Team Duck Hunt
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Design Repository

We have placed all the source code of Duck Hunt in Duck_Repository.zip. It contains the Xilinx Platform Studio (XPS) folder that allows us to download the code to the Virtex V board and run Duck Hunt. It also contains the GlovePie script we wrote for the Wiimote, the Java code we wrote for the serial connection, the necessary Java comm.jar library, our progress on the direct USB approach, and useful documentation for those who try this approach in the future. To get the Duck Hunt program working, simply open the .xmp file inside the DuckHuntGame folder. To see our progress on USB, open the .xmp file in the USBProject folder.

The Duck_Repository.zip file has been uploaded to Blackboard. It contains all the source code of our project. Also, we uploaded the XPS project folder to AFS, located at /afs/andrew.cmu.edu/usr16/dennist/public/18545/DuckHunt

What is Duck Hunt?

We implemented an old Nintendo game called Duck Hunt onto a Virtex 5 board. Our implementation of Duck Hunt includes external user input (from keyboard and Wiimote), video, scoring, and multiplayer capabilities. The one twist to the Duck Hunt game that we will be implementing is making use of the new Bluetooth Technology of the Wiimote.

The Duck Hunt Game is one of the most popular games when we were growing up. It has been duplicated online in flash and many other languages. We considered porting an existing implementation of Duck Hunt over to the FPGA. We found many implementations of Duck Hunt, but all of them were unsuitable for our purposes. Some were written in languages that were unavailable on the Virtex V (e.g. Java, C#, Perl, Flash). Others were unprofessional or unfaithful to the original NES game. Thus, we made the decision to rewrite the game from scratch, choosing only to borrow the Duck Hunt sprites from Internet sources. Bluetooth technology is an amazing technology to use, but it was very challenging to implement.

The objective of the game Duck Hunt is to shoot as many ducks down as possible without them flying away. Each player is only given 3 shots per 1 or 2 ducks, depending on which mode is chosen. In the original multiplayer version, the 1st player would be given 10 ducks sequentially to shoot down. The 2nd player then goes to see if he can outdo his competitor. In our version, we modified this feature and have 2 players play simultaneously. One player controls the duck and flies around while the other player tries to shoot him down.

Our group showed dedication and cooperation in finishing this project on time while meeting most of the specifications.

Design Process

Our first step in this software project was to come up with a feasible idea. Initially, there were six of us with no definite grouping. The six of us bounced ideas back and forth till two ideas were formed. One of the ideas was to build the GameBoy Color and the other was reproducing the classic game of Duck Hunt. Half of us took a liking to the Duck Hunt idea with Wiimote and thus the groups were formed.

Initially, we started the class by researching what it would take to get this project to work. We studied the success and failures of the previous Xilroids group in order to get an idea of what their main challenges were. We immediately realized that the bulk of the project work was going to be getting the USB port to work. We planned for this difficulty by deciding to have one group member constantly focused on USB from the start. We also planned to finish a faithful reproduction of Duck Hunt as soon as possible, finishing it before mid-semester break. We were dedicated to this schedule and successfully created an almost complete version of Duck Hunt and finishing all the labs before mid-semester, leaving the rest of the time to get the USB working.

In the early weeks, we did a lot of research into finding a dedicated port of the game. This turned out to be a dead-end as there were no faithful ports in C. We decided that with our strong programming backgrounds we could successfully reproduce the game even better than the ones on the Internet. This turned out to be a great decision on the team's part. Our implementation of Duck Hunt is, in our opinion, better than any of the ones we discovered on the Internet. One of our group members in the meantime already started dedicating time to researching USB to figure out what we needed to do to successfully communicate with it. This also was a very good decision, because we were able to jump right into USB immediately after the faithful port was created.

The initial weeks came along without a hitch on the Virtex II. We had sound, video, and a PS/2 mouse working successfully and the game was very playable. The USB was looking very difficult to implement on the Virtex II judging from previous projects as well as forums on the Internet. Then, the option of the Virtex V was given to us by Professor Nace. This seemed like a blessing from the sky at first because of the fact that it had a USB port on the board itself unlike the Virtex II. We decided after very careful deliberation to switch due to the fact that getting the USB working with Wiimote was our main priority in the project. This is when the difficulty of our project rapidly increased.

The first difficulty that we ran into was that the Virtex V was not backwards compatible with the Virtex II. Our initial problem was that the Xilinx sample code for video and USB both did not synthesize together or separately. This was primarily due to the lack of documentation and hidden bugs in the Xilinx code. After we fixed up some of the syntax and memory issues that Xilinx had in their code, we still were running into problems with Generating Addresses as well as synthesizing. We finally were able to synthesize their video demo code after 2 weeks. This was the first hurdle we had to cross but it soon led to another problem. When we incorporated USB with the video code, hidden errors would pop up. The sample code was written for an earlier version of Xilinx Platform Studio and EDK, and some parts were not backwards compatible.

There were two major but sneaky problems with the Xilinx implementation. The first was that there were conflicting pins in the Xilinx code with compactFlash and USB. When synthesizing, the Xilinx program would automatically realize that there are conflicting pins, and remove one of them without throwing an error. Then at the end of synthesis, it would error saying that the pin was not there. We had problems understanding why the pin wasn't being recognized considering we saw it in the file declared. We finally had to go through all 200 warnings and realize that Xilinx was removing the pin without declaring it as an error. We then disabled compactFlash, and it finally synthesized with no bugs. We then had to fix the 2nd problem which was more conflicting pins, but since we knew about the previous error, debugging these were a lot easier. In the end, it took us about 3.5 weeks to just transfer over our existing code from the Virtex II to the Virtex V. In the end, these 3.5 were very costly to our overall project, because we went from being on schedule to behind schedule. We thought we could make up for this time, because USB would be easier to implement, but we soon realized that this was a flawed assessment of the situation, because USB was much more difficult than anyone could imagine.

With the USB demo, we got a working implementation of the USB keyboard with the FPGA. This, however, proved to be very useless in the end. This was due to the fact that we were given the keyboard driver in binary and were not given the actual source code. We contacted both Xilinx and Cypress multiple times to no avail. (Cypress makes the actual USB chip found on the Virtex V.) We also searched online and on forums in order to find out where the source code could be found. However, there is no documentation of it anywhere online. There were others with the same types of questions on the forums, but they received no answers as well.

We now had to decide on which way we should progress on our project. There were multiple options we could do for the USB controller. The first option was to attempt to get Linux running on the microblaze processor. In theory, this would allow us to use the Linux USB and Bluetooth drivers so that we would not have to write our own. However, the only versions of Linux that we could get working on any Virtex board required that we have an on-board PowerPC processor. Since our board only had the soft microblaze core, we could find no usable Linux implementation. Also, even if we did get Linux running on our board, we would still need to find a driver that could interface with either the external Cypress USB controller or an internal synthesized USB controller. We were unsuccessful in our search for such drivers.

Another USB option was to establish communication between the FPGA and the Cypress CY7C67300 Embedded Host Controller through writing and compiling our own driver in binary, then loading the binary onto the controller via a C program written for the FPGA. We were able to find a software development kit that at first seemed perfect for compiling the code for the controller (at http://www.cypress.com/?rID=14436), but all of the documentation assumed that we had the development package that could only be ordered directly from Cypress. This package included its own main board and special mezzanine attachment. There was no documentation from Cypress, Xilinx, or Digilent that even mentioned such an approach for an FPGA. We decided it was worth an attempt anyway, so we tried to adapt the documentation and examples to our environment and

create our own keyboard driver that worked as well as the one included by Xilinx. We wrote and compiled a simple program that wrote a single value to memory, and then we checked it with the FPGA code. After dozens of attempts, we were unable to get a successful response; it seemed that the code was not even beginning to run. Also, we had no clues as to where our errors were or why it was not working. While this approach seemed feasible at first, a lack of proper documentation and debugging support made it impossible.

A third option that became apparent while looking through documentation was to use a driver written for the FPGA instead of for the Cypress controller. This code would run on the FPGA but have access to almost all of the controller's internal registers through an interface called HPI (Host Processor Interface). We could theoretically do the same things that a driver running on the controller could but not have to worry about compiling a separate program. We made most of our progress using this new approach. A BIOS automatically runs on the controller and constantly watches for certain register reads and writes; when those key registers change, the BIOS carries out predetermined commands as specified in the Cypress BIOS User's Manual. We were able to use this to perform some simple communication with a keyboard, a mouse, and a USB Bluetooth dongle. We could issue a USB reset to a device, detect if a device was plugged in, detect the speed of the device (either low or full speed, the controller does not support high speed), and read some built-in descriptors that supply details about the device. However, there were two important limitations. We could only issue control transfers (only 1 of 4 possible types), and we could only issue one command per frame (1 ms). We tried with all of our time and resources to find out how to set up different types of transfers and send multiple linked transfers in one frame, but we were ultimately unsuccessful. In the end, there was simply no documentation by Cypress that told us how to do anything except a once-per-frame control transfer. Since everything we wrote was being carefully coordinated by the Cypress BIOS, having no knowledge about the BIOS' processes was crippling to our progress.

When our project was looking more and more impossible by the day, a classmate suggested that we synthesize our own USB controller using a pre-built Xilinx IP core. We spent a couple days attempting to get it to synthesize, but there were multiple errors about unconnected pins and incompatible hardware. As we saw that most people in the class were having similar problems with Xilinx hardware and getting nowhere, we decided to drop this and continue down the previous path.

To recap, a couple weeks into the project, we reached the mid-semester design review. At this design review, we had a good working implementation of Duck Hunt on the Virtex V with the USB keyboard. We now had to try to figure out a way to communicate over USB to a device other than a keyboard. This was our main and only priority at this point. In the next 2 weeks after the design review, we spent a lot of time trying the different avenues of USB to figure out which one would be the best. We had the most success with using the Cypress controller's HPI interface to communicate with the USB device.

We persisted on this avenue for the rest of the semester until a week before the assignment was due. We were only able to send out one transaction at this point per ms,

which was not fast enough. We could only send control transfers, which was not sufficient. We could recognize the Bluetooth device, but that was all. We then had to do a workaround in order to get a final demo together. We decided to quickly route the Bluetooth device through the computer and through the serial port in order to achieve this. This workaround took us less than a day to produce considering the difficulty of this is much less than that of an on-chip controller. We ran the Bluetooth Wiimote through a custom program called GlovePie. We then ran the output of GlovePie through the Java Comm library which we then piped in through serial to detect changes in the Wiimote.

We were very happy about the quick save to our project even though we didn't get the USB on-chip controller working. However, we did learn an abundance of information on USB controllers and drivers in this lengthy process.

Software/Hardware Specifications

On the software side, we wrote modular code to interact with each hardware component. In particular, we had C code to interact with the video frame buffer, code that receives input from the USB keyboard, and code that receives input from the Wiimote. Together, they interact with the hardware to provide us with the necessary inputs and outputs. Afterwards, we wrote code that actually implements the Duck Hunt game. This includes a random number generator, collision detection, and finally, the game itself.

Video frame buffer: DH_video.h / DH_video.c

The video code takes care of the double buffering so that other modules can work with an idealized view of the video output. In particular, we have a Sprite struct.

```
typedef struct SpriteStruct
{
	// Location of top left pixel
	// (default value: x = 0, y = 0)
	int x;
	int y;

	// 0 = farthest
	// (default value: z = 0)
	int z;

	int backgroundColor;

	// An array of Bitmap pointers
	// no default values
	Bitmap* bitmap[5];
	// Length of this array (1 to 5)
	// default values: bitmapArrayLength = 1,
	// currentBitmapNum = 0
	int bitmapArrayLength;
	int currentBitmapNum;

	// 1 if sprite is still alive
	// 0 is sprite is dead
	// (dead sprites don't show up on screen)
	// default value: isAlive = 1
	int isAlive;

	int spriteType;
} Sprite;
```

The Duck Hunt code works only with this Sprite struct. It creates sprites representing the ducks, dog, and every other object on the screen. Thus, the video code is responsible for drawing these sprites onto the screen.

It turns out to be too costly to redraw the entire 640 x 480 screen each frame, so the video code works with three separate layers:

1) Foreground (active) sprites
2) Static sprites
3) Background

The background is drawn very rarely, because it takes about half a second to draw the entire screen. Once we draw the background, we add sprites onto the screen. Each frame, the video code erases the previous frame's sprites and redraws the current frame's sprites onto the screen. Thus, instead of drawing the entire screen each frame, only the sprites are drawn, and the background remains unchanged.

Building on this idea, we also implemented static sprites, which are sprites that rarely move. For instance, although the ducks and dog are constantly moving, sprites that represent the score, round number, etc rarely change. Thus, they do not need to be drawn every frame. (For instance, the score sprites only need to be redrawn when a duck is shot down and the score is incremented.) Thus, *static* sprites are redrawn only when requested, which further increases our frame rate.

Ultimately, we were able to consistently get >25 frames per second. Due to the sprite system, the frame rate depends on the number and sizes of the active sprites. Based on testing, the game only starts to lag when we have about 20 ducks on the screen. (Of course, the actual Duck Hunt game only has two ducks at any given time.)

The Duck Hunt code interacts with the video code using functions that draw and remove these sprites from the screen.

```
void DH_video_initialize();
void DH_video_initializeSprite(Sprite* sprite);
void DH_video_setBackground(Sprite* background);
void DH_video_addSprite(Sprite* sprite);
void DH_video_removeSprite(Sprite* sprite);
void DH_video_addStaticSprite(Sprite* sprite);
void DH_video_clearStaticSprite(Sprite* sprite);
void DH_video_display();
```

Random Number Generator: DH_random.h / DH_random.c

```
void DH_random_initialize();

void DH_random_randomize(int i);

int DH_random_nextInt(int i);

int DH_random_nextBool();
```

This module contains three private variables.

1) `int array[800]`: A pre-computed array of 800 random integers
2) `int index`: An index into this array. `0 ≤ index < 800`
3) `int seed`: A seed value.

This module implements a random number generator suitable for Duck Hunt. `initialize()` initializes the RNG. `randomize(`*seed*`)` is used to set the seed. `nextInt(i)` returns a random integer within `[0,i)`. `nextBool()` returns `0` or `1`, each with 50% probability.

In Duck Hunt, we need two things from the random number generator:

1) A way to generate random numbers in order to simulate the ducks' random movements.
2) Some way to randomize the seed so that each game plays differently.

In Duck Hunt, the ducks fly around somewhat randomly. Their speed and direction are determined randomly. The type of duck (green, blue, red) is also determined randomly. Thus, a random number generator is necessary. However, this random number generator does not need to be very mathematically robust. It needs only be random enough for the user not to notice. For this reason, we chose to simply pre-compute the random numbers that are used. We wrote a Java program to fill the `array[800]` with random integers. When calling `nextInt(i)`, we return `(0x7fff_ffff & (array[index] xor seed)) % i`, and `index` is then incremented.

The above method solves the first requirement; we now have random numbers. However, since the numbers are pre-computed, we have not yet satisfied the second requirement, which is that each game must play out differently. In other words, we need some way to obtain a seed. In most RNG implementations, the default seed is the current system time. Since the Virtex V does not have a system time, we used the very similar notion of the number of frames elapsed. In other words, the seed number is determined by how many frames have elapsed by the time the user hits "start game." This way, each game plays out differently.

Keyboard input: DH_keyboard.h / DH_keyboard.c

```
void DH_keyboard_initialize();

int DH_keyboard_getRawInput();
```

This module interacts with the USB keyboard, allowing the Duck Hunt code to receive keyboard input. The keyboard input is used to allow the second player to control the duck's movement. The keyboard is also used for debugging / cheat code commands.

We simply initialize the code with a call to `initialize()`. Afterwards, `getRawInput()` returns an int corresponding to a key on the keyboard. For instance, `0x29` corresponds to `ESC`. `0x28` corresponds to the enter key. A full mapping can be found easily on the Internet. `#define` statements in `DH_keyboard.h` are given for the keys used in our Duck Hunt implementation. `getRawInput()` never hangs; it returns `0` if no keys are pressed.

Game implementation: DH_game.h / DH_game.c

With the keyboard and Wiimote input, video output, a random number generator, we can now write the actual game.

```
void DH_game_start();
```

A call to `start()` will start Duck Hunt from the very beginning (showing the menu screen). `start()` just calls `showMenu()` and `showLevel()`.

```
int DH_game_showMenu();
```

`showMenu()` shows the menu on the screen, and allows the user to specify either the 1-duck mode or the 2-duck mode. (The input can be given via keyboard or the Wiimote.) Once the user specifies his/her choice, this function returns `0` if the user chose the 1-duck mode. Otherwise, it returns `1` representing 2-duck mode.

```
int DH_game_showLevel(int gameType, int levelNum, int * score);
```

`showLevel()` starts the actual Duck Hunt game. Given the `gameType` (1 duck or 2 ducks) and the current level (from `1` to `100`), this function contains the actual Duck Hunt code to play out a single round of Duck Hunt. (A single round consists of 10 ducks.) Once the round is over, it returns the number of ducks successfully shot, or `-1` if the user hits `ESC` (which quits the round).

```
void DH_game_showScore(int scoreNum);
void DH_game_showRound(int roundNum);
```

`showScore(`*score*`)` draws the given score onto the screen.
`showRound(`*round*`)` draws the round number onto the screen (after the "R=" part).

```
void DH_game_showDog();
```

`showDog()` shows the dog walking across the screen, stopping to sniff twice, and then jumping behind the bushes. (`showDog()` is called at the beginning of each round.)

```
void DH_game_createDuck(Sprite* array, int duckColor);
```

`createDuck()` spawns a duck onto the screen of the given color.

```
// Spawns one/two ducks
// Lets player try to shoot them down
// Returns when all ducks have been shot down or flown away
// Returns the number of ducks shot down,
// or returns -1 if user hits esc
int DH_game_startShootingPhase(int gameType, int levelNum, int*
score, int subroundNum, Sprite* array, Sprite* shot, Sprite*
ducksShot, Sprite* flyawayWord, Sprite* circle, int*
locationOfDeadDuck);

// Spawns the dog, holding numDucks ducks
// (0 ducks = dog laughs at player)
// Returns 0 when dog disappears from the screen,
// or returns -1 if player hits esc
int DH_game_startDogPhase(int numDucks, Sprite* array, int
locationOfDeadDuck);
```

`startShootingPhase()` takes care of the shooting phase, in which the player is trying to shoot down the ducks. `startDogPhase()` takes care of the dog phase, in which the dog pops up from behind the bush (either showing off the dead duck or laughing at the player for missing). A single round of Duck Hunt basically consists of alternating calls to these two functions.

Wiimote implementation: DH_wiimote.h / DH_wiimote.c

`int wiimoteRead()` reads in the input from the serial port and deciphers which button was pressed on the keypad of the Wiimote.
Overall Wiimote Implementation: We connect the Bluetooth device to the computer. We get the connection to the computer with a program named BlueSoleil which can recognize that a Wiimote is connected to the computer. Then we run a customized Wiimote program named GlovePie that can recognize which buttons are being pressed on the Wiimote. We then use the JavaComm library in order to take the value of what button was pressed and pipe it into the Serial Port of the FPGA. Then the `wiimoteRead()` function deciphers this input so that it can move the cursor in the same way that the USB keyboard does it.

Hardware Description

TD list transfer model:

All data sent over the Cypress USB is sent inside a Transaction Descriptor list (TD list). Each TD list contains data about the upcoming transfer, including size, type, device, address, etc. The TD list is a linked list, with the address of the next element at the end of each element. The format of a single TD in a TD list is as follows:

TD		
Offset	Name	Function
0x00-01	BaseAddress	Base address of attached data
0x02-03	Port_Length	USB port number/data length
0x04	PID_EP	Transfer type/Endpoint number
0x05	DevAdd	Device address of recipient
0x06	Control	TD Control, used in status checking
0x07	Status	Transaction status
0x08	RetryCnt	Retry Counter/ Transfer Type/ Active Flag
0x09	Residue	Bytes left over after transfer (could indicate error)
0x0A-0B	NextTDPointer	Address of next TD in list

To transfer a TD list between HCD (our layer) and the Cypress BIOS:

BIOS Process:

- **EZ-Host (our controller) reset:** Sets SIE (serial interface engine) to host mode, initializes the registers, sets the interrupt vectors and enables host interrupts.
- **EZ-Host device checks HUSB_SIEx_CurrentTDPtr (register):** If HUSB_SIEx_pCurrentTDPtr is not zero, there is a TD list waiting for transfer. If [HUSB_SIEx_pCurrentTDPtr]=0, there is no TD list waiting for transfer. Continue checking at the beginning of every frame.
- **EZ-Host device transfers this TD list to USB bus**: If there is a TD list Waiting for transfer, the EZ-Host device begins to transfer this TD list to the USB bus.
- **After completion of the TD list, the EZ-Host/EZ-OTG device sends the HUSB_TDListDone to HCD**: The EZ-Host/EZ-OTG device does this via SIE mailbox. It informs the HCD that the TD list has been finished. It also sets semaphore at HUSB_SIEx_pTDListDone_Sem.

HCD (host controller driver) process:

HCD Configures EOT (End Of Transfer): EOT is a configurable duration of time prior to the end of a frame. All transactions should be completed by the time the starting point of EOT is reached. During this

time the HCD checks the status of the previous TD list and loads a new TD list before the next frame.

• **TD_ Load**: HCD prepares the TD list and loads it into the EZ-Host/EZ-OTG buffer. There are ping-pong buffers in the EZ-Host/EZ-OTG part to speed up the transfer. After loading the TD list, HCD writes the TD list pointer to HUSB_SIEx_pCurrentTDPtr.

• **TD_Check**: After receiving the HUSB_TDListDone, the HCD checks the finished TD (Residue, RetryCnt, Status, and Control Bytes). The HCD handles any transfer errors during this step.

• **TD_DataCopy**: HCD copies the IN data from EZ-Host/EZ-OTG. This is done while the EZHost/EZ-OTG part transfers the TD list for the next frame. This is possible because of the ping-pong buffers.

Diagram of Sample TD list transfer

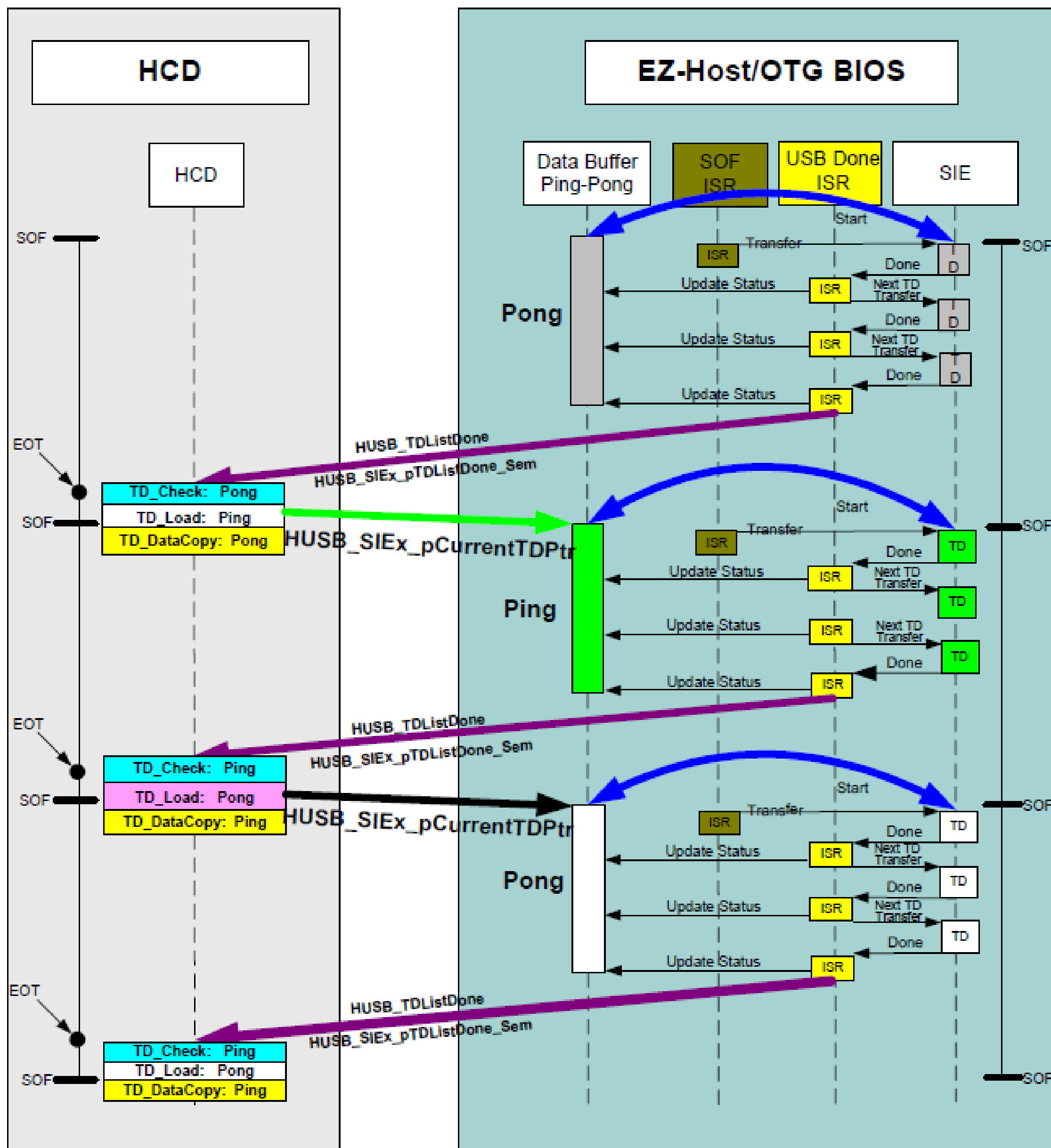


Figure 3-4. Time Domain Behavior

Control Transfers

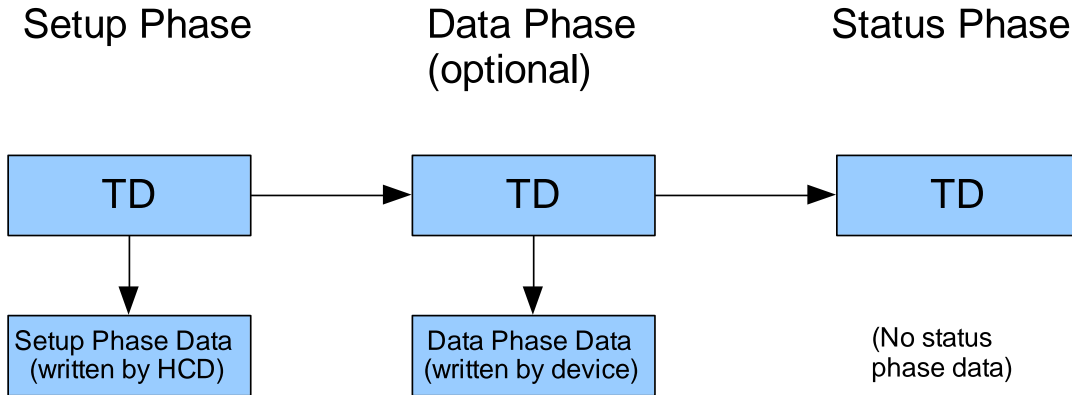
The one type of transfer that we were able to master for our project was a control transfer. Control transfers are just one out of four possible types; there are also interrupt, bulk, and isochronous transfers. Like every transfer done over Cypress, its data must be embedded inside a TD list. Every USB device must be able to communicate via control transfers until its initial enumeration and setup is complete.

There are two possible control transfer structures: Setup-Data-Status or Setup-Status. That is, its TD list can be either 2 or 3 nodes long. In the Setup TD's attached data block, the following data must be sent:

Table 9-2. Format of Setup Data

Offset	Field	Size	Value	Description
0	*bmRequestType*	1	Bitmap	Characteristics of request: D7: Data transfer direction 0 = Host-to-device 1 = Device-to-host D6...5: Type 0 = Standard 1 = Class 2 = Vendor 3 = Reserved D4...0: Recipient 0 = Device 1 = Interface 2 = Endpoint 3 = Other 4...31 = Reserved
1	*bRequest*	1	Value	Specific request (refer to Table 9-3)
2	*wValue*	2	Value	Word-sized field that varies according to request
4	*wIndex*	2	Index or Offset	Word-sized field that varies according to request; typically used to pass an index or offset
6	*wLength*	2	Count	Number of bytes to transfer if there is a Data stage

According to the values sent in these fields, the device will respond by filling in the data block attached to the data node. If the transfer does not require data back from the device (such as in the case of setting the device address), it will simply signal success in the Status phase's response bytes. The entire process is outlined in the figure below:



Each TD is written by the HCD and modified by the BIOS to show either success or failure. If it was a success and data was attached, the HCD can then read the data and send the next TD list. If there was a failure for any reason, the transfer is retried 3 times, and then the device goes into an error state.

The main use for control transfers is to enumerate the USB device. This includes providing power to the device, setting the device's address to use from then on, reading what type of device it is, and then choosing the desired configuration. Each step is done with a separate TD list control transfer. Enumeration is described by the FSM below:

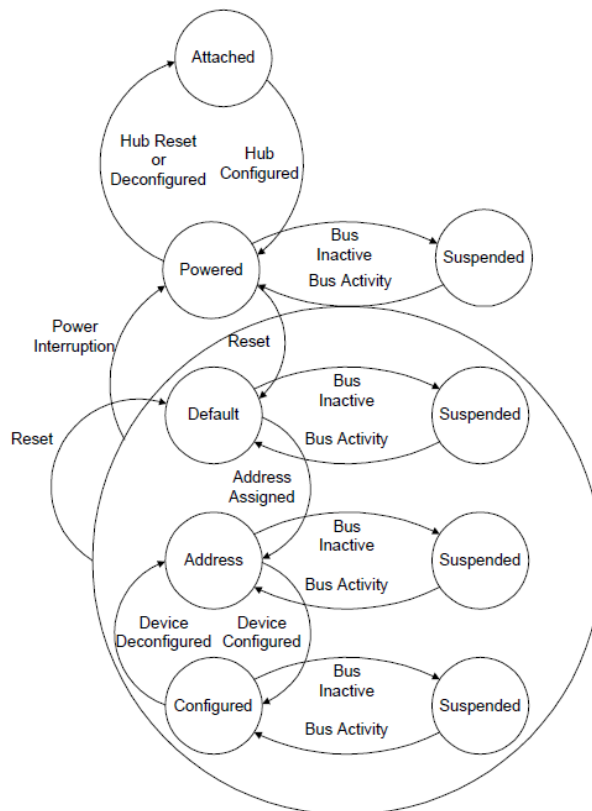
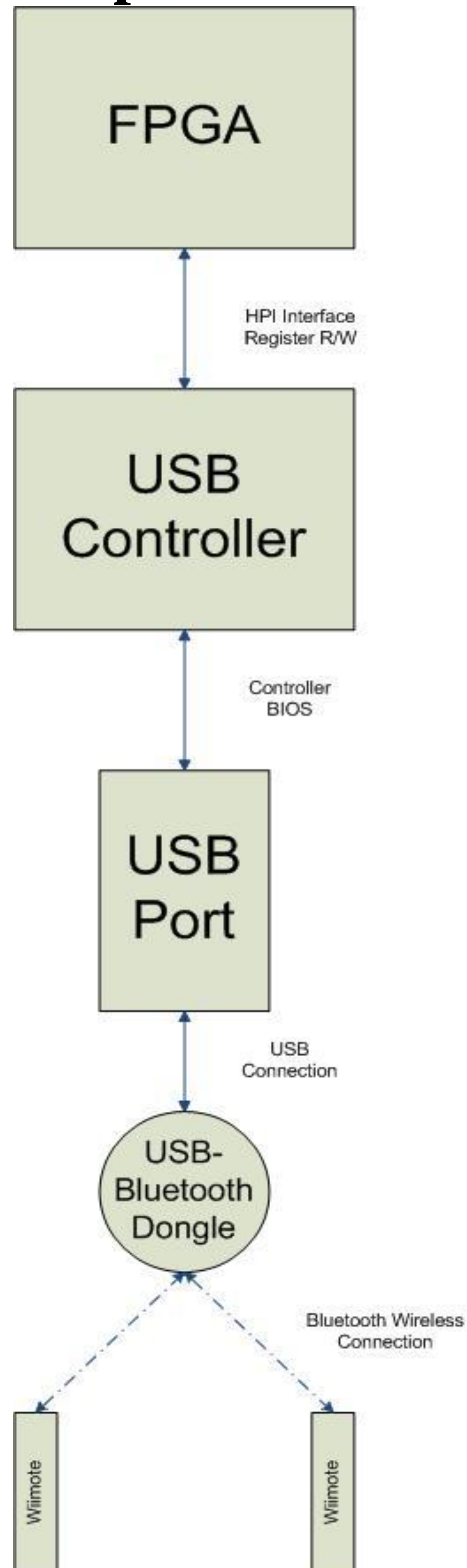


Figure 9-1. Device State Diagram

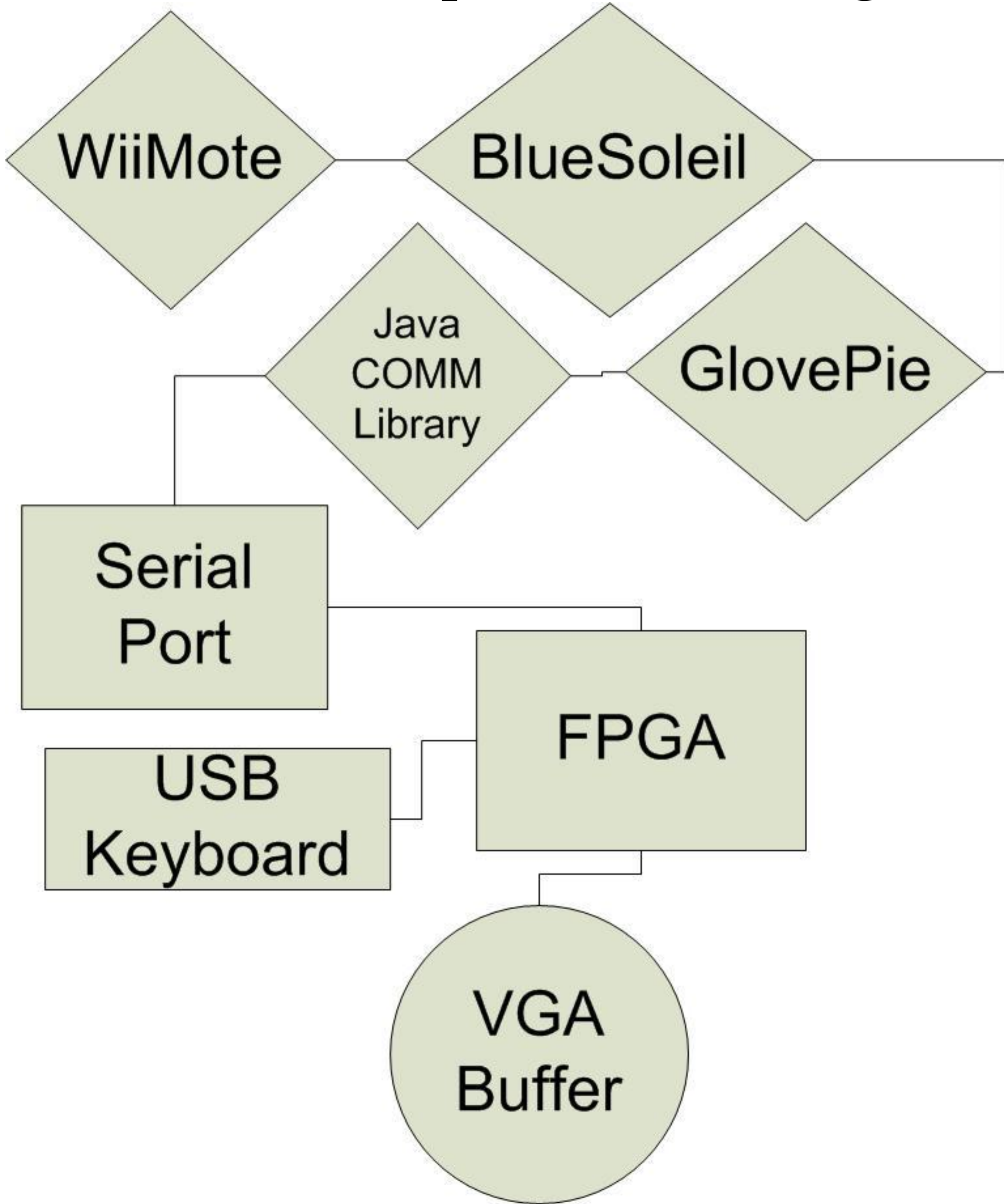
However, making sense of the returned data from the device and knowing what configuration to choose to get into the proper Configured state can be a challenge. Even after a proper configuration is chosen, correctly using the endpoints and structuring the subsequent TD lists is very difficult.

There was barely enough documentation to get the control transfer process working. Since this is the most structured and standardized form of transfer, it was relatively easy to piece together the missing parts of the picture from different sources to achieve success. In bulk, interrupt, and isochronous transfers, however, each device has its own unique way of communicating. Sometimes, if a device is part of a common device class, such as Human Interface Device (HID), or Wireless, the USB Implementer's Forum (USB-IF) will put together a standardized way of communicating so that a new driver is not required for each device. Some HIDs or wireless devices will not follow the specification and therefore require a custom driver. The details of such drivers are not easy to obtain and implement. For something as simple as a Dell USB low-speed keyboard, however, we thought that we could succeed. However, we were unable to find just how to structure Cypress's proprietary TD list format to properly receive the keyboard's interrupt transfers. It was simple from the USB side of things, but there was absolutely no information on the Cypress side of things. We were reduced to a trial-and-error, shooting in the dark style of development. We needed more information from Cypress; an example would have been particularly helpful. As far as we know, nobody yet has succeeded along this path, including those in the Xilinx forums.

Initial USB Implementation Plan



Final Control Implementation Diagram



What We Learned

Time Management:

We learned many useful techniques for time management. One of them, which is very useful, is the Gantt chart. My group at first was very skeptical of the usefulness of the Gantt chart but we soon realized that this was a great way to make sure we stay on schedule and keep tasks organized. We learned that we should always keep the customer (a.k.a. professor) updated and propose a reasonable schedule based on careful analysis of the situation.

Software Life Cycle:

We learned much more about the life cycle of a full project. This compares much differently to any of our experiences in previous classes. Since there is no guidelines on how to run the project, it is up to us to decide how to run the operation. We had to come up with the idea, implement it, and maintain it in order to finish on time. We learned many useful things in this area that could help us in future work projects in the industry.

Debugging:

We learned a few things about debugging for an FPGA. Most of our debugging came in the form of getting the tools to do what we wanted them to do. We learned the ins and outs of the different connections between the hardware and how they could mess up. Debugging this wasn't the normal "find the bug in gdb and fix" but a more application frustrating problem. We realized that the best way was to systematically go through the different steps, read all the warnings, and then proceed after each step was bug proof.

Bugs come in all shapes and sizes. The bugs we encountered ranged from stupid mistakes to nefariously difficult errors that took hours to debug. Examples:

- Stupid bugs include using the wrong kind of serial cable. We initially wondered why we weren't getting any output over the serial cable.
- Debugging our C code was at times frustrating. Obviously, the FPGA never returns "segmentation fault," so when we segfaulted, we simply got back garbage. A segfault early on the program may not manifest itself until a lot later. C's "undefined behavior" made our seemingly correct code break weeks after we thought we had finished debugging.
- One interesting bug was when we ran out of stack space. No errors were given but suddenly, a lot of variables on the stack were being overwritten. It took hours to debug; we finally realized that the bug occurs if and only if we call a function that literally does nothing (we commented everything out so that it just returns), which suggested that the stack was being blown. The fix (increase the stack space) took only five seconds to implement. (Stack size can be easily set and changed in the Xilinx Platform Studio.)

Teamwork:

This was the first full scale group project that any of us had participated in our time at CMU. At first, we had trouble coordinating and working as a team to progress forward. We all had different personalities, sleep schedules, lives, and work habits. However, with the leadership of some members in the group, we were able to coalesce very quickly and efficiently. We were able to come to a middle ground. The one thing we took away was that honesty and trust within group members was the most important. If there were any problems, we voiced them to each other so that it would be addressed sooner rather than blow up later.

Presentation Abilities:

We were able to practice our presentation skills in the class in front of a very technical audience. We had to know what we were talking about and the one thing we learned is that you can’t B.S. your way technically in a room full of very smart people.

What we wish we knew before:

In hindsight, we wished we knew that in coming up with an idea, a lot of research must be done in order to know whether it is feasible or not. The idea may sound feasible at first, but further research must be done in order to confirm this. In our case, we didn’t realize that there was no non-buggy documentation for the USB port for Xilinx. If we had realized this when the idea was made, we could have scratched it and pursued something feasible.

Individual Pages

Ravi Raghavan

I had a great time doing this presentation with my fellow classmates. I really enjoyed the hands on experience working with the FPGA boards. I learned that there is more to hardware than just simulation for Verilog. Synthesizing on an actual board is much different and can be more frustrating at times.

I personally helped out on the making of the game and a lot of the non-USB work. Once the game was finished, I joined the help out in the USB work. In the end, everyone in the group was helping out in the USB department, since it was the main crux of our project. We worked on average more than 15 hours per week. Much of the work came in the form of researching what different avenues of USB were out there and struggling with the Xilinx Platform to do what we wanted it to do.

Even though in the end, we didn't get the Wiimote to work through the USB, I and the rest of the team members worked our tails off the whole semester trying till the very last day to make it happen. I still found that this class was very rewarding in character building. I think that the next time around, with the experience we gained, my team members would be able to successfully complete this project.

As for improvements for the class, I would really like to see more useful demos, especially in the areas that certain groups are working in. For example, there could be a choice between 15-20 demos we could do. We could then pick maybe like 5 that apply to our specific project, making it so that we develop the useful skills to complete our project. This would definitely help the high project failure rate of the class so that people can achieve their initial goal.

In the end, I am very happy with me and my group members. We all put in a lot of selfless effort to get the project to the point it was at. It was apparent that we knew what we were doing judging by the extensive knowledge of USB that is now in all our heads. I would be glad to work with my partners again in any other class or in the industry.

Dennis Ting

I enjoyed implementing Duck Hunt on the FPGA board. In general, the games aspect of the course was very entertaining. I would say my favorite part of this course was seeing Duck Hunt work. Once we got all the input/output systems working (which was the majority of the work), writing the actual Duck Hunt code was a relaxing and fruitful exercise. If we had more time and finished all our tasks, I would've wanted to implement more games using the codebase we already have.

In general, our group worked on most of the tasks together. We first tackled the labs, and then began work on the actual Duck Hunt itself. The one task that was both enjoyable and simultaneously frustrating is debugging the software that we've written, especially debugging the frame buffer code. Finally killing the bugs is by far the best part of software coding, but at the same time, it was frustrating that despite my best efforts, I was unable to write code that was even remotely bug-free.

I also liked the freedom we were given in implementing Duck Hunt. We were allowed to choose how to go about tackling the problem. Our hacked code was difficult to debug, and I learned that it's a good idea to write and refactor code.

Although I enjoyed the software side, I did not really enjoy working with Xilinx's Platform Studio. To give an example, Xilinx's software cannot handle spaces in the command path. If we attempt to load a file with a space in its path, XPS (Xilinx Platform Studio) simply fails to open. No error messages are given.

In terms of time spent, although this course is a 12 unit course, we averaged over 15 hours per week. I would recommend not taking any heavy courses alongside the ECE capstone courses. Also, the job search and on-site interviews made my schedule pretty hectic. I don't regret my schedule, but this semester was definitely more work than I originally anticipated.

We did ultimately get Wiimote working through the computer, using third-party programs that interact with Bluetooth to talk with the Wiimote. However, even then, we realized that these programs were buggy. Bluetooth, at times, simply just failed. Considering that even on the computer, Wiimote interactions are somewhat buggy, in hindsight, trying to get Wiimote working from scratch on the FPGA was perhaps way too optimistic.

Anthony Setto

I liked how open-ended this class was. Any group could do just about anything they wanted in any way they wanted, for better or for worse. This gave me valuable experience for what it would be like to work in the industry as a team leader or a member of a small team. Time management was a huge worry the entire semester; this was something we did not have to deal with much in the past.

At the beginning of the semester, all three of us worked together on everything, including the labs and the beginning of the duck hunt game, as a learning exercise. After the first few weeks, we began to branch out into different tasks. My task, unfortunately, was to get USB to work. My frustration with Xilinx and Cypress is far beyond the scope of this review, but I'll just say that the university should strongly consider switching FPGA providers. I estimate that I spent 20 hours a week in the lab, figuratively banging my head off of hard surfaces.

However, I was proud of the successes that we were able to accomplish, including the communication between some USB devices. I also liked that we were able to quickly fall back to the serial connection for the final demo. Writing the duck hunt game from scratch was pretty impressive, especially since it's better than the original in my opinion. I also liked working with my team, as my lab partners were honest, talented, and fun to work with.

I would like to see more labs and useful demos for the class, especially for the Virtex V and for the newest version of XPS. We wasted countless hours at the beginning wrestling with Xilinx incompatibility errors and other confusing roadblocks.

Citations

www.usb.org – The place to go to get a great overview on how USB works in general. Also contains the USB Implementer's Forum, which is a necessity to get any USB project to work.

www.bluetooth.com – Contains the spec for the Bluetooth protocol and outlines processes used by Bluetooth devices, like the Wiimote.

http://carl.kenner.googlepages.com/glovepie_download - The download location for GlovePIE, a powerful PC input manipulation program used to interpret the input from the Wiimote.

http://java.sun.com/products/javacomm/ - Location of Java's .comm library, which was used to send serial information to the board.

www.cypress.com – Cypress's homepage, contains information on the external USB controller

http://www.xilinx.com/univ/xupv5-lx110t-bsb.htm - Xilinx designs we used as a place to start for our designs

http://tsgk.captainn.net/index.php?p=showsheets&t=sr&sr=151 – Sprites for the Duck Hunt game

http://www.computer-engineering.org/ps2mouse/ - An excellent source that documents the PS/2 mouse interface. Because PS/2 mouses have been replaced by USB mouses, this is one of the few PS/2 references left.