University of Puerto Rico
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Department of Electrical and Computer Engineering

Boardcaster

"A proposal submitted as a partial requirement of the Capstone course ICOM-5047"

by

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Abstract

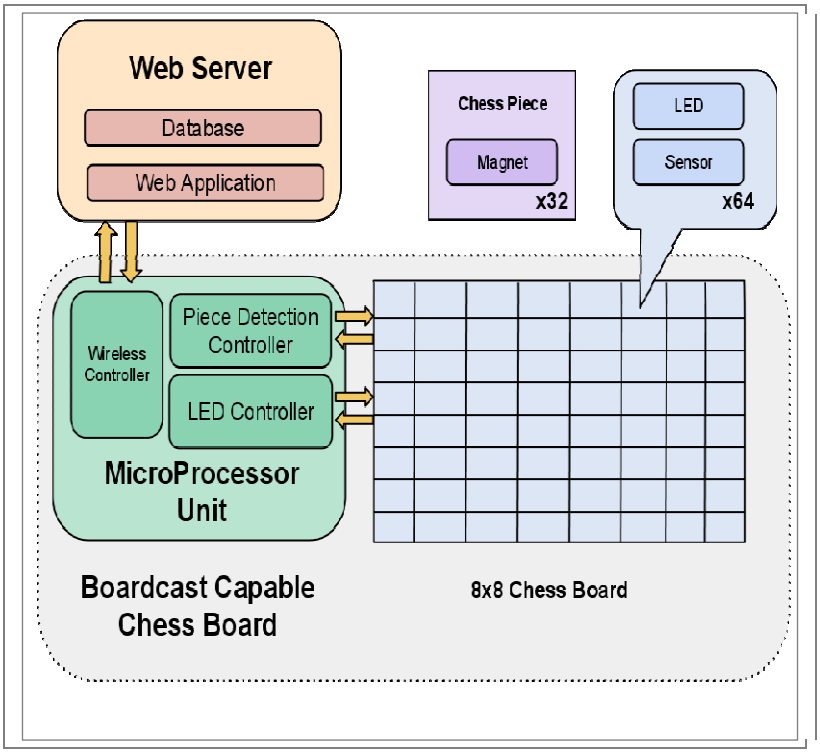
Chess tournaments seldom broadcast chess matches. Although video recording is common, they are not broadcast live; it is easy to find and watch these matches on websites like YouTube.com. Some current electronic chess boards have some capability to transmit a live chess match over the Internet, but they require the installation of hardware drivers and specific applications for a Microsoft Windows based computer.We present a proposal for an electronic chess board that is capable of transmitting live chess matches over the Internet without the need for any drivers or platform specific software. Those interested in watching the live chess match only need a modern web-browser and an Internet connection. To achieve this, a server connected to the Internet will be used as a middle-man. The electronic chess board will send the chess moves to a database on the server, and the website will read from that database to graphically display the chess match on an web-browser.

Our open-hardware and free and open source software design allows it to be hackable/customizable, opening opportunities for more board games, like checkers to be played. More importantly, it democratizes the game of chess; it allows smaller organizations to reach out to bigger audiences via the broadcast of games.
The end result will be a chess board that is portable, wireless, low cost, real-time, easy to use, and hackable.

Executive Summary

Yearly, many board game players meet in different countries to play in tournaments. One of the games that is most played on these tournaments is chess. The problem is that tournaments rarely broadcasts the on-going games. If a chess enthusiast wants to see the game, he or she must be at the event. This is disappointing for that person; being at the event might not be a possible option due to travel costs, lack of time, etc. As for the tournament organizer, not broadcasting the games results in less audience and outreach.

To alleviate these problems, ACM5PT is introducing "Boardcaster", a new approach at broadcasting and watching live chess matches. Boardcaster offers solutions to chess organizations, players that want to broadcast their games, and to those that want to watch live chess matches. The system architecture can be seen below, in the block diagram of the system.



The way the system works by having a chessboard where each chess piece has a magnet, and each square in the chessboard has a sensor that detects whether a piece was picked up or placed on it; that way each move can be detected. Each move is then sent to a web server that accumulates these in a database on the server and shows them on website so that anyone who wants to follow the game can graphically see it on this website. Additionally, each square also has an LED, which can show the user the possible moves that they can make with a piece that they picked up. This can help beginners to learn how to play the game.

The unit will be powered by a battery, and the communication between the board and the server will be done wirelessly.

In the end, the deliverables will be a prototype chessboard where each square has both an LED and a magnetic sensor to detect piece movement, the chess pieces with the necessary magnets, and a web server that manages the storing of game and the displaying to the users. Test results from the individual test of each individual component will be provided, and a user manual to explain how our system is to be used.

Progress will be marked across three relevant milestones: first of all, all the necessary design will be done by September 26, this includes the database schema, the website, microcontroller software, how the sensors and LEDs will be connected and the interfaces among all these components; secondly, each of the components will be built and tested to make sure that they each operate separately by October 24, and finally system integration will be done by November 14.

Investment on this product is justified on several ends. First of all, similar products cost around $900 dollars (about 650 euros), where as by team estimates (shown in the Appendix), Boardcaster will cost about $480 at 1-unit cost. As expected, if launched into production considerable costs reductions and an increased profit margin can be observed. Boardcaster also has the advantage of ease of use and setup and by making the software open source, it helps savvy users make fixes to possible bugs, customize and continue to operate the product beyond end-of-life.

Introduction

Board games have reigned family fun for many decades. These games can be as easy as Tic-Tac-Toe, or complex like table top role-playing games. The oldest board game that has been recorded in history is from Ancient Egypt, circa 3500 BC. Today, whole industries are dedicated to designing, producing, selling, and playing board games.

Yearly, many board game players meet in different countries to play in tournaments. These tournaments decide the world champion for games like Scrabble®, Monopoly®, and more.

Chess is no stranger to these tournaments. Although modern chess dates back to 1475, international tournaments have been held since 1851, the first one being in London. Each year grandmasters of chess play against each other for money, fame, and most importantly, the world champion title.

It seems, however, that technology for chess has stayed stagnant for most of the century. With the exception of chess clocks and computer software (including artificial intelligence players), technology is seldom found in chess tournaments.

Problem statement

Tournaments rarely broadcast on-going chess matches. If a chess enthusiast wants to watch a match, he or she must be at the event. This is disappointing for many; being at the event might not be a possible option due to travel costs, lack of time, etc. As for the tournament organizer, not broadcasting the games results in less audience and outreach.

To show chess matches to an audience, many tournament video record the matches, and later publish them online as videos. The problem with these videos is that the angled view point makes it difficult to clearly see the pieces on the board. [See Appendix C]

The other alternative is to use electronic chess boards. These chess boards transmit the moves to a computer that transmits the game over the Internet. However, In order to watch the game, it is necessary to install a Microsoft's Windows application. This limits the audience to Windows users. It also requires a viewer to download and install an specific application.

Moreover, before connecting the electronic chess board to a computer, it is necessary to install hardware drivers. This approach requires the need for a computer. This can be an issue depending on the type of connection between the chess board and the computer. If the connection uses USB cables, then the limit is the number of USB ports the computer has. If it's a wireless connection that uses Bluetooth, the maximum recommended by Digital Game Technologies, the manufacturer of the most popular electronic chess board, is five. Assuming all electronic chess board use Bluetooth, you would need too many computers to interface with all the chess boards in a tournament; it would also be cumbersome and expensive.

Proposed Solution

To alleviate these problems, ACM5PT is introducing "Boardcaster," a new approach at broadcasting and watching live chess matches. Boardcaster offers solutions to chess organizations, players that want to broadcast their games, and to those that want to watch live chess matches.

Boardcaster uses chess piece recognition to keep track of the chess match. A move is detected by sensors that reside inside the chess board. Each sensor is placed so it instantly reacts to the lifting and placing of chess pieces. These chess pieces use a small magnet to trigger the sensors. When a piece is lifted, and then placed, a move is completed. As soon as this happens, Boardcaster logs that move, and sends it, wirelessly, to a server on the Internet.

Several alternatives are available for wireless communication. Currently Bluetooth and Wi-Fi technologies are being considered.

Once the move is sent to the server, it is stored inside a database that is read by a website. The website uses technologies like Javascript and HTML5 to graphically display the current status of the chess match.

Although it is not possible to completely remove the need for an application, Boardcaster only requires a standard Internet browser. This will allow anyone in the world to “tune-in” and watch the chess match, live. This solution is also multi-platform; today most computers, including smart phones and tablet computers, have built in web browsers.

Furthermore, the problem of teaching chess is also address. LEDs will be placed on each square of the chess grid. These will light up when a piece is lifted. Depending on the chess piece, the LEDs will light up indicating the possible legal moves for that chess piece. An illegal placement of a chess piece will result in the LEDs flashing, indicating the illegal move. Using the LEDs will be optional; a switch on the chess board will turn on/off the feature

Potential Customers and other Stakeholders

There are a wide variety of potential customers available for this product. The most obvious customer for this product would be chess tournament organizers. These could increase their advertising revenue by demonstrating ads online alongside live chess games. Also, they could charge for viewing tournaments and many other forms of extra revenue that could come from the use of this product. Companies or organizations seeking ways to further increase their viewership, participation or revenues will naturally be attracted to the platform.

Another substantial customer base would be advanced and professional chess players. These could benefit from *“boardcasting”* their games to gain more fame and recognition. Also, they could help improve their game by receiving comments from the chess community through the game’s website.

Finally as an open-source hardware and software project this product would be of great interest to hackers, this can also be yet another customer base. The hacker community could show interest in this product as a platform for creating new games that the team hasn’t even considered yet or that they do not have the resources to develop. For example; support for various chess varieties could be added or entirely new games could be invented.

New and exciting features could be added by the community such as support for playing against an electronic AI. These additions by the community could further increase the customer base and the value of the product. In such cases the product could be more appropriately considered a platform. Such customer interest could conceivably create a positive loop of further community development and interaction.

Another important stakeholder in addition to the direct customers are the Chess enthusiasts. This product will allow them to watch games from any modern web browser. Using technologies like HTML5 and Javascript, a live game can be shown in real-time on a webpage. Those that want to watch only need to "tune in" to the webpage, and enjoy. This could be from a desktop computer, a tablet computer like the iPad, or even from a smartphone.

The result will be a fully functional electronic chess board which will benefit our stakeholders: ACM5PT, Kenny Martínez (a competitive chess player from Puerto Rico) Tecnocaribe Expo (see the consultants section for more information) , chess clubs and organizations, chess players, and chess enthusiasts.

Project Antecedents

Previous Work Experience

The members of the development team have known each other for several years, many of which have been spent developing projects for several courses and extracurricular activities. These previous experiences have allowed the team to hone their teamwork abilities and has allowed them to better understand individual member's skills.

An arducopter[2] based project was their latest endeavor. In 2010 the team worked on the development of a remotely controlled quad-copter with temperature sensing and reporting capabilities[3]. This project was realized as part of the Microprocessor Interfacing course at the University of Puerto Rico, Mayagüez Campus. Although the team does not foresee the integration of parts from the previous project, the knowledge acquired during the research and development phase will serve as an invaluable source of guidance.

Products and market competitors

There are some commercially available electronic chess boards. The amount of products available shows there is a market for this type of product. Some chess boards feature Master Level AIs and are built with high quality materials but can cost upwards of $700 [1] while others are just portable electronic boards.

Name	Platform	Open Hardware and FOSS/ Easily hackable	Price	Wireless	AI	Automatic move detection	Records games	Training	Online play	Broadcasting
Boardcaster	Platform independent (web based)	Yes	425.04	Yes; Wi-Fi	No	Yes	Yes; through website	Yes; Simple training through LEDs and comments through webiste	No	Yes; through the web
DGT	Microsoft Windows	No	€649.00 (~$890.00)	Yes; Bluetooth	Yes; but only when connected to a PC.	Yes	Yes; but has space for only 500 moves internally.	No	Yes	Yes; but requires special software to watch
Professional Tournament Manager Hub	Microsoft Windows	No	489	Yes; Bluetooth	No	No; requieres manual entry	Yes	No	No	Yes; through the web
Shacom	Microsoft Windows	No	480	No	Yes; but only when connected to a PC.	Yes	Yes	Yes; this is a special focus of this product	Yes	Yes; but requires specialized additional equipment

Market Overview Table

Other competitors

Potential competition could come from the current providers of electronic chess boards and chess tournament equipment such as the ones previously mentioned. Since the team will the develop an open-source software and hardware product, competition could spawn in the form of spin-offs based on the project's design and code.

Fortunately, by making use of copy-left licenses the team will also be able to take advantage of advances made by other developers. Copy-left will protect the end-users and developers from the product becoming proprietary but it won't protect the developers against parasite competitors that only manufacture the product but don't contribute back to its development. The team can only hope that the product's quality and customer loyalty by themselves shield the product from parasitic competitors [8]. This model has worked in the past for other open-source-hardware projects such as the Arduino and Arducopter projects.

Proposed system objectives

To achieve the Boardcaster system, the team will accomplish the following objectives in the following two months:

- Create a sensor array for the game's board to detect when pieces are being moved.
- Modify the game's pieces so that they can be detected by the sensor array.
- Build an LED array for the board so that each square can be turned on, so that the user can know legal moves that they can make.
- Create a database where all the moves made are being stored.
- Implement a website that can read the moves made from the database and then display them to the users so that they can follow the game live.
- Implement communication between the board and the website.

The first four objectives are related to creating the first deliverable, which is the prototype board game that can transmit the moves being made. The last three objectives are directed to creating the second deliverable, which is the website where users can go to watch the game being broadcasted in real time, and the integration between the website and the board.

Proposed system features

By allowing games to be broadcasted online the product aims to bring chess and other boardgames into the age of the web. Gaming event coordinators could conceivably offer online streaming services of their live matches as an alternative to physical presence. This could easily allow for an increase in viewership. At the organizer's discretion, this could also be translated into an increase in advertising revenue for the event. The product would also give up-and-coming players another venue to make their presence felt in the arena of competitive gaming, even if they don't have local chess club. Amateur gamers could benefit from the ability to record and display live games to be coached remotely by more skilled players who can leave comments about the overall game or specific moves. All together, it aims at lowering the entry level into world of chess.

Boardcaster has two main deliverables: a portable electronic chess board capable of broadcasting an ongoing chess match and a website where anyone can watch aforementioned games in real time.

ACM5PT proposes a design for an electronic chess board that will be portable, wireless, low cost, real-time, and easy to use.

Portable

The design includes a rechargeable battery to power the chess board. The owner of the chess board will also be able to take it and move it around.

Variables

Battery life will depend on usage. Battery could be extended by turning off the feedback LEDs.

Wireless

Using wireless communication, the need for a cable connecting the board with the computer is eliminated. In fact, if Wi-Fi is used, there might not be a need for a computer. The only requirement would be a router providing internet. Boardcaster will communicate to the Internet and update the server as needed.

Variables

Depending on the method and device used to achieve wireless communications, a single computer or router will only be able to serve a maximum number of Boardcaster chess boards.

Another variable to consider is the maximum distance possible between the a Boardcaster board, and a computer or router. While Wi-Fi might offer a maximum of 32 meters indoors (using a stock antenna), a class 2 Bluetooth device has to be within 10 meters of a computer.

Easy to use

No need for installing drivers or applications. It's a matter of having a wireless communication, and Internet.

Variables

For the website, it depends proper and effective use of user interface. For the chess players, it will depend on the amount of switches on the chess board.

It will also depend on the quality of the user manual.

Low cost

A rough and early estimate for the material to build the board is $480.01. Compare to the competition's (Digital Game Technologies) minimum of €509.00 for a non-wireless chess board, our product is much cheaper. Even after adding a markup to the price, our product is cheaper. Also, $480.01 is for the initial prototype. After the first board, improvements and mass-production will bring the price down.

Variables

Cost depends on many factors, however it will mostly depend on the price of the components and how many boards are produced. If the components are expensive so will the board. If thousands of boards are produced, the price for the components will be reduced, and therefore the product will be cheaper.

Real-Time

As soon as a player moves a chess piece, the move is published on a website. Everyone watching will see this move within 10 seconds.

Variables

Response time on the website will depend on:

1. Number of connections to the website (server load)
2. The bandwidth of the connection Boardcaster is using

Standards

IEEE 802.11 - Wi-Fi

The chessboard will be connected to the Internet through a Wi-Fi connection which is based on the IEEE 802.11 family of standards. Wi-Fi is regulated by country-specific regulators such as the FCC in the United States. If the product were to be exported local regulations would have to be considered.

HTML 5, CSS, and Javascript

The website broadcasting the games will make use of industry standards such as HTML 5 and CSS, as standardized by the World Wide Web Consortium. Javascript running on the client side will handle logic and some elements of the presentation layer. Javascript is standardized by the ECMA-262 standard by ECMA International.

Forsyth-Edward Notation (FEN)

Internal representation of the board state will be done in Forsyth-Edward Notation or FEN, a de-facto standard in chess software. This notation allows for convenient storage of a particular game state, including castling availability and half move clocks all in a single line of ASCII. As

the website server understands this notation the transfer of game state is simplified to the transfer of an ASCII string. Additionally, by utilizing a recognized notation such as FEN in plain text, we leave the door open to the modification community to adapt the board to other clients.

Impact and Other Related Issues

Social impact

ACM5PT strives to deliver an electronic chess board that will bring people together. Users will be able to easily watch chess matches, leave comments on them, vote for the games they like, and share it with friends. It also brings together chess tournaments, clubs, and organizations with the rest of the world. In this matter it levels the playing field, allowing anyone with ACM5PT's chess board to watch chess matches. Now it's not a matter of who has the money and human resources to organize a chess event.

Environmental issues

So far, all the selected electronic components that will be part of the chess board are compliant with the RoHS (Restriction of Hazardous Substances Directive) standard.
This means that the electronic components in the chess board will not contain any of the following hazardous materials: Lead, Mercury, Cadmium, Hexavalent chromium, Polybrominated biphenyls, or Polybrominated diphenyl ether. These six materials are hazardous to humans and the environment. It reduces damage to people in third-world countries, where most electronic trash ends. RoHS has also provided immediate health benefits to workers in the electronics industry.

Legal considerations

ACM5PT must watch to not violate any existing patents. Although research on similar solutions to this present proposal has been made, no relevant results turned up. Further and more comprehensive research would require more time, and perhaps legal guidance.

In the case patent violations occur, the design will be jeopardized; the group can be sued.

Scope

This project is divided in two parts: an electronic chess board and a website.

The electronic chess board will have sensors that detect chess pieces. Once a move is made, it will record and send that move to a server on the Internet. This shall be done using wireless communication.

The website will graphically display the moves made on the chess board. This will be watched by a web audience.

Commitments and Scope

Scope division is as follows:

The electronic chess board will:

- Recognize chess pieces on the chess board.
- Know chess rules, a LED will blink rapidly on the square where a piece has landed after an illegal move.
- Recognize a chess piece that has been lifted from the chess board.
- Light up LEDs that will show all legal positions on the board for a piece that has been lifted.
- Recognize a chess piece that has been placed on the chess board (Completion of a move.)
- Generate a FEN after each move, and stores it on memory.
- Sends the generated FEN to a server on the internet.
- Connect to the internet wirelessly, using Wi-Fi.
- Have a rechargeable lithium battery that provides 2200mAh.
- Be portable.
- Be open-hardware.

The server/website will:

- Have a database system.
- Have a web framework.
- Have a system of users and profiles.
- Receive data sent by the chess board.
- Show, graphically, a chess board that represents the current status of a chess match.
- Update, in real-time, the graphic chess board shown on the website.
- Have a search system for games.
- Allow replays of played games.
- Have a comments section on each game.
- Have votes/"Like" for every game
- Integrate with social networks like Facebook and Twitter.

Limitations

- No more than one Boardcaster chess board will be broadcasting a chess match to the server. (Maximum number of Boardcaster connections = 1)
- The chess board might not work properly for blitz chess matches, or really fast chess play.

Deadlines

- System Design - 2011-September-25
- Build System - 2011-October-01
- Chess Board - 2011-September-25
- Testing - 2011-November-01
- Website - 2011-October-31
- Testing
    - Individual Components - 2011-September-26
    - Integration - 2011-November-07

Project Management

To successfully meet the deadlines some technical and managerial approaches must be rigorously followed. Every team member will have access to an online mailing list and will be required to check the mailing list's emails at least once per day and reply if necessary. It's up to the relevant team member to send a message to said list if it's not possible to meet one of the deadlines due to circumstances beyond the team member's control such as: lack of Internet access, delays in required hardware component, weather, family issues, among others. This will ensure constant communication, even at times when it's difficult to physically meet.

Meetings

The team will have weekly meetings to discuss progress, modify the schedule if necessary and share concerns. If at some point the majority of the team feels one of the members is not progressing with the work load that has been assigned, the team should inform their project manager and corrective measures will be taken. The project manager will first attempt to talk with the member that's falling behind and determine if it is reasonable to distribute his or her workload among other members or if the person should be reported to the professors in charge of the course. A work load redistribution procedure will also occur if one of the team members leaves the project, hence it's encouraged that every team member is aware, at least in a high level, of all aspects of the project.

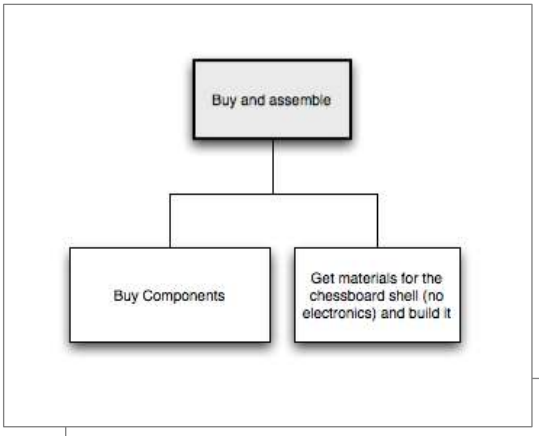
Team Organization

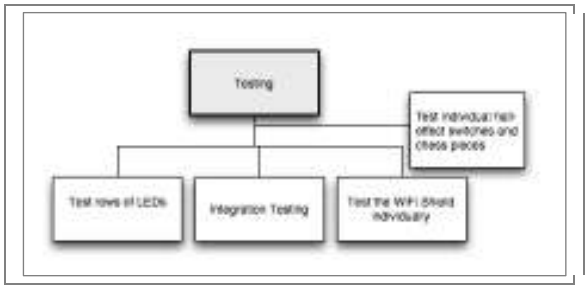
The team will be divided into sub-groups to deal with different aspects of the project. One will take lead with the website; one member will be in charge of setting up the server, configuring and creating the database schema, programming the web application and ensuring it operates as expected, internal testing will be performed when required. The next group will be working on the LED array, and both its pertaining hardware and software components. A third group will be working with the sensors that detect piece movement across the board, again this team will be involved in both software and hardware aspects of the task.

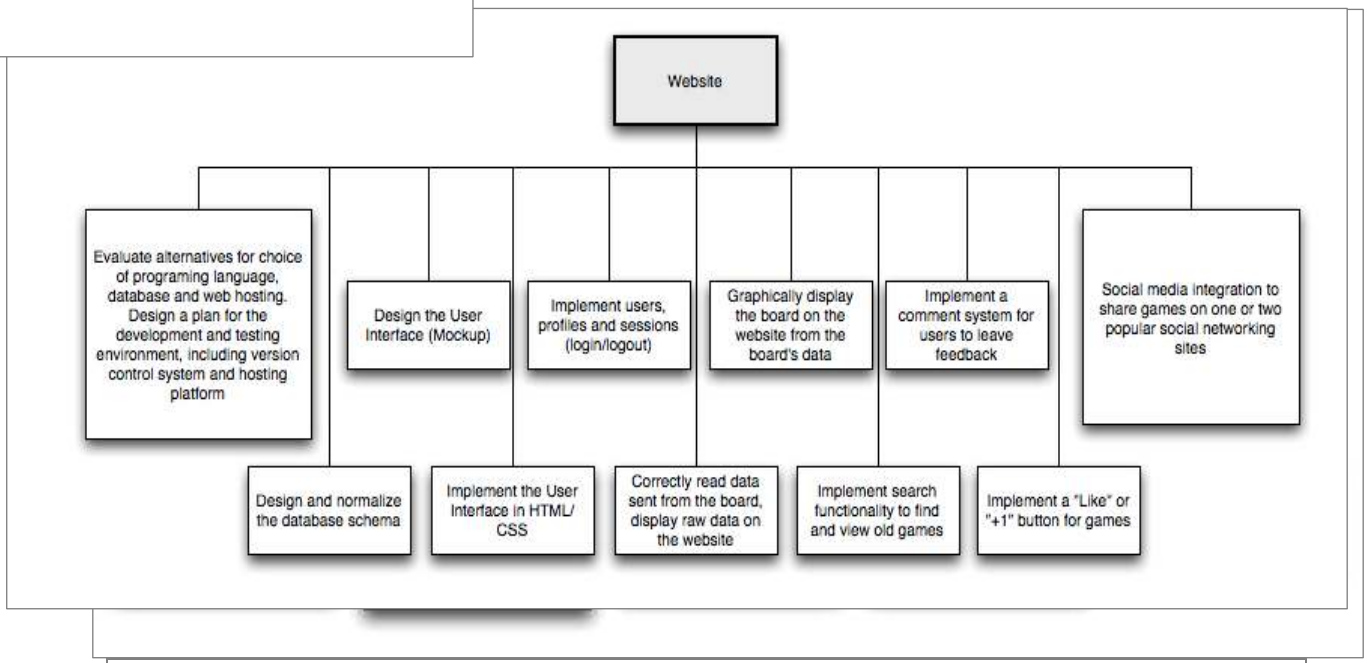
After the board is able to correctly determine the locations of the game pieces across its surface data the active task will switch to enabling data communication via a wireless link to the server. During the development process testing will be done on every hardware component individually to ensure it is working correctly. If necessary, calibration of the component-MCU process will be performed to ensure signaling with correct timing and magnitude. The group recognizes the importance of incremental integration and testing and as such individual and as-a-whole testing will take place to ensure effortless integration into the final product. In a parallel manner software will undergo testing to ensure quality by designing different test cases and exercising the code under them. An effort to develop modular and well documented code will be paramount to the team's efforts.

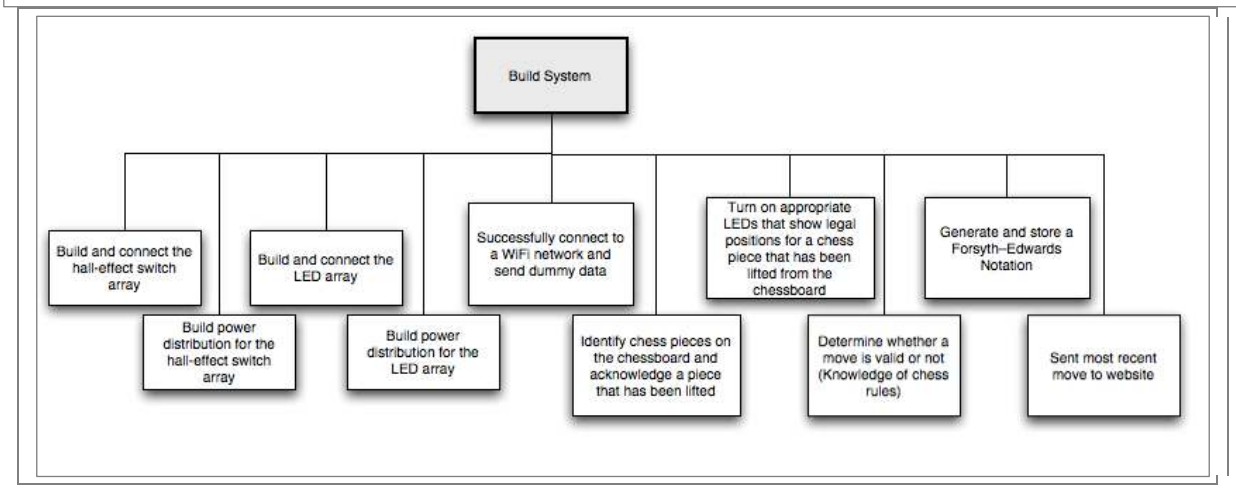
Schedule

Work Breakdown Structure



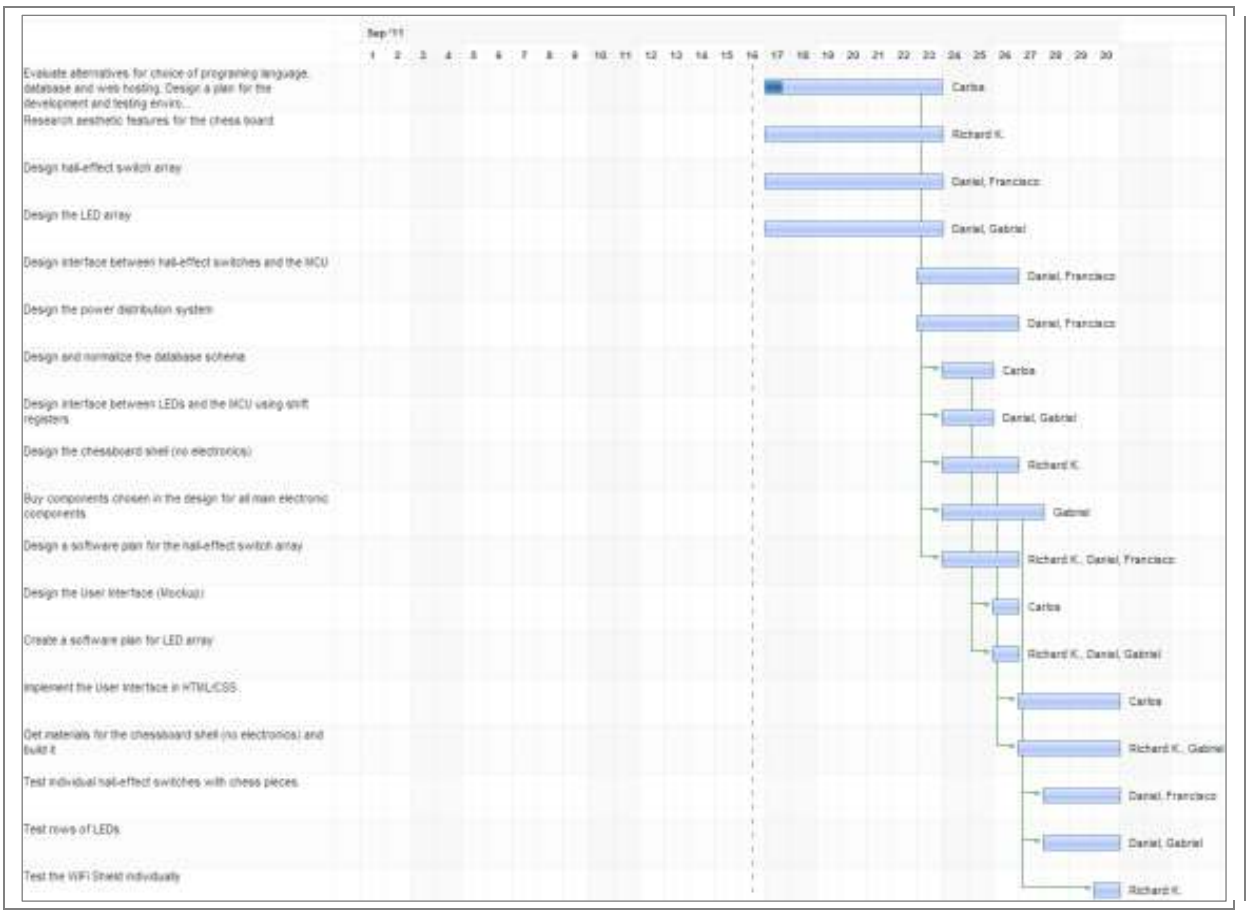


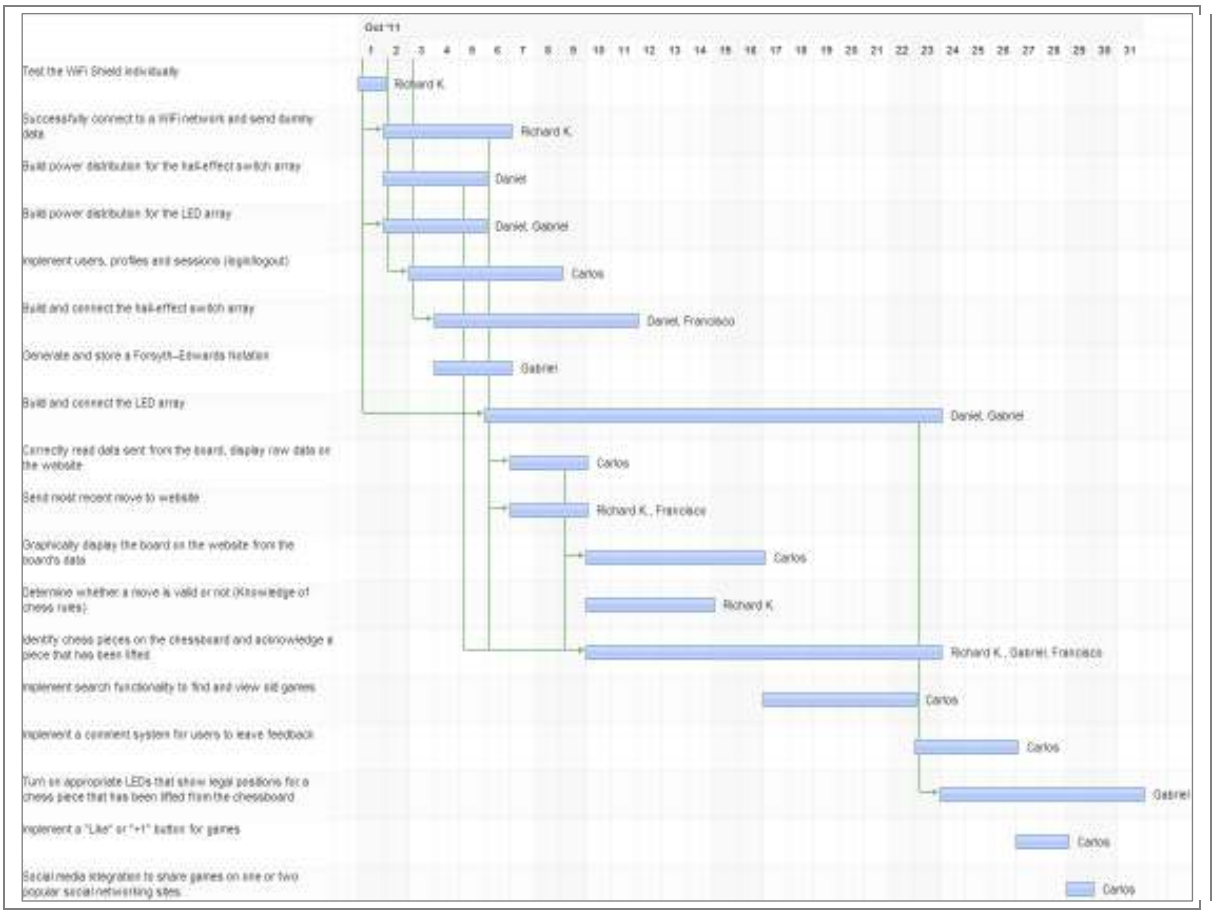


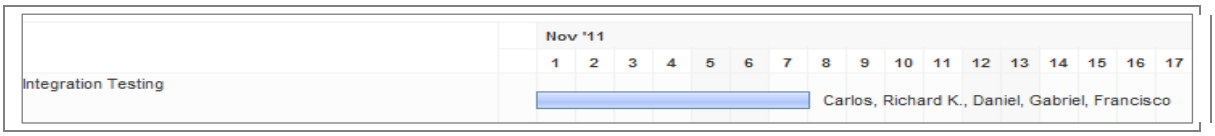


Gantt Chart

During the Critical Path analysis it was determined this was the most critical path for the project was: design hall-effect switch array, buy and wait for components, build and connect hall-effect switch array, identify chess pieces on the board and integration testing. If this path is successfully complete without delays two secondary critical paths appear. One for the LEDs including: design the LED array, buy and wait for components, build and connect LED switch array, identify chess pieces on the board, turn on appropriate LEDs on the board to show legal positions and integration testing. There's also one for the Website composed of: evaluate alternatives for choice of programming language, database and web hosting, design the DB schema, design the UI, implement the UI, create user profiles and sessions, read data from the board, display data on the website, find and view old games, comment system, like button, social media integration and integration testing.







Personnel

Necessary skills

To ensure effective and timely progress towards the project's goals the team will require a wide skill set. It's crucial to have members capable of understanding and tackling the hardware aspect of the design process, including but not limited to: reading data sheets, interconnecting different analog and digital components with a Micro Controller Unit (MCU). Also, the ability to do power analysis and the safe handling all electronic components with care is necessary. It is also critical for the team to have at its disposal knowledgeable software engineers; capable of designing software and databases in different programming languages, working under various programming paradigms and a proven ability to work with different platforms and environments.

Team Member	Relevant Skills	Tasks
Carlos Andreu	Experience with Linux, web servers (Apache), web development (PHP, JavaScript, HTML, CSS) and databases (MySQL), team leader in previous projects. Relevant projects 'Yet Another Professor Rating' (yapr.org) and enterar.me.	Web development and project management
Richard B. Kaufman-López	Wrote driver to interface LCD display with a Arduino Mega. Has experience with the C programming language. Has worked with wood and power tools.	Hardware and software for the sensors and wireless data transmission. Board and pieces construction.
Francisco De La Cruz	Has worked with many types of sensors including thermometers, sonars and GPS modules. Has also built interfaces for such sensors.	Hardware interfacing tasks and software for sensor interfacing.
Gabriel J. Perez Irizarry	Experience with Arduino, LED control and the game of Chess. Has written software for Arduino in C and assembly including additions to large existing code bases.	Hardware and software for the LED array.
Daniel Gonzalez	Has worked with and interfaced gyroscope sensors and has experience with different MCUs	Hardware and software for the LED array and sensors.

Legal requirements

NDAs and similar agreements will not be necessary, actually they would be counterintuitive and counterproductive, since our product will be Open-source Hardware and Free and Open Source software. No software patents will be claimed since the team believes software patents do far more harm than good and they are too expensive to obtain so they would rather expend the scarce resources they have in more innovation and development. Also patents would hurt the development of community projects based on our software. Hardware patents will not be pursued in the interest of further development by the community. Website components will be released under the GNU Afferro General Public License and Harware specification and documentation will be released under the Creative Commons BY-SA version 3.0. Copyrights will be held by all team members.

Consultancy resources

For the design of the game feedback will be requested from competitive and casual Chess players including players of the UPRM chess league and players who have played competitively in Puerto Rico and abroad. The group is confident that receiving input from actual potential users will improve the product design. In later phases they could serve as game testers for the intermediate and finished product order to fix potential flaws and improve consumer satisfaction.

For general product design and development consulting will be done with Tecnocaribe. Tecnocaribe organizes the biggest technology in education conference in the Caribbean. For this conference Tecnocaribe has developed various projects such as a social website for technology educators. With their industry experience they could help the team make better informed high level decisions pertaining to risks and maximum efficiency.

Budget and resource requirements

Accurate estimates of budget and resource requirements are of great importance to team as it greatly reduces the risk of going over budget. Projected resource use and component price analysis gives an approximate figure for non-human related costs. Realistic wages, benefits and additional human resource costs, taking into consideration experience and projected work hours, are included in the analysis.

Parts Description

● **LEDs** – LEDs will be placed on the board, one corresponding to each board position. The LEDs will illuminate when the player lifts a chess piece showing the valid moves of the lifted piece.

● **Hall-Effect Sensors** – These are the main sensing elements for the board. Each sensor responds in proportion to an applied magnetic field perpendicular to its surface [16]. The output voltage response can be used as an indicator of piece absence or availability. By keeping track of individual board location occupation and vacancy the MCU can know where each piece is.

● **Arduino Mega 2650** – This is the considered open source prototyping platform. The Arduino will operate the decoders and multiplexers in charge of hall-effect sensing of the parts, the Wi-Fi shield and corresponding LED array control mechanism. It will also process and keep track of board piece movement across the board and generate status FEN updates for transmission to the Boardcaster website.

● **Wi-Fi Shield** – This component connects with the Arduino Mega providing Wi-Fi (IEEE 802.11) connectivity to an existing wireless access point.

● **Router** – The router provides a gateway for the board's communication to the internet. The system's Wi-Fi Shield will connect to this device to access the internet and submit the required data. This is an optional component for the end user. In the case that the user can already provide for a router with wireless access point capabilities, such item is not required. *Note: This component is included for budgeting purposes to better represent a worst-case analysis.*

● **Multiplexer** – To reduce the amount of required inputs/ouputs on the Arduino Mega, multiplexers have been chosen. These 8 to 1 multiplexers allow the control of 1 whole rank of the board. A total of 8 multiplexers will be required to control the 8 ranks available on a complete game board.

● **Decoder** – A 3-to-8 decoder will be utilized to control the 8 multiplexers with 3 binary control lines.

● **Magnets**– These magnets will be retrofitted onto the existing chess pieces allowing them to be detected by the Hall-Effect sensors.

Preliminary non-electronic components such as screw, wood costs are also included. An additional technical and non-technical resource allocation chart is included showing projected use of Free and Open Source (FOSS) software and facilities available on-campus.

The Additional Resource table considers only projected necessary items. As the software utilized will be FOSS, budgeting for these is included in a descriptive manner. UPRM lab resource use includes the use of devices such as oscilloscopes, multimeters and the campus provided access to the Cadence's OrCAD suite.

Additional Resources Table

Resources	Provided on Campus?	Other
Oscilloscope	YES	
Multimeter	YES	
OrCAD License	YES	
Variable Power Supply	YES	
Compiler Suite		Free Open Source Software
Arduino SDK/IDE		Free Open Source Software

Hardware Components

To provide a buffer for risk management an overhead calculation is included as well. The overhead percentage is shown as the ratio of billable to non-billable hours. This shows an overhead estimate of about **179%.** Derivation of overhead percentage can be found in the appendix.

Component	Model Number	Unit Price	100-Unit Price	Quantity	Total
LEDs		$0.19	$0.19	64	$12.16
Hall-Effect Sensors	SS351AT	$1.91	$0.86	64	$55.04
Cables	PRT-08022	$2.50	N/A	1	$2.50
Solder tin	TOL-09325	$7.95	N/A	1	$7.95
Battery		$47.36	$47.36	1	$47.36
Arduino Mega 2560	DEV-09949	$58.95	50	1	$58.95
Router		$49.99	N/A	1	$49.99
Wifi Shield	WRL-09954	$89.95	$71.96	1	$89.95
Resistors	P1.0KBACT-ND	$0.09	$0.03	128	$11.52
Multiplexer	MAX4581CPE+-ND	$1.85	$0.90	8	$14.80
Decoder	568-1398-5-ND	$0.69	$0.44	1	$0.69
Magnet Square	COM-08644	$0.95	$0.76	32	$30.4

Hardware Totals

1 Unit Total	$405.66
100 Unit Total	$171.73
Subtotal	$405.66
Shipping	$50.00
Total Component Cost	$480.01

Overhead Considerations

Overhead Type	Hours per day
Seminars	0.71
Report Writing	0.95
Total Labor Hours	212.67
Average Wage	$49.47
Billable Dollars	$10,520.87
Non Billable Hours	1179.333333
Non Billable Dollars	$58,342.98
Overhead Expenses	$18,267.28
Adjusted Overhead (3.6% Inflation)	$18,924.91
Overhead	179.88%

Wages are taken from the United States Bureau of Labor Statistics. The *median wages* and annual salaries are chosen in an effort to present the most accurate budgeting calculations.

Team member experience and the amount of responsibility undertaken impact the hourly wage. For example, Architectural and Engineering Managers observe an hourly wage of $57.34 and an annual salary of $119,260 [10] while Computer Hardware Engineers can observe $47.50 and $98,810 [11]. Considering all members apply as junior engineers with no previous work experience then the wages are presented will be utilized.

Human Resources

Employee	Position	Annual Salary	Working Hours per Year	Hourly Wage	Project Hours	Payment per Contract
Carlos N. Andreu-Martínez	Project Manager, Web Developer	$119,260.00	$2,080.00	$57.34	$42.92	$2,460.88
Richard B. Kaufman-López	Computer HW Engineer	$98,810.00	$2,080.00	$47.50	$42.92	$2,038.91
Daniel A. González-Pérez	Computer HW Engineer	$98,810.00	$2,080.00	$47.50	$42.92	$2,038.91
Francisco De La Cruz-Sánchez	Computer HW Engineer	$98,810.00	$2,080.00	$47.50	$42.92	$2,038.91
Gabriel J. Pérez-Irizarry	Computer HW Engineer	$98,810.00	$2,080.00	$47.50	$42.92	$2,038.91

Employment Cost	$10,616.51
Additional Costs	
Social Security Rate (6.20%)	$3,291.12
Healthcare (1.3% of salary)	$796.24
Other Benefits	
Transportation	$2,320.00
Catering	$3,480.00
Parts	$480.01
Labor and Parts Subtotal	$20,983.88
Estimated Overhead (179%)	$58,729.62
Grand Total	$79,713.49

Total project working hours is estimated at 42.92 hours. This estimate is based on a total of approximate 2 month work and takes into consideration other team member responsibilities. The non-overhead labor and parts cost for the project is estimated at around $20,938.88 for a 5 member group working for the length of the project *(58 days)*. Part-only cost is estimated at $480.01. A detailed calculation of the project working hours is shown in the appendix.

Assessment Methods

To help manage the project and collect information on each member's individual progress on their tasks, it was decided to use Zoho Projects. This tool helps know which tasks are still to be done, and lets each user specify how much they have progressed. It is expected that each user states how much they believe they have progressed, since only the actual person working on it knows how much they still have left. The team will also have a repository where all code that has been written will be stored, so that progress can also be measured from the amount of code already written.

Risk Management

To attempt to minimize the effect of unexpected conditions, we decided to take into account several possible events that might occur that could put in risk that we can finish on time, and how we plan to mitigate the effect of these risks. In addition to what is specified below, we have also calculated an overhead for our budget to account for the case whether we have to order more parts that were damaged. We also will consider how these will affect our critical path, defined on the Schedule section, for each risk.

Risk	Probability	Impact	Mitigation Plan
Strike	Low	HIgh	To mitigate this risk, we will keep our software on a repository so that we can access it from anywhere, leaving us only having to deal with getting the hardware and its testing components. For this we will try to do the hardware as fast as possible to not have to worry to be physically in the university if there is a strike. This could affect our critical path if we are at the stage of building the sensor array, sincewe might need to test it using a variable power supply which we have in the lab, but we could still use it by providing the power from the microprocessor itself

			and the battery.
Hurricane and other weather conditions	Low	High	As with the strike, we can keep on working on the software remotely using the repository, so that if people cannot get to a particular place but have access to internet they can keep on working; we will also stick to our schedule to avoid delays as much as possible, minimizing the impact caused by any such weather conditions. The critical path is affected in the same way as with the strike.
A member leaves, gets sick or cannot work for any other reason	Low	High	We will have everyone be aware of what everyone else is doing and the status of their work, so that if someone has to leave, others can keep on working with it without much trouble. The status reports can be done on the mailing list set up for the group, so that if someone wants to know what has happened with that component, they can read the relevant emails. We also have several components that are worked on by several team members, mitigating the impact of one of the members leaving. The critical path could be affected if the person absent is working on one of these components, but since most of the components have two people working on it, it should not be much of a problem.
Pieces arrive late or are damaged	Low	High	We will order our parts as soon as our project is approved, so that they can get here as soon as possible, and we can deal with damaged pieces as fast as possible. We will also have spare parts for most of the components, mitigating the impact of pieces that get damaged. This does affect our critical path directly, since pieces arrival is part of this critical path; for this we should order the pieces as soon as possible to avoid delays as much as possible.

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Appendix A

Additional Components

Chessboard Components	Model Number	Unit Price	100-Unit Price	Quantity	Total
Screws	N/A	$4.43	N/A	1	$4.43
Wood	N/A	$12.97	N/A	1	$12.97
Chess Set	N/A	$6.95	$4.45	1	$6.95
				Chess Parts Total	**$24.35**

Appendix B

Overhead Calculation Detail

Overhead percentage calculation takes into account: paid wage, labor hours, and overhead expenses. The calculation of billable work hours does not include time taken in seminars, report writing, training and travel [12].

An additional 60% buffer is added overhead expenses to compensate for cost of shipping and replacement of damaged or faulty the electronic components.

The hourly wage utilized for the calculations is the average of all employee wages:

$$AverageWage = 57.34 + (47.50 * 4) = 49.468$$
$$HourlyWage = AverageWage$$

$$WorkDays = Days\{Sept\ 17,2011 \rightarrow Nov\ 14,2011\} = 58$$

$$CreditsOfCourse = 3\ Capstone\ Credits$$
$$RecommendedHoursPerCourse = CreditsOfCourse * 4/5$$
$$CapstoneHours = (RecommendedHoursPerCourse - Seminars - Report\ Writing)$$
$$CapstoneHours = \left(\frac{12}{5} - 0.71 - 0.95\right) = 0.74$$
$$LaborHours = WorkDays * CapstoneHours * Employees;$$
$$LaborHours = 58 * 0.74 * 5 = 214.6$$

$$BillableDollars = LaborHours * HourlyWage$$
$$BillableDollars = 214.6 * 49.468 = 10615.83$$

$$TotalAvailableHours = WorkDays * 24\ hours$$

$$NonBillableHours = TotalAvailableHours - LaborHours$$
$$NonBillableHours = 1392 - 214.6 = 1177.4$$

$$NonBillableDollars = NonBillableHours * HourlyWage$$
$$NonBillableDollars = 1177.4 * 49.468 = 58243.62$$

$$AverageYearlyExpenses[14] = 186{,}000$$
$$AverageBussinessExpenses = (AverageYearlyExpenses / 365) * WorkDays$$
$$AverageBussinessExpenses = 29556.16$$
$$OverheadExpenses = AverageBussinessExpenses - BillableDollars - (PartCosts * 60\%\ Part\ Damage\ Overhead)$$
$$OverheadExpenses[14] = (29556.16 - 10615.83 - (480.01 * 160\%)) = 18172.31$$
$$AdjustedOverheadExpenses = OverheadExpenses + 3.6\%\ inflation\ [13]$$
$$AdjustedOverheadExpenses = 18172.31 * 1.036 = 18826.52$$

$$Overhead = \left(\frac{AdjustedOverheadExpenses}{BillableDollars}\right) * 100$$

$$Overhead = \frac{18826.52}{10615.83} * 100 = 177.90\%$$

Appendix C

This top-down angle view makes it difficult to see exactly what is happening.