FPGA-BASED HARDWARE EMULATION ARCADE SYSTEM

PROJECT PLAN

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definitions</td>
<td>1</td>
</tr>
<tr>
<td>Executive Summary</td>
<td>1</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>2</td>
</tr>
<tr>
<td>Problem Statement</td>
<td>2</td>
</tr>
<tr>
<td>Operating Environment</td>
<td>2</td>
</tr>
<tr>
<td>Intended Users and Uses</td>
<td>3</td>
</tr>
<tr>
<td>Assumptions and Limitations</td>
<td>3</td>
</tr>
<tr>
<td>Expected End Product and Other Deliverables</td>
<td>3</td>
</tr>
<tr>
<td>Proposed Approach</td>
<td>4</td>
</tr>
<tr>
<td>Statement of Work</td>
<td>7</td>
</tr>
<tr>
<td>Estimated Resources</td>
<td>9</td>
</tr>
<tr>
<td>Schedule</td>
<td>9</td>
</tr>
<tr>
<td>Closing Material</td>
<td>10</td>
</tr>
</tbody>
</table>
DEFINITIONS

- ALU – Arithmetic Logical Unit
- CPU – Central Processing Unit
- FPGA – Field Programmable Gate Array
- I/O – Input / Output
- NES – Nintendo Entertainment System
- PCB – Printed Circuit Board
- PPU – Picture Processing Unit
- VGA – Video Graphics Array
- VHDL – Very High Speed Integrated Circuit Hardware Description Language

EXECUTIVE SUMMARY

The Iowa State Reconfigurable Computing Lab would like a way to showcase the capabilities of reprogrammable hardware. To accomplish this, our group will be showcasing that a simple FPGA board can replace the entire NES. This project is the continuation of a past group that created a simple emulation of the NES. Our primary goals are to continue the work done by the past group and improve the presentation of the system by building an arcade cabinet.

There are several major issues that still need to be resolved. In order to resolve these issues, time must be spent familiarizing ourselves with the past work. Currently the system works on a development board, and will only work with a limited amount of games. Some things that we plan on addressing are adding side scrolling to the PPU and audio to the already working CPU. The current system was designed for a high powered and expensive development board. To reduce project costs, we will need to choose a board more specific to our application, and redesign the code to work on the new board. The past project is implemented simply with a computer monitor, FPGA board, and two Nintendo controllers. Our goal is to house the emulator in a professional looking arcade cabinet reminiscent of arcade machines from the 1980’s. The system will include traditional joysticks, buttons, and possibly a track ball.

Our team is composed of five computer engineering seniors. We have all taken Computer Organization and Design (CPRE 381), and all have experience with computer architecture. Our group will be dividing tasks between the two main modules: designing the FPGA and building the arcade cabinet. Specific tasks will be flexible as our interests and current objectives change.
ACKNOWLEDGMENTS

- Senior Design group May10-01 (FPGA-based NES Emulator)
  - Ashley Good
  - David Graziano
  - Tim Meyer
  - Ben Petersen
  - Matt Saladin
- Philip Jones (Advisor)
- Joseph Zambre (Client)
- ISU ECPE Department

PROBLEM STATEMENT

GENERAL PROBLEM STATEMENT
We have a partially working emulator from the past group, but it didn’t include audio, side scrolling, cartridge based memory, and a good way to load games. We will also need to choose an appropriate FPGA board for the system. To make the system more presentable, we need to create a professional looking arcade cabinet to enclose the emulation system.

MARKET / LITERATURE REVIEW
We will be looking into the various other software emulators for examples on ways that they have solved common problems. Additionally, we have found a similar project (https://rm-rfroot.net/nes_fpga/) that should provide very valuable knowledge.

GENERAL SOLUTION APPROACH
To enable side scrolling, we will have to further understand and develop the PPU that was implemented last year. To enable audio on the FPGA board, we will need to further develop the CPU. We will need to research different FPGA boards, so we can choose a scaled down counterpart that will better fit the scope of the application and will lower costs. Research will be conducted on other arcade cabinet projects to gain knowledge on ideas and direction to take with the design of the arcade cabinet.

OPERATING ENVIRONMENT
When the system is in its final location, it will be in a climate controlled environment. It will not need to withstand extreme temperatures or physical shock. However, it may encounter small amounts of dust. An example location would be a lobby of a building on campus.
INTENDED USERS AND USES

INTENDED USERS
The intended users of the system are anyone that will be visiting the computer engineering facilities at Iowa State University. This includes current and future students, faculty, and visiting family members.

INTENDED USES
The system will be used to showcase the capabilities of reconfigurable hardware and to promote the department and Iowa State University. The system should be representative of the interaction users have with professional arcade machines. We don’t expect people to treat the emulator in such a way that could cause damage to the system. We don’t expect that people will have to move the system very often.

ASSUMPTIONS AND LIMITATIONS

ASSUMPTIONS
• The two-semester time period is adequate to complete the project
• The system will be used by one or two users simultaneously
• The documentation provided online will be sufficient to understand the system, so we can implement the required components.
• We will have adequate funding to complete the project
• Last year’s group implemented the current features according to the online specifications we are using.

LIMITATIONS
• The two-semester time period is a firm deadline.
• The system must be powered by a standard 120 volt wall outlet.
• Limited budget.

EXPECTED END PRODUCT AND OTHER DELIVERABLES
The final design will include a specially chosen FPGA board that will run the entire NES. The emulation will be complete including side scrolling, audio, and support for extended cartridge based memory. It will be housed in a specially designed cabinet that will allow others to use the system easily. It will include a new control system that is also part of the cabinet. We will also create a project plan (this document), a design document, a team website containing weekly status reports, and a presentation outlining what we plan to accomplish with the project.
PROPOSED APPROACH

FUNCTIONAL REQUIREMENTS
- Accurately Emulate the original NES
  - Run NES rom files
  - Include Side Scrolling
  - Include Audio
  - Include cartridge based extended memory
- Provide a method of accessing the NES rom files
  - Interface to choose games from removable storage (Compact Flash)
- Have impressive looking enclosure to house the system
- User should be able to interact with system like a real arcade

NONFUNCTIONAL REQUIREMENTS
- Durable Design
- Modular
- Maintainable
- Portable
- Easy to use

CONSTRAINT CONSIDERATIONS
Our project must be able to be completed within a two-semester period. We will need to support one or two users simultaneously. We will have to gain all of our knowledge from online documentation of the NES system. We must be able to purchase all needed components in our limited budget.

TECHNOLOGY CONSIDERATIONS
We will need to be able to synthesize and run our code on the new FPGA board. The NES has many components designed around old technology which must be reverse engineered to work on our FPGA board.

TECHNICAL APPROACH CONSIDERATIONS
We will be working as a team to complete this project, so we will need to split the tasks and keep to our schedule. We will try to complete all our FPGA work by the end of the first semester. This way the long process of fine tuning and testing can be completed in the second semester. An SVN server will be used to store all the source code for this project. This will allow us to share our work with the rest of the group, and provide good version control.

TESTING REQUIREMENTS CONSIDERATIONS
Testing will have to be done on every part of the system. We will be looking into user input and making sure that the system produces the correct output. When necessary we will simulate individual VHDL components to ensure that they are working on a low level. During the integration phase we will have to thoroughly test the system to make sure the components are working together as expected. The system will be tested on a wide range of video games to check for errors in the system.

SECURITY CONSIDERATIONS
The system that we are creating has no known security considerations.
SAFETY CONSIDERATIONS
The system should be sturdy enough to avoid unintentional tipping, as to not injure any users. Safety will be a top priority during the construction of the arcade cabinet. Many potentially dangerous tools will be used to construct the cabinet. Proper measures will be taken to ensure safety while using these tools.

INTELLECTUAL PROPERTY CONSIDERATIONS
Any components that we will use will be created by our team, or be provided to us as open source software. This means that there are no intellectual property violations to consider.

COMMERCIALIZATION CONSIDERATIONS
The system that we are creating is for internal use only, so there are no commercialization considerations to consider.

POSSIBLE RISKS AND RISK MANAGEMENT
Our group has limited hardware design experience and even less experience with using FPGAs. We will combat this problem by doing extensive research. This includes stepping through some of the class work of CprE 583 (Reconfigurable Computing), which our advisor recommended us to work through. These exercises are beneficial to us, because this class uses the same FPGA board that the previous semester’s group used and is the same board we will use until we order our new FPGA board.

Some of the expanded features to the emulation may require the old design to be reworked. This would require more work than was originally expected. In order to counteract this risk, we will begin work immediately in order to complete our expanded features before the end of the semester. This will allow us time to overcome any unexpected obstacles that may arise.

After purchasing a new FPGA board, transferring the old emulation may provide extra complexities. It may require work that was unforeseen and delay work on expanded features. The FPGA board will be selected as soon as possible so that any issues can be taken care of.

Only a couple of team members have experience in woodworking. Their experience is limited, so constructing the cabinet could take more time and resources than expected. To avoid any issues, outside firsthand experience in arcade construction will be utilized.

PROJECT PROPOSED MILESTONES AND EVALUATION CRITERIA

<table>
<thead>
<tr>
<th>Deadline</th>
<th>Milestone</th>
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</thead>
<tbody>
<tr>
<td>Oct. 1, 2010</td>
<td>Design Complete</td>
</tr>
<tr>
<td>Oct. 15, 2010</td>
<td>Side Scrolling Complete</td>
</tr>
<tr>
<td>Oct. 15, 2010</td>
<td>Board Selection Complete</td>
</tr>
<tr>
<td>Nov. 1, 2010</td>
<td>Boot Loader Complete</td>
</tr>
<tr>
<td>Nov. 1, 2010</td>
<td>CAD of enclosure complete</td>
</tr>
<tr>
<td>Dec. 15, 2010</td>
<td>Audio Complete</td>
</tr>
<tr>
<td>Dec. 15, 2010</td>
<td>I/O Complete</td>
</tr>
<tr>
<td>Feb. 1, 2010</td>
<td>Enclosure Construction Complete</td>
</tr>
<tr>
<td>March. 1, 2010</td>
<td>Test/Code Integration Complete</td>
</tr>
<tr>
<td>April. 1, 2010</td>
<td>Final Integration Complete</td>
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When the project is complete, we will evaluate the system to make sure that we have met all of the goals that are stated in this paper. Additionally, we will make sure that we have the approval of both our advisor and client.

PROJECT TRACKING PROCEDURES
In order to keep our budget and schedule we will maintain constant communication through team meetings and email. We will also meet with our advisor and client once per week to make sure that we are meeting our schedule and updating the rest of the team on our individual progress. This is also a good time to get feedback and advice on any challenging problems we may face individually or in smaller groups. Weekly reports are sent out every Monday to all team members, client, advisor, and the senior design instructor. These reports give a summary of how much work was done and the contributions of each individual from the previous week.
STATEMENT OF WORK

- **Initial Background Research:**
  Initial background research is needed to gather information about the function of the NES system and its components.
  - Similar Projects
    - By looking at similar projects, we can better understand the way the system works. We can also determine potential ways to solve common problems encountered when dealing with emulation.

- **Documentation:**
  As required by the class, documentation will be a large part of what is required from the project. We will create several documents discussing how we plan to accomplish the goals for the project.
  - Project Plan (This document)
    - The project plan is the outline of how we plan on completing the project. It contains a schedule of tasks and budget plan.
  - Design Document
    - The design document details the specific design methods and issues used in the project.
  - Weekly report
    - We will create weekly reports to document our accomplishments for the week. Additionally, it will have the amount of time each member has put into the project, so that we can track hours of labor.
  - Other
    - To document the progress that we are making, as well as easily share information with others, we will be creating a website. Additionally, we will be giving a presentation early in the first semester to show others in the class what our project is and how we plan on completing it.

- **VHDL Design:**
  - PPU
    - We will have to modify the PPU to enable the system to use side scrolling games.
  - CPU/Audio
    - The CPU will need to be modified to allow it to output audio. This may be modifying old VHDL code, or remaking parts of the CPU to enable us to use audio. We will also have to research how the FPGA board that we use interfaces with the audio outputs.
  - Cartridge based expandable memory
    - The NES allows for more memory to be added via a game cartridge. The previous group did not implement this, so we will need to add this so all games can work.
  - Input / Output
    - The current implementation works for the original NES controllers. We would like to allow for the arcade style buttons, so we will need to modify the code to accept this type of input.
  - Boot loader
    - The current implementation does not allow for multiple games to be played without re-synthesizing the code. To allow for this, we will need to come up with a system for dynamically loading the ROM files into memory. We plan on using compact flash for this.
- Arcade Cabinet
  - CAD blueprints will be created to show the detailed design of the cabinet. After the blueprints are created and approved by our client, we can begin constructing the cabinet. The cabinet will resemble an 80's style arcade system. This will allow for multiple users to use the system, and give the department a way to show what reprogrammable hardware can do.

- System Block Diagram

- Testing
  - To make sure that we create the highest quality product, we will test each component separately. We will also do testing as we integrate components together. After all components are integrated together, we will test the system as a whole to make sure that it functions as expected.
ESTIMATED RESOURCES

LABOR COSTS
We anticipate having to put 10 hours a week into the project. With 5 members on the team, and at an hourly rate of $20, the expected labor costs are around $30,000.

MATERIAL COSTS
A new FPGA board will be needed to complete our project in full. We expect the cost of the board to be around $200. Arcade controls are inexpensive, but we will need quite a few for a full control panel. All controls should cost about $100 in total. The addition of a trackball would add another $130 to the budget. Cabinet construction is expected to be the most expensive part of the project. Wood and screws are estimated at $130, decorations such as paint and marqueses will be approximately $100. Speakers for the cabinet will be around $60. Monitor costs may vary based on what size and technology we decide to use as well as what kind of deals we can find. With these considerations in mind, we expect a monitor to cost about $500. We may need to fabricate and populate a printed circuit board which will cost around $100. All these materials add up for a total of $1320.

OTHER RESOURCES
We will need the use of the computing labs within the Computer Engineering facility at Iowa State University. This includes lab equipment so we can compile and download code to the FPGAs. Additionally, we will need the development FPGAs that are currently available for other classes at the university.

SCHEDULE

DELIVERABLE SCHEDULE

<table>
<thead>
<tr>
<th>Deadline</th>
<th>Task</th>
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<tbody>
<tr>
<td>Oct. 12, 2010</td>
<td>Project Plan Complete</td>
</tr>
<tr>
<td>Nov. 9, 2010</td>
<td>Project Design Presentation</td>
</tr>
<tr>
<td>Dec. 14, 2010</td>
<td>FPGA VHDL complete</td>
</tr>
<tr>
<td>End of May</td>
<td>Project Complete</td>
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PROJECT SCHEDULE
CLOSING MATERIAL

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CLOSING SUMMARY
This project is important to showcase how Iowa State University is a leader in FPGA technology. This is an important marketing opportunity for Iowa State’s Electrical and Computer Engineering Department. It will showcase to incoming staff and students the exciting project opportunities available at Iowa State University. Last year’s group has already made significant progress on this project that we can build on. We should be able to make the necessary changes to the PPU and CPU to add side scrolling, extensible cartridge memory, a boot loader, and audio features to the project. The new arcade cabinet will create a professional way to enclose the emulation system. We will be relying heavily on online documentation of the original NES system to help replicate their functionality on the newer FPGA technology.