GRID (Gesture Recognition Interface Device)

Pamela Garcia, Evianis Cruz, Martin Rodriguez, and Landon Splitter

Department of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — GRID is a Gesture Recognition Interface Device that provides a modern method of interfacing with the computer by only using intuitive hand movements. The user will wear a glove with a circuitry on the hand of his/her choice. The circuitry contains a set of sensors and electrical components that will send user input data to the host computer and there the driver will interpret it as a specific action the user is trying to perform within the gesture library. A camera will be placed facing the user's workspace and tracking the LEDs located in the set of gloves for cursor location purposes. Clicking among other features are also incorporated in this design.**

I. Introduction

GRID is a Gesture Recognition Interface Device. It seeks to take the world of control devices to the next step using image tracking and gesture recognition to interface with the host computer. The device will be embedded within a glove that fits over the users hand and uses a camera module to sense and track near-IR LEDs on the glove. It will also have other instruments like an accelerometer and gyroscope which will be used to determine if the user has made a specific gesture, if so then it will send the commands via Bluetooth to the host computer where the command will be translated into an action. Other features will be a removable PCB design that will allow the user to use either hand as the main control device. This will make GRID usable to both right hand and left hand users.

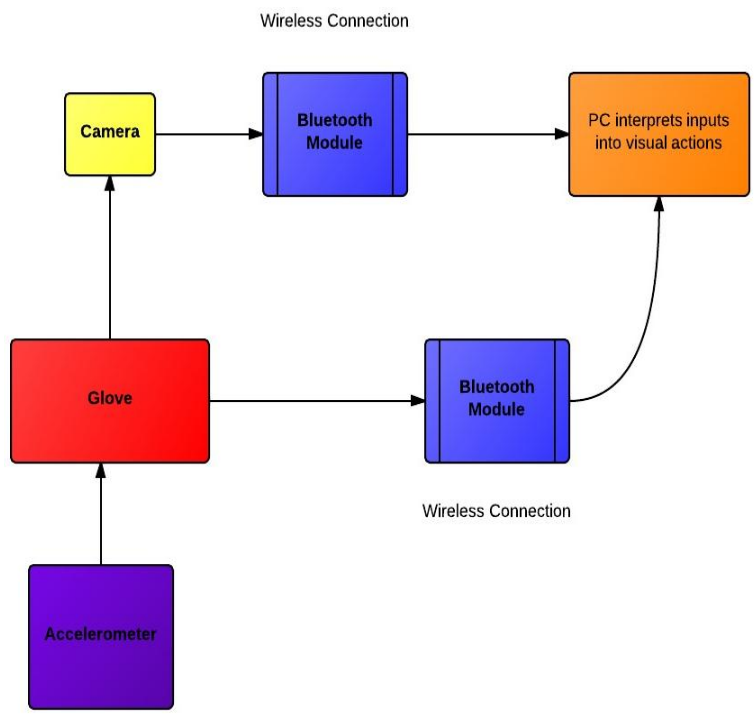
The desired design of GRID will be well fitting to the hand and light so that there will be no issues with fatigue while using the device. It will function and carry out all the operations that a typical mouse would with the added features of a gesture design. What that means is that there will be special "gestures" the user can do in multimedia programs to control the features of that program, as well as a few other special features for application specific actions.

GRID is the next step forward in consumer control devices, with its sleek design and universal user abilities as well as the application specific actions it will have the ability to run. As technology progresses so should the control devices.

II. System Components

This project is best presented in terms of system components; that is, the individual physical models that are interfaced to create the overall design. Figure 1 shown below shows the system components and how they are integrated with each other via Bluetooth communication.

Figure 1: Interfacing Subsystems



A. Camera

The camera is the part of the project that tracks the position of the user's hands. The camera will be placed at an appropriate position that outlines the user's workspace. A glove will have a near IR-LED on the index fingers that will be tracked by the camera. The camera has an integrated processor that outputs the X and Y coordinate positions as well as the size of up to four bright IR points when interfaced with the microcontroller. This will allow the user to control the cursor of the computer, like a mouse. For further hardware details on the camera read the section called Camera Hardware Details, which explains the individual components of the camera.

B. Glove

The glove is one of the main parts of this project. It consists of a regular set of gloves with a lightweight circuit mounted on it. The main purpose of the glove is to power the LEDs that the camera will be tracking for cursor location purposes, send fast IR light pulses to the IR receiver in the camera circuit for clicking purposes and gather hand movement information from the accelerometer via Bluetooth to the host computer which will be interpreted as gestures. In the glove hardware detail section below there will be more specifics about the individual components of the glove.

C. Driver

The driver is basically the part of the project that will tie all components together by receiving information from the glove and the camera simultaneously via Bluetooth. When the driver receives user input data from the gloves it will interpret gestures being performed, and interpret data from microcontroller into defined computer actions. If the driver is receiving feed from the camera it will interpret it as a cursor movement, which involves mapping the coordinates of the object to the appropriate locations on the display, and solve for any difference in resolution. Clicking commands will also be received from the camera circuit board.

III. Camera Hardware Detail

This section provides a summarized technical report to each of the components used in the final design for the camera system.

A. Microcontroller

Due to the nature of this project, low power is critical in order to meet the design specifications. The MSP430 is one of the most flexible MCUs on the market with multiple clock sources, programmable modulation for each source, and low- power modes. The chip runs at 16 MHz, which is necessary for component interfacing and computation. The Code Composer Studio allows the user to write all code in C or in assembly. For the purposes of this project C was chosen as the preferred language for the microcontroller. In order to properly communicate with the msp430g2553 header file msp430g2553.h were looked in order to see register definitions and interrupt vector definitions, as well as example code found on TI's website. Code Composer studio also facilitates debugging through its own debugging environment. This feature gives the user full control of the chip at any given time, even allowing access to current variable values. All of the msp430g2553 control registers are also available for viewing at any one instance in the code.

The I2C bus is being used to communicate between the msp430g2553 and the camera. I2C, also known as a two-wire interface, is a multi-master, multi-slave environment meaning that, should the design make use of the ITG-3200 and the MMA8452Q, no additional bus lines are required (No additional pins on the MSP430G2553). The I2C bus consists of two bidirectional open-drain lines, the Serial Data Line (SDA), and the serial clock line (SCL), with both lines needing pull-up resistors for proper functionality. Through some testing it appears that the value of the pull-up resistor is not critical; the bus operated with values in the range of 2k to 47k. Connecting the microcontroller to the camera is straightforward. Giving a 3.3V power to the camera the details for the power are explained in this section under power supply, ground, a 25 MHz clock, and connect the SDA and SCL lines with pull up resistors and pull up the reset pin. Once this connection is established the microcontroller outputs the X and Y and size to the host computer via Bluetooth communication.

B. Camera Module

The PixArt IR camera sensor is capable of tracking up to four IR spots. Its image processing provides location data at 1024x768 resolution. The PixArt IR camera was physically extracted from the Wii remote due to the budget restrictions of the group. The IR camera is interfaced with the microcontroller via Bluetooth controlling a servo. The IR camera has an integrated processor, which output the X and Y positions and size of the near IR LEDs that it detects. The details for the near IR LEDs will be explained later under the Glove Hardware detail section of this paper. This is very beneficial for tracking the position of the cursor.

C. Bluetooth Module

The RS232 TTL Transceiver module is a 3.3v operated (operating voltage of the msp430g2553), Bluetooth Spec v2.0+EDR compliant, class 2-type output power device that allows wireless connection to a computer. It is also programmable to a variety of baud rates, as well as other settings like pass code and device identification name.

This module is specifically made to interface a Bluetooth enabled computer and a microcontroller, as it cannot establish communications between two embedded devices. One advantage of this device over other Bluetooth modules is its usage of UART, a simple communication protocol. This feature makes interfacing the RS232 TTL transceiver module with the msp430g2553 simple, with minimal communication error at 9600 baud. Configuration of the device is accessed through the logic level of a single pin upon power-up. Once is this mode, simple commands terminated by \r\n are sent over UART. By default the module is configured to 9600 baud, one start bit, 8 data bits, one stop bit, and no parity.

D. IR Receiver

The infrared (IR) receiver module is a component that receives an infrared signal from the transmitter and interprets the request to detect right or left click. These infrared signals are transmitted to the IR receiver module in wavelength of 940 nm. The Stellaris using an IR-LED at a viewing angle of 60 degrees sends an infrared signal at a particular frequency one that the camera can't detect, and the signals are received by the microcontroller. For the purposes of this project the frequency is set to 38 kHz with a duration of 600µs for left click and 1.2ms for right click. The IR receiver recognizes only the 38 kHz frequency to the exclusion of all other frequencies.

E. Visible Light Filter

In this project an IR filter was adapted in front of the camera module. The purpose of the IR filter is to block the visible light and only allow the IR wavelengths to hit the sensor. An advantage of using a visible light filter is that it will make the viewing angle of the LED less critical; it will do this by blocking the background noise.

F. Power Supply

The design of the power supply for the camera consists of a bq24090 Single input, Single cell Li-Ion and Li-Pol battery charger and a MCP1252 positive-regulated charge pump DC/DC converters, both ICs from Texas Instrument. One of the advantages of this charge pump is that is an inductorless configuration, which suits our portable design.

A USB will be used to supply power to the recharge circuitry. This circuitry will then be connected with the charge pump through a single pole double throw switch to regulate the voltage coming into the PCB. The switch will be placed in the power circuit between the battery and the charge pump; this will turn "on" or "off" the system. The battery charger will indicate if the battery is charging or if it is done charging by using LED indicators. Once the switch is "on" the 3.8V Li-Ion battery will be connected to the charge pump that will adjust the output voltage to 3.3V and deliver up to 120 mA output current, which will then power the microcontroller and camera. The accepted voltage for the microcontroller is in the range from 1.8V to 3.6V and 3.3V for the camera, which is why the charge pump was chosen. The power efficiency for the charge pump is about 85% for a supply voltage of 3.8V.

G. Camera Printed Circuit Board (PCB)

The printed circuit board used for the camera circuitry was ordered through www.4PCB.com. The dimensions of the board are 2" X 2.5". The group was able to reduce the size of the board by using mostly surface mount (SMT) components. The SMT size used in this board is 0805 for capacitors, resistors and LEDs. Some other components were not available in SMT package but they are still very minute. The board is a 2 layer lead free PCB of .062 in thickness with solder mask in both sides and white silkscreen only in the topside. The traces contain a standard 1oz of copper, which will be able to withstand the maximum current of this circuitry, which will be around 75mA.

IV. GLOVE HARDWARE DETAIL

This section provides a summarized technical report to each of the components used in the final design of the glove system.

A. Microcontroller

The microcontroller used in the glove circuit is the Stellaris LM4F120 series from Texas instruments. The Stellaris features a wide set of serial connectivity that allows the GRID system to communicate to all its embedded devices. The microprocessor in the glove is in charge of detecting user motion, gathering data from gyroscope and accelerometer using I^2C, compute whether user completed a valid gesture using the dynamic time warping and the greedy algorithm, sending data flags to the host computer via Bluetooth using UART, and optimize code with the use of interrupts in order to take advantage of low power modes in order to extend battery life.

The Stellaris is the right balance between high performance and low power consumption at an affordable price. Some advantages of the Stellaris over the MSP430 are that it is faster. It uses the ARM Cortex-M4F core with single-precision floating point at 80 MHz, up to 256kb single-cycle Flash memory and 32kb single-cycle SRAM. Its package is a bit more complex to work with since it is a LQFP with 64 small pins. One of the drawbacks from the Stellaris that it is an advantage in the MSP430 is that the chip has to be programmed before it is implemented in the circuit board. The versatility of the DIP package of the MSP4320 allows the designer to easily transfer it from the development board to the final PCB with no problem.

B. Gyroscope and Accelerometer

In the project it was chosen as a motion sensor the MPU-6050 made by InvenSense, which features a three-axis accelerometer, as well as a three-axis gyroscope. The main objective of this component is to use its sensor data to capture hand movement. These hand movements will then be sent to the host computer to be able to detect pre-defined motions, and translate them into computer actions.

In this project we are mainly using the accelerometer from this chip to track dynamic forces made by the glove rather than to know the location information of the hand movements, which will be done by the camera. The device is operating at a sampling rate of 20 Hz. The MPU 6050 chip operates at a nominal supply voltage of 3.3V like most of all of the other components on this board, which is a convenient feature. The accelerometer on this chip normal operating current is 500uA that makes this chip very convenient for this portable design and its idle mode supply current is 5uA. The MPU 6050 communicates with the microcontroller via I^2C at a fast rate of 400 kHz. Another advantage of this chip is that the package is very small and thin package, QFN 4X4x0.9mm, which fits great in the compact design of this project.

C. LEDs

The purpose of the LED on this project is to make the index finger stand out from the background noise for better object tracking. The LED will remain pulsing at a rate of 1MHz for tracking purposes. The two main parameters that we considered when choosing the right LED for the project was wavelength and viewing angle. Wavelength refers to the distance over which the wave repeats itself. The near-infrared LED will best suit the purpose of our project since they have a longer wavelength, which will minimize interference with background noise and are often used for night vision that is the closest application to the one used in this project. The wavelength chosen for the LEDs in this project was 940nm.

The viewing angle or degree refers to the spreading of the light emitted by the LED. An LED with a small angle will have less dispersion of light and more energy in the spot. For this project the main goal was to get a bright LED with a viewing angle big enough to be able to be detected by the camera but small enough so it does not saturate the camera. The viewing able we chose for our project was 60˚.

Moreover the main LED will not only by used to send clicking information to the IR receiver on the camera PCB but it will also send clicking data. Once the push buttons on the glove are pressed the LED will change its pulsing rate and the system will know the user is trying to perform a clicking action. The details of this are included in the next section; Buttons section of the Glove Hardware Detail.

D. Buttons

In this project there are two standard push buttons being used to send clicking commands. The push buttons will be located in the glove, in a position that is comfortable for the user to be able to click in a natural way. The button clicking will activate a command for an LED in the glove PCB to pulse at a faster rate. Usually the LED is pulsing at a rate of 1MHz until a right or a left click is performed. The clicks are falling edge interrupts and will make the LED pulse at a rate of 38kHz for 600us for a left click and 1.2ms for a right click. These IR pulsing will be captured by the IR sensor located in the camera PCB and will be recognized as a right click or a left click. Once the button is depressed the clicking light pulses will be sent again so the system will know how long the click for was. These flashes are fast enough for the camera not to detect them and confuse them with a cursor location pulse. The operation of the IR sensor is explained more in detail in the hardware detail section of the camera.

E. Bluetooth Module

The Bluetooth module in this circuit board is the HC-06 Bluetooth module, same as the one for the camera circuit board. It communicates with the microcontroller via UART it is explained in detail in the Camera Hardware Detail portion of this paper.

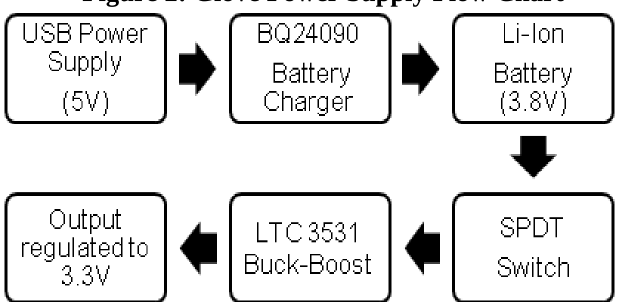
F. Power Supply

The power supply circuit of the Glove PCB it very similar to the one of the one from the camera. It consists of a bq24090 single input, single cell Li-Ion and Li-Pol Battery charger from Texas Instruments and the LTC3531 Buck-

Boost synchronous DC/DC converter from Linear Technology. The advantages of using these two chips is that they are targeted at space limited portable applications. The 5V input to the battery charger comes from a USB port, which is connected to the host computer when necessary and will only serve for this purpose, not for data transfer. The charger also provides 1% charge voltage accuracy, 10% charge current accuracy and a 10 hour safety timer window to charge the battery. There are two LEDs in this circuit, one will indicate when the input voltage is greater than the under-voltage lockout voltage (UVLO) and battery voltage and the other one will indicate when the battery is completely charged.

The input from the fixed Buck-Boost converter comes from the Li-Ion battery and the responsibility of this chip is to regulate the output voltage to 3.3V. Although the circuit uses a 15uH inductor is still a very small circuit, great from handheld instruments like the glove. The efficiency of this Buck-Boost converter is up to 90% and can provide up to 200mA at 3.3 output voltage from a 3.6 input voltage which will suffice for the glove circuit whose maximum current draw will be about 150mA. Figure 2 shows a graphical representation of the Glove power supply.

Figure 2: Glove Power Supply Flow Chart



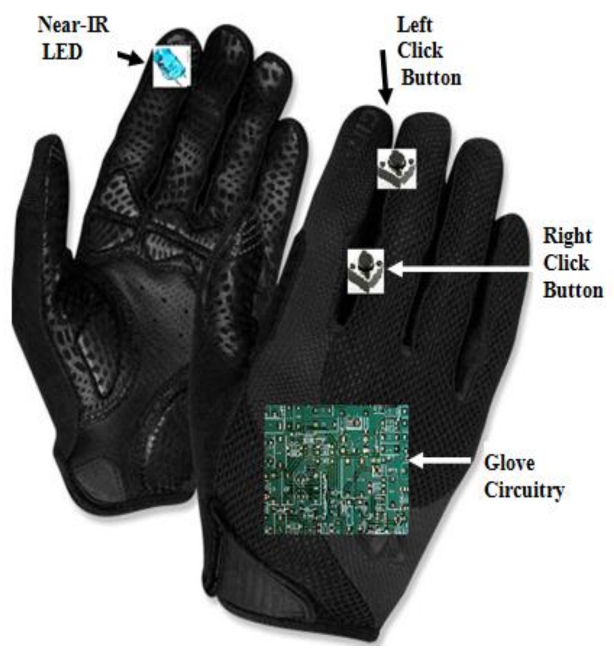
The single pole double throw switch in between the battery and the Buck Boost converter will create a current path from the battery to the Buck Boost converter to power on the PCB or open the path to turn it off. As a safety feature bypass capacitors were installed in the input and outputs of this circuit to dampen any noise.

H. Glove Aesthetics

The glove will have a 2" X 2.5" circuitry on the back of the hand. As a result of the small size of this circuit it makes it simple to detach and can be placed on the hand of choice of the user to accommodate right and left handed users. The index finger will have the LED attached on the palm side. The LED will be power via an extension cable running from the circuitry in the back of the hand. The wire extension will be sawn in so it is comfortable and permissive when the glove is on.

The push buttons used for clicking will be place in the middle finger. In the top of the middle finger will be the left click because that is a more natural movement to make and left clicks are used much more often. The right click button will be placed in the lower side of the middle finger because right clicks are less frequent than left clicks and that movement is comfortable for the user yet somewhat forced. Below there is a pictorial representation of the glove and its component locations.

Figure 3: Glove Aesthetics



The gloves used in this project are a pair of spandex utility gloves. The gloves contain stretch panels between fingers to provide better range motion and ventilation. They are made of a light cloth material so they are comfortable for the hand.

I. Glove Printed Circuit Board (PCB)

The printed circuit board used for the glove circuitry was ordered through www.4PCB.com. The dimensions of the board are 2" X 2.5". The group was able to reduce the size of the board by using all surface mount (SMT) components. The SMT size used in this board is 0805 for capacitors, resistors and LEDs. The microprocessor, Bluetooth module, battery charger chip, Buck Boost converter chip, inductor for the power supply circuitry, gyroscope and accelerometer, and transistor are also of very compact packaging. The board is a 2 layer lead free PCB of .062 in thickness with solder mask in both sides and white silkscreen only in the topside. The traces contain a standard 1oz of copper, which will be able to withstand the maximum current of this circuitry, which will be around 150mA.

V. Software Detail

A. Camera Microcontroller

At the start of the program the MSP430G2553 MCU will initialize its Universal Serial Communication Module for I^2C communications on UCB0 and UART communications on UCA0. The MCU's Main clock will be sourced from the internal Digitally Controlled Oscillator (DCO) at 16 MHz, The Sub-main clock (SMCLK, Also sourced from the DCO) will pass through 1/4 divider resulting in a 4 MHz clock rate. UCB0, sourced from the SMLCK allows the usage of Low Power Mode 0 (CPUOFF) during interrupt driven transmission. Because UCA0 is sourced from the external 32 KHz crystal, during transmission to the Host computer, as well as idle delay resulting from the camera's maximum sample rate of 100 Hz, the MSP430 will remain in LPM3, effectively turning off the CPU as well as the DCO and consuming only 0.7 micro Amps. The Master (MSP430) will initiate a read operation on the I^2C Bus every 1/100 of a second, and proceed to decode the camera's internal registers. If the camera detects an object the MSP430 will send 4 bytes (2 bytes per coordinate axis at a 10 bit resolution) on the UART line corresponding to the X and Y coordinates of the object. Else, if a left or right click occurs the upper 6 bits of the first byte send will be used as command bits, signaling the host that a click has occurred or to wait for the second byte of coordinate information.

B. Glove Microcontroller

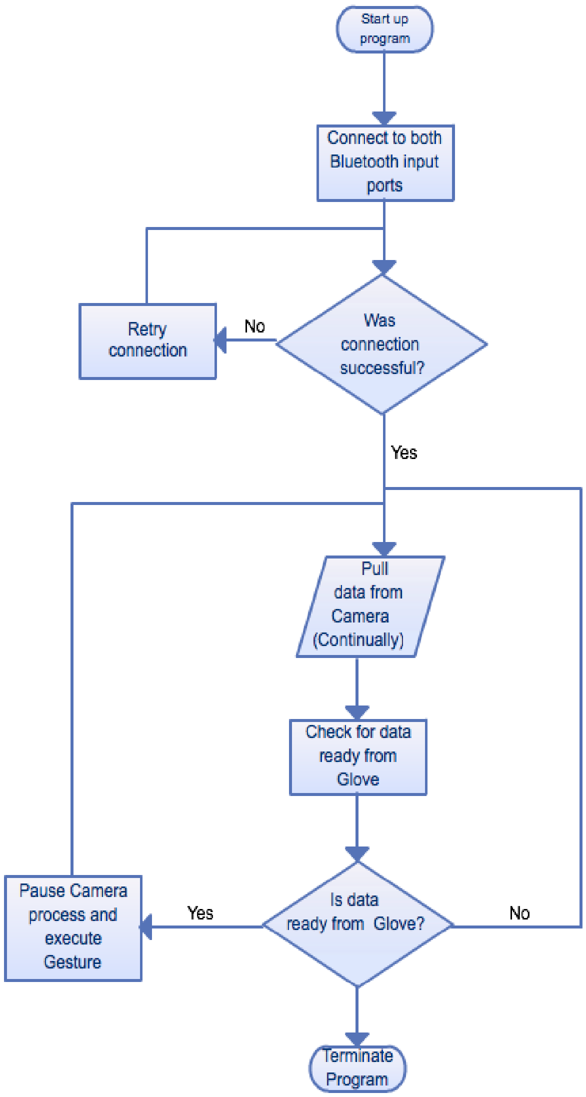
At the start of the program the Stellaris MCU will initialize its Clock system (80 MHz) as well as the various peripherals being used. Port B is used for UART1 and will transmit to the Bluetooth module. Port A will be used for I^2C communications to the mpu6050 with the interrupt pin connected to pin 7 on Port B with a falling edge trigger. TIMER0A is used to control the PWM output from pin 6 to the gate of the transistor at a 50% duty cycle with frequency of 1MHz. A second timer, TIMER1A, is used to control the duration of the 38 KHz pulses for the right and left click distinctions. The 38 KHz pulses are activated on the falling edge (Due to button press) of pin 5 and 3 on ports A and D respectively. The MPU is configured to send interrupts when a full write cycle has been completed on its internal registers, as well as if high accelerometer date is detected on any axis. High Gs interrupts depend on the threshold force and the duration of the motion. For every sample, if it meets the threshold, a counter is increased; once the counter reached the duration value and interrupt is sent. The Stellaris will read accelerometer data from the mpu as dictated by the data ready interrupt and will store the values in a circular buffer of type int with an unsigned character type used as the index variable. Once the index reaches a value of 256, the index will overflow back to 0 on the next sample. Lastly the Stellaris will check the current sample against a "trigger value" which will signify a possible gesture has been performed. If the trigger flag is set, the stellaris will perform the DTW algorithm on the last 20 sampled values on the Z-axis and determine if it matches the template. Lastly, the MCU will transmit the corresponding command byte through the UART line to the host computer.

C. Driver

For any external device to interface with a PC it must have a driver which tells the system how the device behaves and how it is suppose to interact with the system. These drivers hold the specific instructions that can be passed then from the device to the host system and vise versa. For this project the host system will be a Windows OS system. The communication between the operating system and device drivers is primarily done through the USB human interface device (HID) class. The USB HID class is a part of the USB specification for computer peripherals such as, mice and keyboard. Windows' built-in HID drivers are use to communicate with devices that conform to the USB's HID class specification.

This project is using java to run an executable program accessing the port via RS-232 communication. GRID will be coded using Bluetooth signal to communicate to the camera and glove. The executable program will be listening to two ports simultaneously, the first port is dedicated to the camera where data is being pulled continuously and the second port is set to listen to the glove, only pulling data when it is ready to be received. The Stellaris sends a flag when data is ready to be sent to the computer allowing the code to pull the data and perform a gesture. Figure 4 below shows the typical process that the driver undertakes:

Figure 4: Driver Design Flow



D. Gesture Library

The design of the gestures needs to be intuitive and natural to make it easier for the user to learn how to use the glove and also to make it an enjoyable experience. The location of storage for the library will be split by the nature of the intended gestures. What is meant by that statement is that all gestures that are detectable by the microcontroller via the instruments in direct connection will be stored in the memory that is directly accessible by the microcontroller, the gestures that are detected by the host computer will be stored on the host computer where the driver can do the necessary actions to carry out the desired gesture.

Below there is a list of the gestures that will be implemented in the library. Gestures used in this project will be mostly application specific, though there will also be general gestures to accommodate normal computer functions. This list is the initial implementation ideas and is not an exhaustive list of gestures for the device, as development of the project continues this list may grow.

- **Clicking**- to click the user will press the buttons on the middle finger with the thumb on the main hand in and then release. The two buttons in the middle finger are for right or left click.

- **Zooming in and out**- the user will move the hands closer to the monitor for zooming in or further from the monitor for zooming out. This gesture is dependent on the image processing to detect the position and direction of the motion. This gesture is also linked with the accelerometer data to determine if it passes the threshold for this gesture.

- **Rotation**–Rotation is the same motion as zooming, the difference is instead of moving the hands closer or further from the monitor the user simply will keep the hands straight and rotate their hands position about the centroid axis.

- **Swiping in any direction**-This is one of the application specific gestures, when using an application that has multiple pages the user waves the main hand past the boundaries, which were pre-set in the direction they wish to swipe. For example to move to the next page the user would wave their main hand to the left past the leftmost boundary.

- **Refresh**–The refresh gesture is a very unique gesture, which is one of the defining characteristics of our project. To execute this gesture the user will take their hand in the rest position and rotate their palm in a clockwise motion 180^{o} then return it to the rest position. This gesture makes good use of the gyroscope and accelerometer data to determine if the gesture was performed accurately.

- **Multimedia Gestures**–These are all application specific gestures that can only be used within a media application. These actions will need to be distinct so they will be easily determined by the video image processing,

    - **Play**–To execute the play motion the user will take their hand at rest position and move it in a dropping motion. The data is then calculated by the gyroscope and accelerometer data to determine if it was indeed a proper gesture.

- **Fast-forward**–To execute the fast-forward gesture the user will take their hand in the rest position and make a swiping motion to the right. Data is collected from the gyroscope and accelerometer to determine if it was a proper gesture.

- **Rewind**–To execute the Rewind gesture the user will take their hand in the rest position and make a swiping motion to the left. Data is collected from the gyroscope and accelerometer to determine if it was a proper gesture.

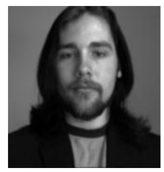
- **Pause**–To execute the pause gesture the user will take their hand at rest position and move it in a dropping motion. This gesture is the same as play; the reason for this is because in modern applications the command for play/pause is the same so we are keeping with modern convention. The data is collected from the gyroscope and accelerometer to determine if the motion preformed was valid.

BIOGRAPHY

Pamela Garcia is a 26-year old graduating Electrical Engineering student who is taking a job with Harris Corporation in Palm Bay, FL, as part of a circuit design team that is working to develop low size, weight, and power communication systems.

Evianis Cruz is a 22-year old graduating Electrical Engineering student who is taking a job with Texas Instruments in Dallas, TX, as a product engineer, which involves developing production test specifications, managing documentation, and providing development support.

Martin Rodriguez is a 22-year old graduating Electrical Engineering student taking a job with Intel Corporation as a Post Silicon Validation Intern. He will continue to graduate studies in the field of Analog and Digital Communication systems in the spring of 2014. He currently is interested in embedded system design using the Stellaris and MSP430 platforms. Martin has also been involved in several projects involving control systems and power electronics.



Landon Splitter is a 24-year old graduating Computer Engineering student who is currently working for the Wave Propagation Research Group (WPRG). He will be attending graduate school at UCF in the fall to pursue his Masters in Computer Engineering with plans to possibly pursue his PhD in Computer Engineering. Landon enjoys the Beach and spending time with family and friends as well as traveling the world.

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