diameter hole and is fastened with a nut. To fasten all the electronic things to the acrylic M3 screws, rubber washers and M3 nuts are used. The M3 screw is fastened to the acrylic with a nut. This method should relieve some stress from the electronic parts. Then the electronic parts are fixed between 2 rubber washers and to hold them in place another nut is used. The last nut is loosely fastened on the screw to keep the hardware in place. The touch screen is taped onto one side of the shell. The touch screen pin goes through the hole that was made before into the acrylic glass. The connector is placed inside the shell. Figure 6 shows the Smart Object with all assembled parts.

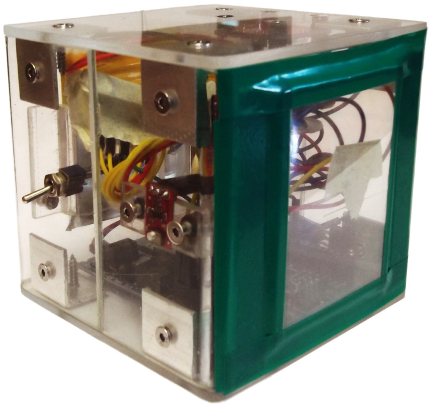

Fig. 6 The Smart Object with all assembled parts

5 Conclusion

This paper presents the Smart Object developed to interface with a 3D virtual environment. The system consists of three main modules: (*i*) an Arduino microcontroller connected to a set of sensors including an IMU that gets six degrees of freedom measurement of the position of the object; (*ii*) a Bluetooth wireless data connection; and (*iii*) a 3D virtual environment which was programmed in Java. The latter is to be installed in a laptop, PC or tablet with a Bluetooth interface.

The prototype needs, in order to become a product, to be redesigned in size, aesthetic and electronics terms. At the moment the prototype shell is made of acrylic glass, which is not suitable for mass production. The shell should be made from a moldable material like acrylonitrile butadiene styrene (ABS) plastic, which is a robust material with good impact resistance that can be easily molded with proper machines. As far as the electronic components are concerned, although the Arduino BT is ideal for prototyping, the design of a dedicated circuit board including all electronic components is necessary to reduce the size, weight and cost. The battery should also be more compact.

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