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**Proceedings of the 9<sup>th</sup> Winona Computer Science  
Undergraduate Research Symposium**

**April 22, 2009**

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# Symposium Schedule

Student Activity Center, Kryzsko Commons  
April 22, 2009

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# Efficient Splitting of Instructions for Code Compression

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## ABSTRACT

Use of embedded devices like smart phones, GPS navigation systems, pdf readers, mp3 players and others is vast and their demand is rising rapidly. Since these devices need to run multiple applications simultaneously as determined by the user, the availability of adequate free memory space in these devices is very important. The goal is to develop efficient programs for these devices that take little memory and run fast. One method for saving memory is to use *code compression* techniques before execution. This paper presents a *code compression* technique that can save memory space using *constant splitting* of the instruction before the program runs. This technique usually generates a smaller decoding table, and thus requires less memory space than the conventional approach of code compression. This paper also shows a comparative result of structured testing using a Benchmark named *MiBench* against the previous test results and shows that the new method would save 17-22% of memory space for those devices. The resultant decoding table and its logical representation is also presented.

## Categories and Subject Descriptors

B.3 [Hardware]: Memory Structures

## General Terms

Performance, Design

## Keywords

Code compression, splitting instructions, embedded system, Huffman coding, modified Huffman coding.

## 1. INTRODUCTION

Embedded systems are a combination of hardware and software where the software is enclosed (embedded) in a customized hardware [10]. The goal of designing an embedded system is to implement it in such a way that the memory can be utilized efficiently. In the case of memory usage, compiled code and its execution take a big portion of memory space. Therefore *code compression* has been a common research topic for the last several years. An embedded processor in an embedded system is highly constrained by cost, power and size. Thus code size has become a very important constraint for software designers targeting embedded applications [1,3]. While parameters such as speed and simplicity of decoding are important, the primary

metric for a good code compression algorithm is the **compression ratio**, shown in the following equation:

$$CR = \frac{\text{Compressed code size} + \text{Decoding table size}}{\text{Original code size}}$$

where size represents the total number of bits.

Previous work about code compression uses different compression techniques. Liu, Zhang and Cheng presented their idea about code size reduction without performance loss. They developed a *fine-grained mixed code generation* scheme that can switch between processor modes while executing operations and that leads to a better encoding without sacrificing the performance [11].

The goal of **Error! Contact not defined.** and **Error! Contact not defined.**'s code compression work was to reduce the size of the decoding table since traditional compression techniques take a large amount of space for the decoding table. They introduced the idea of *instruction splitting* for a better compression when using Huffman coding. Before compression they split each instruction using an algorithm (*Splitting algorithm*) in a different variable-length [1]. The algorithm finds the most repetitive patterns in each instruction and leads to much better frequencies for Huffman coding. The problem with this technique is that the lengths of the variables in the decoding table are different sizes resulting in a non-sparse decoding table. Such tables present challenges for designing the hardware support for decompression time.

## 2. CODE COMPRESSION

This paper focuses on reducing the size of code that is executed by a machine. There is a difference between data compression and code compression. In data compression we replace the frequent words with a shorter code words while code compression is expressing same code portion to represent the original copies [2,8]. Both compressions target reducing the original size and have a decompression technique. Overall compression efficiency measures take into account both compression and decompression complexity in terms of time and memory.

Computer programs are small enough to fit in memory. But in the case of embedded systems where memory is a concern and multiple applications need to be run simultaneously according to user demand, improvements in code compression can improve performance. When decompression happens, the system retrieves the original code segment from a lookup table (decoding table) and this table also needs to be stored in the memory. Therefore the idea of generating efficient code compression always demands a shorter decoding table. This

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paper describes an efficient splitting technique before applying the Huffman coding to achieve a shorter decoding table.

## 2.1 Using Huffman Coding

There are two kinds of compression methods: dictionary and statistical. The dictionary compression method uses fixed length codewords that act as indices for the dictionary table. On the other hand, statistical compression methods look at the entire program and replace the most frequently appeared text patterns with shorted codewords [4,6]. Compression techniques also can be divided into two different categories: lossless and lossy. The lossless compression technique allows the exact original data or code to be reconstructed from the compressed code after performing the decompression. The goal of lossless compression is to not lose any single bit, whereas the lossy compression technique retrieves an approximation of the original data to get a better compression ratio. Lossy compression is highly used for image and video compression where human eyes cannot detect any difference between the original data and the retrieved data after the decompression. But in the case of code compression, where a single bit change makes a big difference, lossless compression would be the only choice.

A good example of statistical compression is the Huffman encoding algorithm, which is a lossless data compression where efficiency is based on the frequency of encoding the source symbol. Instructions in a program that appear the most usually get the smallest encode, whereas instructions with the lowest frequency get the biggest encode. Thus, the efficiency of Huffman coding highly depends on the frequencies of these instructions. The idea of the splitting instruction technique increases the frequencies significantly.

## 2.2 Using Modified Huffman Coding

Since instructions with lower frequencies lead to longer size encodes, this paper uses a modified Huffman coding for code compression to focus on instructions with lower frequencies. In the case of modified Huffman coding, the instructions whose frequencies are really low will be grouped together and be given a name "Escape" to find the right Huffman coding [6]. Then those instructions will be initialized in such a way so that they can be identified uniquely. For example, if we have 4 instructions with low frequencies, those instructions will be given a name "Escape," and the Huffman coding (suppose: 11) for it will be assigned. Then a sequence of bits (00, 01, 10, 11) will be added after "11" to identify those newly formed encodes uniquely, as shown in Table 1.

**Table 1: Key concept about modified Huffman coding.**

Name			Huffman coding
Escape	11		
A	11	00	1100
B	11	01	1101
C	11	10	1110
D	11	11	1111

The main idea of using modified Huffman coding in code compression is to skip the compression algorithm for finding

encodes for low frequency instructions. A table will be generated to find out the right Huffman coding for low frequency instructions.

## 3. INSTRUCTION SPLITTING

**Error! Contact not defined.** and **Error! Contact not defined.** introduced the idea of Instruction Splitting in 2007. They showed that before performing the Huffman coding, if we split the instructions, the frequency of different types of instructions is increased resulting in good compressed codes with a shorter decoding table. For this technique, they determined how to split the instruction using a pattern-matching algorithm. In this paper, we researched splitting instructions using a constant pattern.

### 3.1 Pattern Machining Splitting

The splitting algorithm introduced by Talal and Jorg finds a unique pattern from all the instructions that appear in great numbers. The problem with this technique is that each instruction needs to go through the splitting algorithm to find the best pattern for splitting that generates the smallest compressed code, which in turn leads to a sparse or scattered decoding table where each item in the table doesn't have the same size. They have also applied *canonical Huffman coding* to improve sparseness [1].

### 3.2 Constant Splitting

Since we are concerned with the embedded system, we want an efficient technique for code compression that takes into account the manner of execution time as well as the memory usage. Based on the idea of splitting instructions but avoiding the Splitting Algorithm, this paper introduces the technique of constant splitting. First of all, if we know the best constant pattern for splitting, we don't need to go through the algorithm at all, and secondly, we can have a prior idea about the decoding table size. The constant splitting technique leads to a bigger size of compressed code compared to the splitting by the pattern matching technique, but it achieves a much more shorter decoding table and, as a result, the overall compression ratio improves. For example, if we split an instruction by 4 bits, at most only 16 different patterns of instruction would appear. So, the size of the decoding table would be at most  $16 * 4 = 64$  bits. This technique could be really helpful for a system as the system would know exactly how much memory space would be required to hold the decoding table. In this aspect, we have performed a structural testing that gives the best constant splitting pattern for different processor architectures.

## 4. RISC PROCESSOR ARCHITECHTURE

RISC (known as Reduced Instruction Set Computer) is a kind of a microprocessor architecture for embedded software systems that utilizes a small, highly-optimized set of instructions instead of a more specialized set of instructions often found in other types of processor architectures. RISC architectures simplify the CPU design and follow a strategy of "do less" to make instructions execute very quickly [3][5][7]. There are different types of RISC processors, which are based on architectural design and the need of use. Well-known RISC families are Alpha, ARC, ARM, AVR, and MIPS. Two types of RISC processors relevant to this research are ARM and MIPS. Both are highly used in embedded devices.

The ARM (Advanced RISC Machine) architecture was developed by ARM Limited. ARM is a 32-bit RISC processor

that is widely used in embedded systems [9]. We have used the ARM (version: SA-110) for the testing part of this research. MIPS (Microprocessor without Interlocked Pipeline Stages) is a RISC processor developed by MIPS technologies Inc [10]. The main difference between ARM and MIPS is the size of the instruction sets. ARM uses 32-bit instruction set whereas MIPS uses up to 64-bit [10].

## 5. COMPRESSION AND DECOMPRESSION USING CONSTANT SPLITTING

The idea of efficient splitting of instructions is focused on the technique of constant pattern for splitting. Figure 1 shows the compression technique using the Huffman coding without any splitting. Here the total compressed code size becomes only 45 bits whereas the original code size is 104 bits. But the size of the decoding table becomes very high (88 bits). Since the frequencies or repeating of each instruction is very low, the technique actually led to a poor compression ratio in this example.

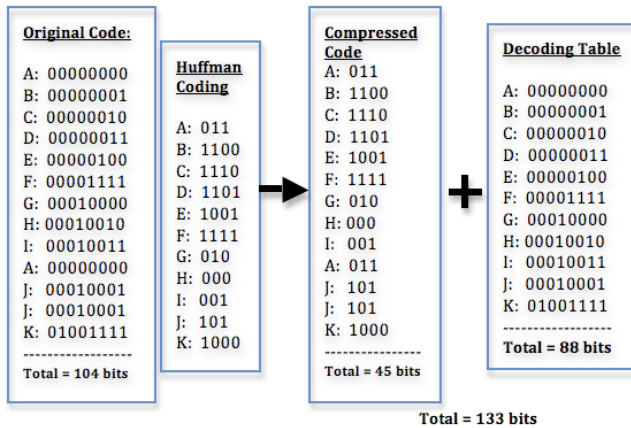


Figure 1: Code compression using Huffman coding without splitting.

Figure 2 shows an example of compressing the same set of instructions using the constant splitting technique and then using the modified Huffman coding. Here, we split each 8-bit instruction using a constant splitting factor of 4. The compressed code size becomes 58 bits, which is more than the previous technique, but due to having higher frequencies of each instruction, we achieve a much shorter decoding table (only 24 bits).

## 6. EXPERIMENTAL PROCEDURE

The key concept of this research was to do structural testing to come up with the right constant pattern for a fixed size instruction that would give the shortest decoding table as well as the best compression ratio. Using a constant pattern, it would also improve sparseness of decoding table. For testing purposed, an embedded benchmark suite, called *MiBench* (pronounced as “my Bench”) was used. *MiBench* is a free, commercially representative benchmark suite, which is targeted towards embedded system [5]. This benchmark contains 35 embedded

applications for benchmarking purpose, and among those we have chosen 8 applications considering their sizes (number of instruction).

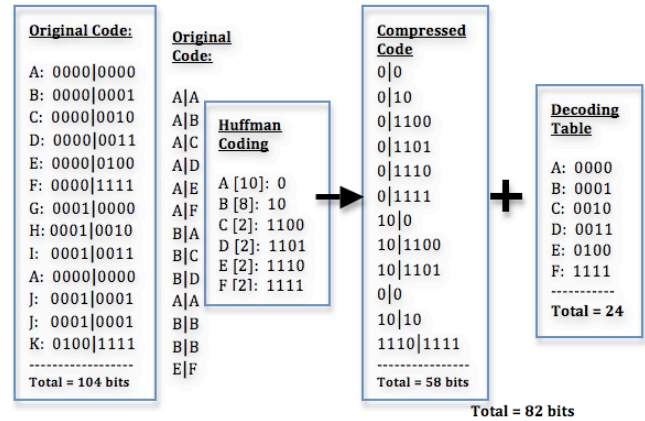


Figure 2: Code compression using Huffman coding with constant splitting.

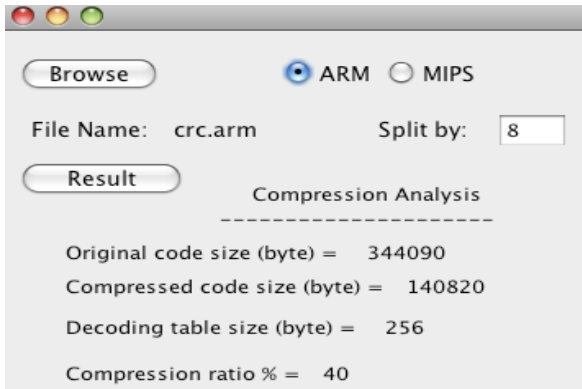
*MiBench* version 1.0 also provides the source codes (written in C) and sample output files of those applications. This benchmark contains several source codes ranging from a smaller sorting program (about 25 lines of C code) to much bigger programs (about 500 lines) of object recognition from an image. They have the C source code files, sample output files, and also the compiled binary files where each binary file contains text section, data sections and other sections for debugging purposes [5][13]. We have used those binary files for targeting the ARM and MIPS architecture. The main idea was to use this binary files and form different sizes of instructions. Here we were required to read those binary files, form instruction sets, split in a different constant pattern, apply the *modified Huffman coding*, and measure the size of compressed code, decoding table, and the original code. Figure 3 shows the basic procedure of this testing method.

<b>Step 1</b>	Binary files downloaded from “Mibench” embedded benchmark suit.
<b>Step 2</b>	Java program “readBinaryFile.java” reads binary files and extracts 0’s and 1’s; saves as Ascii in a text file.
<b>Step 3</b>	Java program reads that text file and forms instruction (32-bit or 64-bit) then applies different compression techniques: Huffman coding without splitting and with different constant splitting. It results: <ul style="list-style-type: none"> <li>• Total bits for all instruction (original code size)</li> <li>• Compressed code size.</li> <li>• Decoding table size</li> </ul>
<b>Step 4</b>	Calculate the compression ratio.

**Figure 3: Testing procedure for calculating compression ratio.**

The compression ratio was calculated from the equation shown earlier. Finally, the different compression ratios were compared and the best *constant splitting* technique for ARM and MIPS architectures was found.

For this whole process, we have generated our own application. Figure 4 shows the user interface to this program that reads the binary file extracting 0's and 1's, forms different sizes of instructions, splits those instructions based on the user's choice of constant patterns, applies Huffman coding, and calculates the compression ratio. This application is divided into three parts: reading binary files, forming instructions for two different RISC



**Figure 4: Testing Interface for calculating compression ratio.**

processor architectures, and applying modified Huffman coding followed by different constant splitting patterns. The size of the output files containing 0's and 1's were checked against the size of the input files to validate the reading binary file part. The integrity of the Huffman coding part was compared with a web application found from Kansas State University's website [12]. This web application (huffman.jar) reads any text file and gives the desired Huffman coding for each character presented in that file. Our java program that generates the Huffman coding read the same text file and gave the same output.

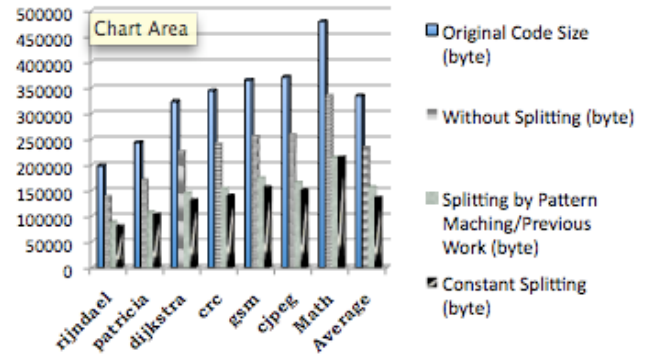
Different constant splitting patterns were used with the benchmark programs before applying the modified Huffman coding. The size of the compressed code was then added to the size of the decoding table, and the total size was divided by the original size of the instructions. Results from all the desired testing files were saved in an excel file and used to generate a graph. The purpose of this graph was to compare the results that were found in the previous work done with the same *Mibench* Benchmark.

## 7. RESULT ANALYSIS AND COMPARE WITH OTHER TECHNIQUES

In this section we analyze the results found from our structural testing. We chose 8 binary files among 25 from *MiBench* benchmark for the testing. The reasons for choosing these 8 files

were that they were different in sizes, and the exact same eight binary files were tested for the previous work about *code compression*. Our concern was to find the constant pattern for splitting that would give the best compression. We applied different constant splitting patterns: split by 4, 8, 16, 32 (only for MIPS processor) and found 8 was the best splitting factor. Splitting by 4, gave the shortest decoding table, but it also gave a bigger compressed code. Splitting by 16, gave the smallest compressed code size but led to a bigger decoding table since the average number of items in the decoding table was 18,517 and the size became  $(18,517 \times 16) = 296,272$  bits or 37,034 bytes. But if we split by 8, then the total number of items in the decoding table (i.e., different patterns after splitting) would not be more than 256 ( $2^8$ ), and the size of this table would not be more than 2,048 bits or 256 bytes. Splitting by 8 led to a bigger compressed code size compared with the splitting factor of 16 or 32 (only for MIPS processor), but overall it achieved the best compression ratio.

To show that constant splitting saves memory and gives a shorter table compared to other methods, we compared the compression ratios of the same set of binary instructions. We tested the benchmark files using 3 different compression techniques: conventional *Huffman coding*, splitting by pattern matching that was introduced in the previous work, and the *constant splitting* technique. The results were compared with the original instruction size. Figure 5 presents the final results of compression for the 8 different sets of applications for the ARM architecture, and Figure 6 presents the results for the MIPS architecture.



**Figure 5: Comparing the original instruction size with different compression techniques for ARM processor**

Compression ratios for the ARM files were between 43-49% for all 8 applications when *constant splitting* was applied, whereas the average ratio for splitting by pattern matching was 44% [1], and without the splitting was 71%. In the case of the MIPS architecture, compression ratios were between 45-51% for *constant splitting*, whereas 49% was the average ratio with splitting by pattern matching and 73% was the ration without splitting [1].



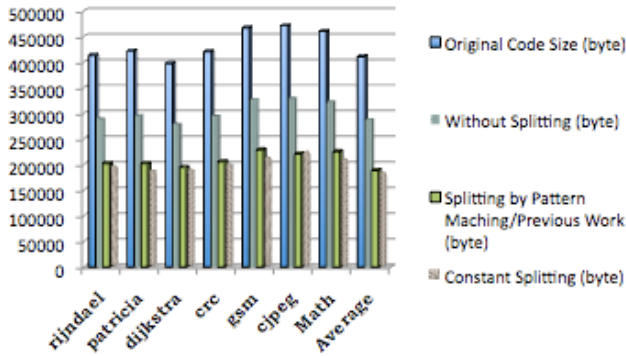


Figure 6: Comparing the original instruction size with different compression techniques for MIPS processor.

When *Huffman coding* without splitting was applied, the average decoding table size was 40% of the size of the code, and splitting by pattern matching was only 8% [1]. But in our *constant splitting* (factor 8), it was only 0.9% for ARM and 0.7% for MIPS.

From the structural testing procedure, it was observed that the size of the decoding table played a large role in the compression ratio calculation. Splitting the instruction before applying compression results in a much smaller decoding table when compared with traditional compression techniques. In the case of traditional compression technique, we need to enter all of the different instructions into the table and it takes a big portion of the memory space. Conversely, constant splitting leads to a consistent fixed sized decoding table, as shown in Figure 7.

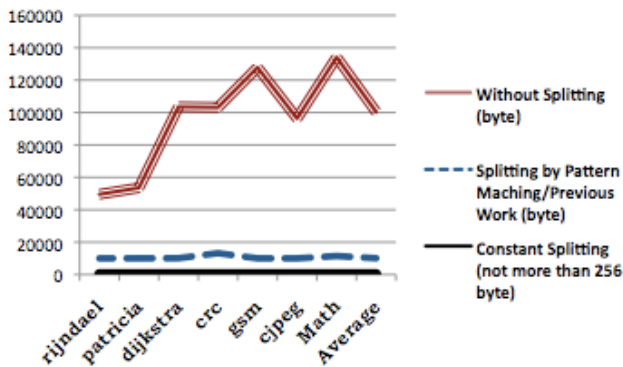


Figure 7: Showing the key idea of constant decoding table size (256 bytes)

Another approach observation of using constant splitting is that each splitting pattern in the decoding table is of a fixed sized but pattern matching leads to a sparse decoding table where each pattern does not have the same length. So hardware design for the decoding table and memory allocation would be complex.

## 8. CONCLUSION

We intended to have a research about *code compression*, and to this aspect, we utilized the idea of *constant splitting* of the

instructions for testing our hypothesis by performing adequate structural testing. From all the results, we can conclude that a *constant splitting* factor can reduce the total number of bits by at least as much as the pattern matching method, and this approach would generate the shortest decoding table among all other techniques to save memory space in embedded system to improve performance.

## 9. ACKNOWLEDGMENTS

Special thanks to Dr. Joan Francioni, Dr. **Error! Contact not defined.**, MiBench, Danish Shrestha, Jeff Ringenberg and Matthew Guthaus, Pratic Singh.

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# Usability Study of Web Forms on a Mobile Device

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## ABSTRACT

Mobile web browsing is becoming more popular as technology advances and handheld devices with web browsing capabilities become more easily available and less expensive. The ability to browse on these devices efficiently is becoming easier as standards are evolving, but understanding and completing forms on some of these devices can still be a challenge. For this project, we developed a specific form application for the Eagle Bluff Environmental Learning Center for inputting data about animals in their natural habitat that is accessible from a mobile device. Four different interfaces were developed and a usability study was conducted to compare them. Results show which design users felt was easier to use and understand, and the amount of time that it took users to complete specific tasks using the mobile forms compared to similar PC-based web forms.

## General Terms

Measurement, Documentation, Performance, Design  
Experimentation, Standardization, Languages.

## Keywords

Mobile Web browser, Mobile device, Web form.

## 11. Introduction

The availability of the internet on a mobile device has exploded in the last couple years and designers are faced with new challenges of creating a layout of a webpage that is easily accessible on a mobile device, as well as a desktop or laptop[5]. There are many studies about designing WebPages for a mobile device and strategies for browsing but there is relatively little documentation about designing web forms for a mobile device

Browsing on a mobile device can be a very confusing and unfriendly task. Filling out Web forms on a mobile device can be something that users refuse to do completely because it is often times hard to tell if you are filling out the correct form or to even know what the form is for [1,7].

Web forms on a mobile device are important to the field because the number of people browsing the internet on a mobile phone is growing at an exponential rate and currently it can be difficult to understand and follow some web forms that don't conform to a standard on a mobile device.

The challenges of designing these mobile Web pages can be a

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daunting task as well. The challenges of designing for the mobile Web are similar to those of designing for accessibility [7]. Now not only designing your Web page to render correctly on multiple browsers, you have to design it so that it renders correctly on a mobile device. This can be a challenge for several reasons including the screen size limitations, the different mobile browsers, and user's purposes of browsing on a mobile device. There have been efforts made to alleviate the screen size limitations including optimizing a web page once a mobile device has been detected, or to divide the page into several subpages [1]. The users' purposes of mobile browsing is something that has been studied and people using the Web tend to engage in open-minded exploratory behaviors, while mobile devices are usually intended to support task-specific use [5].

In this paper we will study four different designs of a web form and conduct a usability study on each of the designs on both a PC-based browser and a mobile browser. Each of these four interfaces will be able to process the same information; it is just presented in a different way. The form will be able to accept data from the user easily and accessibly and will process the information and ultimately store it in a database where users can access it at a later time.

## 12. Background

Eagle Bluff Environmental Learning Center currently has a system in use where an environmentalist conducts a survey three specific times a year by stopping at ten specific locations on their property and listens for the sounds of certain frogs and toads that live in our region. The environmentalist records for each species, whether there are any frogs or toads heard, a single or couple frogs or toads heard, or if there is a chorus of frogs and toads heard. At the end of the year when the survey has been conducted all three times, the environmentalist sends the records to the Department of Natural Resources (DNR) to be used for their purposes.

Our project was created for Eagle Bluff so that the environmentalist who listens for the frogs and toads can use a mobile device and enter the values into a system while conducting the survey. The DNR can retrieve these values at any time by accessing the database. The use of our Web application will eliminate the need for the environmentalist to have to send in the records at the end of every year. Our Web application will also make the data easily accessible any time of the year, even if the survey has not been conducted all three times, because it will be put directly into the database. By putting the data into the database directly, time is saved for the DNR as well because they do not have to have someone enter the data. This will increase productivity of computations and analysis of things which are done by the DNR.

### 13. Methods

What we did was developed a Web application with four different interfaces for the form and then conducted a usability study on each of them. The tools we used to develop this software were Adobe Dreamweaver as the IDE, Firefox, Internet Explorer 7, Google Chrome. Since we were unable to get a mobile device, for testing purposes we used the Opera Mini demo and the browser simulator for the Blackberry Pearl 8100 as our mobile device simulators. The languages we used to construct the Web forms were XHTML, CSS, PHP, and for the database we used MySQL.

#### 13.1 The Interfaces

The four interfaces that were used from a mobile perspective are depicted in figures 1.a through 1.d. These layouts are typical of what you see on the Internet today. In figure 1.a, there is a colored box that contains both the label and the input box. This colored box helps to correlate the label with the input box. Figure 1.b looks similar to figure 1.a except that there is no colored box to help distinguish which label goes with which input box. It is assumed that since the label and input box are both on the same horizontal line, the user should understand which label corresponds to which input box. This is not always the case though, especially when viewed on screens that are too small to display the label and box in the same view. Figure 1.c has the label so that it is very close to the left side of the input box no matter how long or short the label is. Figure 1.d has the label so it is right above the input box.

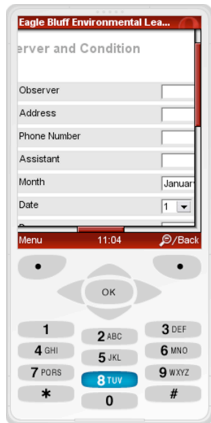


Figure 1.a LinearColor Layout

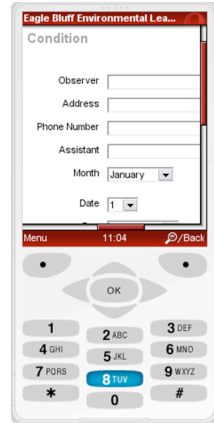


Figure 1.b Linear Layout

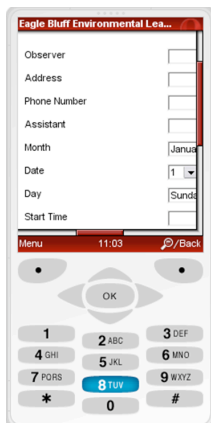


Figure 1.c LinearR Layout

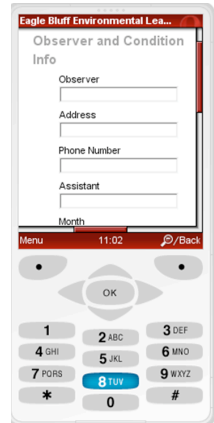


Figure 1.d Above Layout

We developed a web form that is accessible and functional, which includes supporting scripting, by most mobile Web browsers as well as PC-based browsers. The form accepts input from the user and stores the data into the database. The DNR or the environmentalists at the Eagle Bluff Environmental Learning Center are then able to manipulate the data in the database.

### 14. Results

To conduct our usability study we had 17 females and 21 males between the ages of 18 – 23 who were all high school graduates who were attending college for an undergraduate degree. We first had the participants complete a demographic questionnaire with some general questions about their age, race, education background, and number of years using the Internet. Each of the participants had stated that they had been using the internet for either 10 or 11 years, and they all stated that they use the Internet for things such as email, entertainment, games, sports, and research for school projects. None of the participants claimed to have browsed the Internet from a mobile device more than two times.

After completing the demographic questions, participants were timed while asked to perform four specific tasks on the Web application. Participants did this on all four of the different interfaces. Half of the females and half of the males performed the tasks on a PC-based browser while the other half of each gender performed the tasks on a mobile browser simulator. After each participant had completed all of the tasks, they were asked to complete another questionnaire which asked them what things could be improved on, things they liked or disliked, and which interface they thought was the easiest to complete.

The graph in figure 2.a shows the results for the PC-based browser. On average, users seem to complete the Above layout faster than any of the others for each of the four tasks, although not significantly faster. The results for the mobile browser are shown in figure 2.b. For each of the tasks, on average, users completed the LinearR layout the fastest, with the Above layout being the second fastest. The times for the Linear and LinearColor layout were very close and had no significant difference.

One possible reason why the LinearR layout was completed by participants the fastest could be because the label is justified so it is right next to the input box. With the Linear and LinearColor layouts, we noticed that participants had to do a lot of horizontal scrolling as between the label and the input box for some of the items as well vertical scrolling. In the LinearR and Above layouts, little or no horizontal scrolling was needed.

By observing the participants perform the tasks, it seems as though initially, it takes a user time to analyze the page once it loads, but once it has been loaded for a couple seconds they catch on quickly.

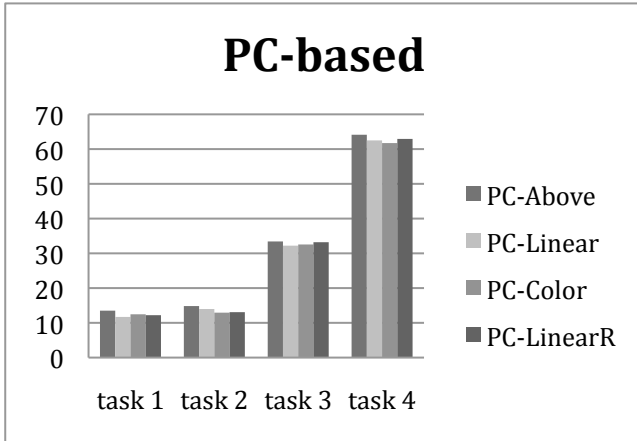


Figure 2.a PC-Based

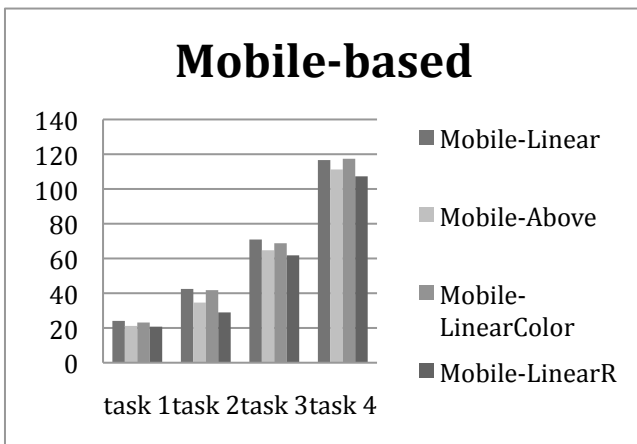


Figure 2.b Mobile-Based

## 15. Conclusion

As mobile browsing becomes more available and the price for mobile devices with these capabilities continues to decrease, it is apparent that Web developers should make their Web pages so that they are accessible to PC-based browsers as well as mobile browsers. It would take an enormous amount of time for developers to go back and update current Web pages so that they are more user friendly for a mobile browser, but the work that we have done will help developers of future Web pages create Web forms which are more user-friendly and faster for users to complete.

## 16. ACKNOWLEDGMENTS

Our thanks to Eagle Bluff Environmental Learning Center for allowing us to implement this project into their system.

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# AutoCompose: Music Generating Kernel

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## ABSTRACT

Software for music composition is abundant in the market place. Most of this software is tailored for musicians or those trained in musical notations to compose musical pieces. Although music can be composed this way, another approach to music composition can be viewed as a simple process of combining basic and elementary characteristics that is inherent in all intelligent activities. These simple but elementary pieces can then subsequently be aggregated into larger musical structures that can be appealing as well as be aesthetically pleasing. We use this approach of basic musical units of measures to design and implement a simple core music generating kernel. The Model-View-Controller paradigm was used to develop this system. We utilize a set of software tools to make the kernel flexible in terms of notes, beats, and scales. The JFugue library was used as the music playback tool. Our software is web-compatible and can be used to extend as well as collect composition pertinent data for further analysis of musical structures.

## Categories and Subject Descriptors

**Design Pattern:** Paradigm - *Model-View-Controller*.

## General Terms

Software Design, Verification, Experimentation.

## Keywords

Computer Music, Artificial Intelligence, Event Driven Architecture,

## 1. INTRODUCTION

Music has always been a part of the human nature. Whether preserved through artists playing musical instruments or vocally transferred from generation to generation, it served as entertainment and the way for people to express themselves. Although not many of us are capable of composing music using musical notations, many of us enjoy listening to it. Analogously, there are people who cannot write or read, however, they can understand when being spoken to.

So far, the market has offered software solutions that are tailored to individuals who understand how to read and write conventional musical notations [4]. Our goal was to design and implement an

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environment that will interest those who would want to create their own music without necessarily understanding the conventional notations.

The core elements of the environment were borrowed from [2], whereas the structural architecture was devised and implemented by the author. We intended to make this environment flexible and adaptive to a different variety of concepts such as notes, beats, scales, and instruments.

At the moment, the environment in question is capable of producing only simple chants. However, the established architecture could be further developed to create more complex musical compositions.

## 2. MOTIVATIONS AND HYPOTHESIS

With the development of computing hardware and the introduction of new programming languages and paradigms, computing is becoming more ubiquitous with every year. Consequently, a lot of opportunities have opened up for artificial intelligence (AI) and in other areas as well, to utilize computing power to explore and develop applications there were not possible earlier. One of such areas is the world of musical composition.

According to Roads [9], AI falls into two broad categories: a scientific side (also known as cognitive science), devoted to the development of theories of human intelligence, and an engineering side (also known as applied AI), devoted to the development of programs that exhibit intelligent behavior, whether of human or nonhuman quality. Our approach is more relevant to the applied AI. It could also be described as a generative approach to music theory as defined in [9].

Roads also notes that programs that generate musical scores have at least three goals: scientific verification of music theory, producing an object of aesthetic interest, and recreational value (also known as fun). Our motivation was to satisfy two of the abovementioned goals: original composition and recreational value. However, in addition, our intent was to also develop an environment that would allow an individual with a non-musical background to exercise his/her creativity and enjoy the overall process.

We also hope that by allowing the “average” person to interact with the application, we will be able to gather information based on the established set of the application constraints. We will then be able to develop an application that will learn from observation and discovery of these constraints and imitate human intelligence via music composition.

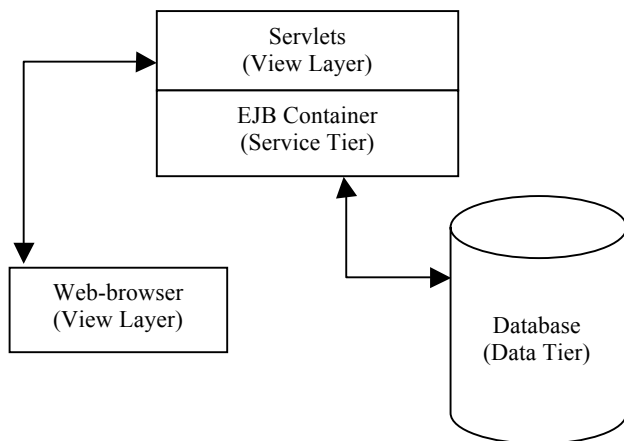
## 3. SOFTWARE ARCHITECTURE

AutoCompose has been implemented based on the Model-View-Controller (MVC) paradigm as shown in Figure 1. The MVC

paradigm was introduced with Smalltalk-80. It is frequently presented as a development environment requiring the programmer to separate application into three categories of objects to develop their systems: models, views and controllers. Models are responsible for handling data related operations. This includes retrieving data from data source, fetching it to the requesting object (most likely controller), and storing it back to the data source when requested. Views are responsible for presenting the data to the user. This would include rendering data on some sort of interface (e.g., a graphical user interface or GUI) and passing users' input to the controller. Controllers are responsible for processing of users' input and updating of the model and view appropriately. This layer would contain core logic that drives the application. Hansen [1] states that

“This approach nicely separates three basic concerns of the system, thus promoting code maintenance and reuse. Each application, however, has subtle issues that must be thought through and addressed. The central problem is that the inherent coupling among the model, the views and the controllers. The way that coupling is realized in an implementation has a profound impact on how easy the code is to develop, maintain and reuse.”

Although the MVC paradigm was originally designed for a one-tier environment, we have extended this paradigm to a three-tier architectural framework. This approach works out the best as it provides at least three major benefits: ease of user-interface extensibility, clear separation between controller and presentation



layers, and data collection.

Figure 1. Model-View-Controller

### 3.1 View Layer

In essence, AutoCompose is a web application. Therefore, no special installation is required on behalf of the user. In order to work with the application a web browser with a plug-in capable of playing .midi files is required. It is important to note that the requirements of AutoCompose are satisfied by default, as most of the operating systems nowadays come with both of the software components pre-installed.

Availability of the user interface via web browser enables the possibility of using Cascading Style Sheets technology. Because the separation of the view layer development, modifications to this layer can be carried out without major changes to the controller layer. As the result, the application can satisfy creativity needs not only of those who do not know how to read music, but also for those who are visually impaired.

The view layer was developed using Java Server Faces (JSF) technology. As defined in [3], this technology is a server-side user interface component framework for Java™ technology-based web applications that offers two main components. The first component is an API that is capable of the following:

- representing UI components and managing their state
- handling events
- server-side validation and data conversion
- defining page navigation
- supporting internationalization and accessibility
- providing extensibility for all these features.

The second component is the capability to bind widgets in the web browser to the back-end objects on the server, thus allowing one to easily manipulate states of the widgets based on the actions of the user via AJAX technology without the burden of writing JavaScript code [7].

Every .jspx file is “bound” to a backing-bean, which is a traditional Java™ file, following a convention of Java Beans technology, with methods and back-end objects that represent widgets on the screen. Backing beans fundamentally represent an interface between the view and the service tiers (or controllers).

### 3.2 Service Tier

The Service Tier was implemented in J2EE environment utilizing IBM’s Rational Software Architect IDE. The tier was separated into two major pieces: Enterprise Java Beans (EJBs) and traditional Java™ classes.

#### 3.2.1 Entity Java Beans (EJBs)

EJBs represent entities within the application that could be mapped to the relational database tables. In fact, EJBs represent the layer that connects J2EE environment to the database. “Conventional” Java™ objects could have been utilized; however, that would require to manage persistence and, potentially, concurrent access to the same representation of the entity. EJBs alleviated this burden and allowed to concentrate on the functionality aspects of the entities, instead of the side effects associated with the technology chosen.

#### 3.2.2 Conventional Java™ Classes

Conventional Java™ classes were used as utility classes. One example of their use is the transformation of the user-chosen criteria into .midi music file. We deemed it necessary to have an instance of the utility class per user session, in order to avoid dealing with concurrency access of the threads that could lead to the unpredictable and undesirable behavior.

Music composition is delivered to the client in the form of a .midi file. The MIDI format originated in 1982 [6]. Due to its long history and success, virtually every computer is supplied with a

web browser that contains an application capable of playing it. This is what alleviates requirements on behalf of the clients to download any special plug-ins to listen to the musical pieces that they compose. Generation of music in .midi format has become possible because of an open-source library called JFugue. JFugue is an API for the Programming Music in Java™ programming language that can render music in the Java™ platform MIDI [5]. To generate .midi files, we use settings defined by the user via the view layer. We are not storing .midi files in the database, as we can regenerate them if the user wants to listen to the composition again in the future. This will offer storage efficiency with more complex compositions.

### 3.3 Data Tier and Data Collection

Along with the delivery of the user-friendly web-based application, one of the other main objectives of the application is to gather data that will help to define music that users consider aesthetically pleasing. It is intended to analyze such data for verifying and validating cognitive primitives. Data collection is accomplished through the data tier in our application as shown in Figure 1. The backbone of the data-tier is open-source Relational Database Management System MySQL. We chose MySQL because of its ability to maintain referential integrity constraints between tables, primary key constraints for uniqueness, and “indexing” of the tables for faster data retrieval.

The main challenge in development of this layer was the creation of the proper internal representations for the musical domain under consideration [8]. To overcome this challenge, we have used the methodology proposed by Iyengar [2] and defined a set of constraints based on the following:

1. Measure: A record that contains a user-defined set of values based on the constraints.
2. Note Scale: One of the constraints defining range and sequence of the notes in the scale.
3. Note Sequence: Settings related to sequential progression over the note scale.
4. Beat Sequence: Various combinations of possible beat durations grouped by amount of notes.

These representations serve as the basis for the data tier development and have been mapped into the relational database. In addition to the abovementioned constraints, after further analysis, we have added measure group and users tables. Relations between the tables could be observed in the ER Diagram shown in Figure 2.

### 4. BASIC USE CASE

In order for users to be able to work with AutoCompose, they have to be registered with the system.

1. A user provides credentials. If the credentials are correct then control is transferred to the Measure Group Manager.
2. In the Measure Group Manager, the user can create additional groups and delete or edit existing ones. By clicking on the desired group name, control is transferred to the Measure Manager.
3. In the Measure Manager, the user is able to create “measures” and delete or edit existing ones. Measure is identified as a combination of a sequence number, the

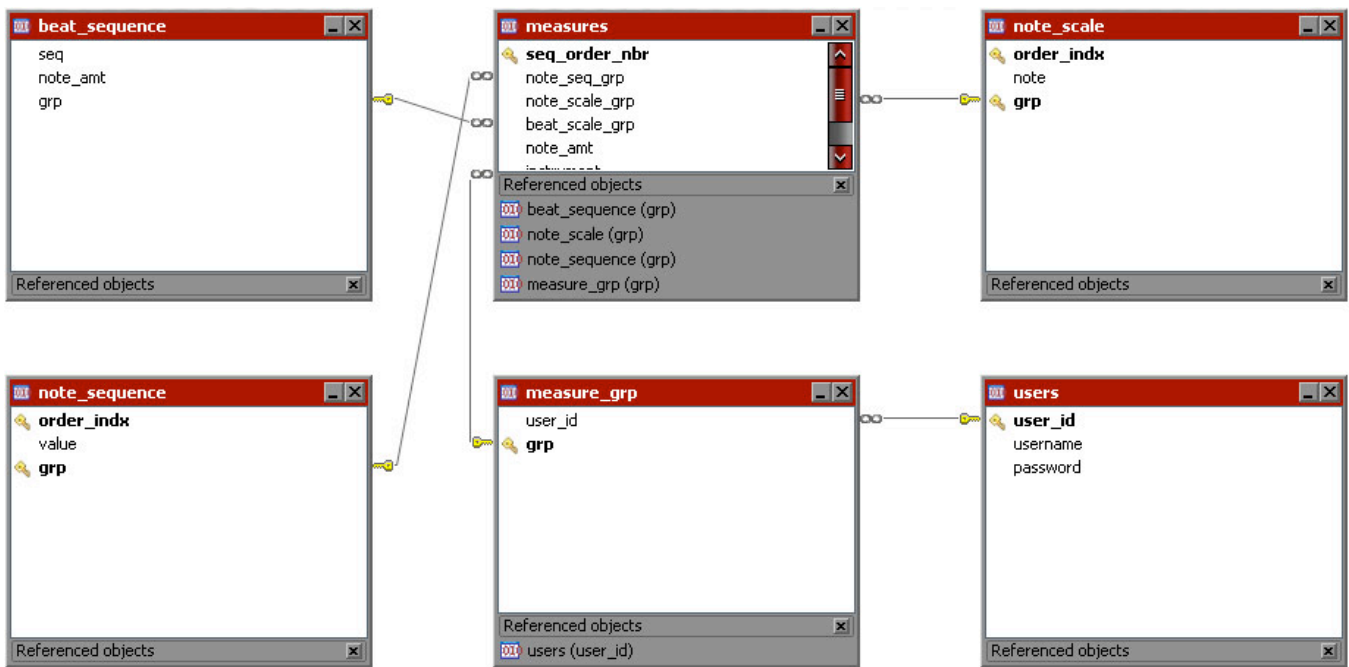


Figure 2. Entity-Relationship Diagram

note sequence group, the beat sequence group, the note amount, and the instrument. Clicking “Edit” transfers control to the Measure Editor.

4. In the Measure Editor, desired settings via the provided set of controls can be modified. Clicking “Back” returns control to the Measure Manager.

5. Clicking “Compose” will generate musical composition based on the defined settings and causes a new window to pop-up with a player plug-in capable of playing .midi files.

See Figures 3-7 for a visual illustration of this process.

## 5. DISCUSSION

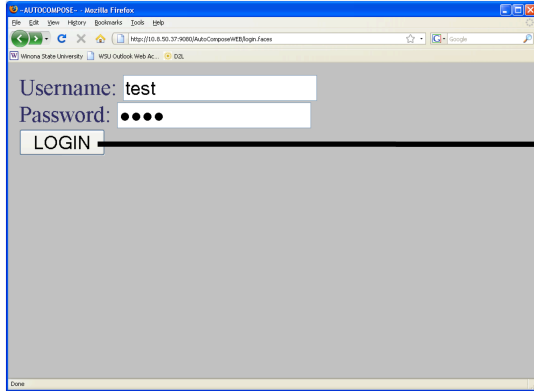


Figure 3. Login page of the application

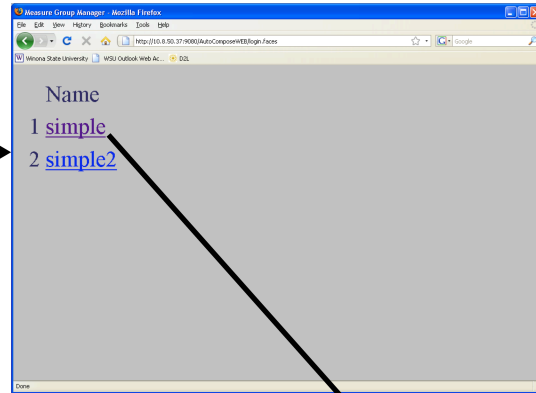


Figure 4. Measure Group Manager page

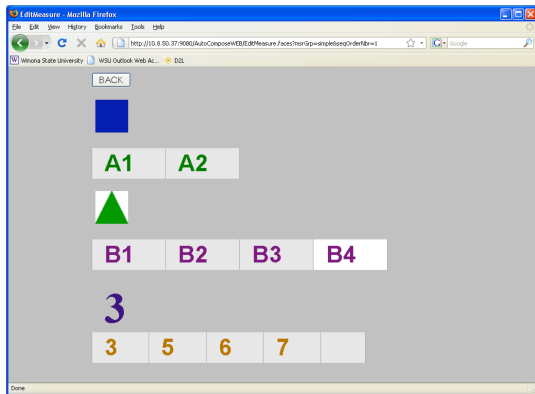


Figure 5. Measure Editor page

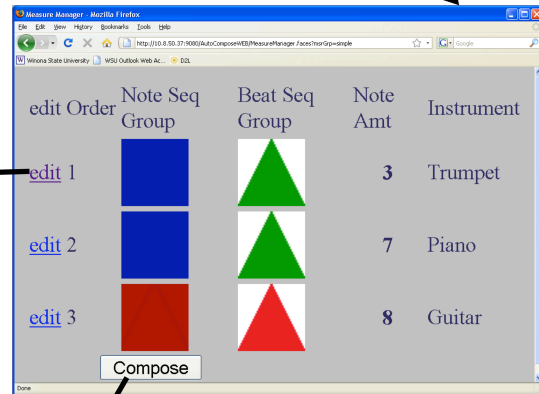


Figure 6. Measure Manager page

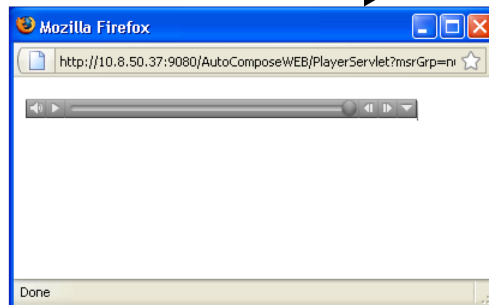


Figure 7. Built-in music player. It could vary based on the plug-in of the client capable player .MIDI files



As a prototype product, AutoCompose has met the expectations from the perspectives of ease of maintenance, extensibility, flexibility, and data collection for verification and validation of cognitive primitives. The foundation of the framework is established, however, the current release is still a prototype and requires more development time and effort. Future development of AutoCompose needs to concentrate in two different areas. First of all, we need to improve the “skin” of the application to make it more appealing and pleasing to the eye and complement current set of features with primitive functionality such as addition and deletion of measures and measure groups. Secondly, we need to develop a module for data analysis and management of the internal constraints. No load testing was performed to determine average response time of the application. Due to on-demand generation of .midi files, this testing would prove to be beneficial in determining lag times. Despite this, the product is ready to be deployed for a small set of users, and can be iteratively re-deployed as new functionalities and features are added.

## 6. ACKNOWLEDGMENTS

I would like to express my gratitude to my advisor and supervisor, Dr. Sudharsan Iyengar, for his support, guidance, and expertise during the development of the project. This study was performed as part of an undergraduate capstone research project at Winona State University.

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# Including Children in Participatory Design of a User Interface: Feedback and Analysis

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## ABSTRACT

This paper addresses the inclusion of children in the participatory design process of a web interface for displaying gathered real-time environmental data and how this affects the design of the final product. This participatory design involves the use of low-fidelity prototypes that are presented to the user. Both children and adults are identified as user types of this interface and so both were considered in the design process. The web interface in question is part of a real website for the Eagle Bluff Environmental Center and was tested on students on-site. An analysis of the differences between feedback from children and feedback from adults is presented as well as a discussion on how these may be implemented to meet the needs of both user types.

## Categories and Subject Descriptors

[HCI]: Participatory Design and Usability – *participatory design, low-fidelity prototype, task scenarios.*

## General Terms

Documentation, Design, Experimentation, Human Factors.

## Keywords

Participatory Design, Low-Fidelity Prototype, Children.

## 1. INTRODUCTION

The project associated with this study is one that was requested by the staff of the Eagle Bluff Environmental Learning Center. They are a nonprofit organization dedicated to making a difference by “connecting individuals to nature through education” [2]. The center is located just outside of Lanesboro, MN. They specialize in a number of educational programs throughout the year for adults as well as K-12 students.

Eagle Bluff currently has instruments that measure weather, river, wind power, and other environmental data. Their goal was to put this real-time data on their website so anyone could access it. The first requirement of the project was retrieving the data from the respective monitoring stations. Making the data available to a web server and displaying it on the web was the next step. However,

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the focus of this research project is about the participatory design of the website.

The website will be used by both children that visit the center to learn about the environment as well as adults, such as teachers. Since these two types of users were to be considered for the design, conducting a participatory design of the web interface was the next logical step. Participatory design involves the “direct participation of those who will be affected by the development of a particular computer application in the decision-making, design and/or development process” [10], which will be discussed in more detail later.

Including children in the design process, if children are end-users, has been overlooked by many companies, resulting in a product of lesser quality [6]. It is important then to consider the ideas of children if a satisfactory end result is to occur. In one case, success was achieved when children were involved in the design process of a PDA storyboarding program, through the use of paper prototypes. In this paper, it was concluded that involving children in the design process was helpful in generating new ideas, but was not as “clear cut” as they had first expected [7]. Another paper reconfirms this claim, saying that adult designers can learn something from children participants, which was illustrated by the amount of creativity and unexpected effects that resulted in the design process [5].

Low-fidelity prototypes such as paper prototypes are generally quicker and easier to make than electronic ones. Not only this, but they are more portable and error-free. These prototypes tend to be simple and can be changed easily. In a study comparing low and high-fidelity prototypes, the results supported a claim that the quality and amount of feedback given in a participatory design is generally the same between high and low-fidelity prototypes [9], suggesting that either one is useful.

Designing content on the web for children can be difficult, especially when the site is also meant for adults. In a learning situation, children must be kept engaged [4] and this will be likely to have a significant effect on the design. Both types of users will have to be taken into account for the final implementation. This means that an analysis on the feedback from these user types is crucial and a happy medium must be achieved for further implementations.

The goals of this research are to: 1) get an idea of a satisfactory user interface which will be useful, educational, and engaging to children by measuring user feedback through participatory design and 2) establish the differences in feedback from child and adult user types.

## 2. BACKGROUND

### 2.1 Participatory Design

The basis of the research, as mentioned earlier, is the participatory design aspect. Participatory design is a way for designers to involve representative users in the design process to determine requirements, gain feedback, and improve the design early on. An alternative definition is “an approach to the assessment, design, and development of technological and organizational systems that places a premium on the active involvement of workplace practitioners (usually potential or current users of the system) in design and decision-making processes” [1].

Why do we use participatory design? “Participatory design sessions are useful for producing design ideas at the beginning of the process and anytime new features need to be added, or new solutions need to be developed” [3]. Douglas Schuler and Aki Namioka say it best in their book on participatory design: “The most basic motivation is the idea of democracy. To be more concrete: People who are affected by a decision or event should have an opportunity to influence it”...”The other compelling idea is that quality can improve with strong and effective participation of the people involved” [8].

When designing technology that children will use, it is a good idea to consider including them in a participatory design. Dr. Juan Pablo Hourcade of the University of Iowa writes, “The advantage of children joining as design partners is that they will provide more input into the design process which is likely to result in technologies that better address their needs, interests, and abilities” [3].

### 2.2 Low-Fidelity Prototypes

Low-fidelity prototypes represent the “visualization of ideas at very early stages of the design process” [9]. They are used in design as a quick and easy way to form a prototype that is not necessarily close to what the final product will look like. The main difference between low-fidelity and high-fidelity prototypes is the notion that low-fidelity prototypes are composed of materials such as paper or generally anything else that can be used to represent the early design [3].

In website design, low-fidelity prototypes can be achieved rather easily. Paper mock-ups of the web pages can be used to represent what the user sees when they are browsing the site. Basic layouts can be achieved with pertinent information and clickable items such as buttons that will be quite close to what can be created in an actual web page. This approach was used in the creation of the low-fidelity prototype for the website, as will be discussed later.

## 3. HYPOTHESIS

Involving children in the design process will yield an increased amount of feedback on the design of a web interface than there would be if only adults were involved.

## 4. METHODOLOGY

When starting the project, task scenarios and initial requirements were gathered from the client. These aspects were then used to create a low-fidelity prototype for use in the participatory design. An analysis of the results follow and are presented.

The study itself is survey-based. A participatory design was implemented entailing a low-fidelity prototype (paper) of the web

interface to be presented to a user. In testing the navigation a facilitator was used to administer tasks and an observer to observe the user and collect data. Based on the client’s requirements, task scenarios were used to determine the tasks the user must go through. Users were able to provide feedback using a questionnaire on the ease of use of the interface, what they like about the interface, their interest level of the material, the overall “rating” of the interface, what could make it better and/or what features they would like.

### 4.1 Initial Requirements

Before a proper design for the web interface could be developed, some initial requirements were gathered from staff members at Eagle Bluff. The general goal was to create a web interface that would 1.) display the real-time data, 2.) be easy-to-use, and 3.) be accessible to a broad range of users. One of the possible extras was to be able to download data directly from the website, which was also included in the design.

### 4.2 User Types & Task Scenarios

From the start, the ultimate goal of the project was to make all of the real-time data available to all kinds of people by putting it on the website. This meant that the website should be accessible. Beyond this, there were more specific user types that were identified which were likely to use the website on a regular basis.

Task scenarios were also developed from these user types. Task scenarios basically represent common, everyday scenarios in which users will perform tasks on the website. Task scenarios can be described using step-by-step procedures on how a user will perform a certain task.

The first user type identified was a DNR employee. The environmental data from Eagle Bluff’s monitoring stations would be useful information to the DNR and making it available on the website would make it easier for them to access it. The second user type identified was a teacher. Since the data would be used as an educational tool, teachers are likely to use the website to teach students about the environment and about different types of measurements. Finally, the third user type identified (and most important to the research) was a student. Eagle Bluff has educational programs for students from K-12 and many of these students would be using the website for educational purposes as well. It was made clear by an Eagle Bluff staff member that their focus is on grades 4 through 8, which gave a more specific perspective on this user type.

Before the prototype or survey was created, task scenarios were first established. The core of these tasks focused on a few basic goals: 1.) Users finding the data they are looking for; 2.) Users being able to download data; 3.) Users being able to navigate between pages easily as well as find the home page. The prototype was created with these goals in mind as well as more specific tasks being developed for the participatory design.

### 4.3 Prototype

To get a general feel for what the staff of Eagle Bluff wanted in the design of the website, I was given an example from another environmental center called Wolf Ridge. Wolf Ridge’s renewable energy website contains a home page that has image links directing to other pages representing each form of renewable energy they have. The various renewable energy pages contain real-time data gathered from their energy monitoring stations,

such as alternative energy, solar generation, wind generation, and power consumption of the science center.

Using this design idea as well as the task scenarios gathered before, a low-fidelity paper prototype of the website was developed (Figure 1). The prototype consisted of four web pages total. The first page is the home page, or index page in which image links to the monitoring pages are located. When a user clicks on an image link, they are brought to its corresponding monitoring page. Each of the three monitoring pages contains information and images relevant to that monitoring station. The monitoring pages also have a “back” button to take the user back to the monitoring index page. All pages contain a button labeled “Eagle Bluff Home” that directs the user to the home page of Eagle Bluff’s main website.

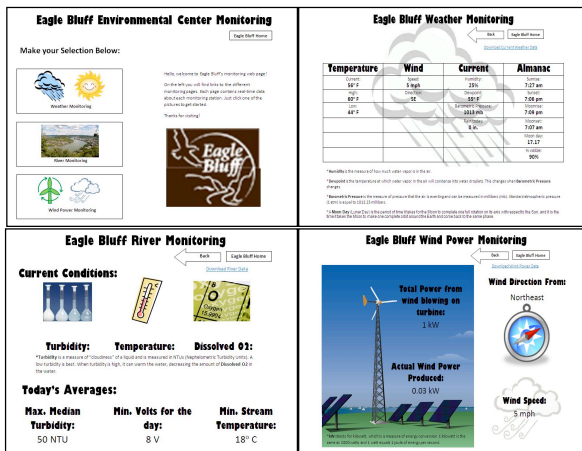


Figure 3. Low-Fidelity Prototype of Website

Because the website was going to be used by children, images were used to increase interest in the material and also to easily identify what is being presented on the page. Also, because some of the measurements and units may be confusing to children, text explanations of the lesser-known ones were added to the weather monitoring and river monitoring pages.

#### 4.4 Navigation Study & Survey

The study that was performed consisted of two parts: 1.) A timed study measuring the ease of navigation; 2.) A survey on likes/dislikes of the website and any suggestions for improvement. The navigation study was used as an objective way to test users’ understandability of how the website was structured as well as how easy it was to find certain information or buttons. The survey portion was a more subjective approach in finding out what users thought of the design.

The navigation study was created in such a way to cover all of the tasks a typical user would need to perform. Users were told to touch the page of the prototype to show where they would click as if they were actually browsing a website. When navigating to another page, the pieces of paper were switched to emulate the loading of a different web page. The study consisted of 8 timed tasks for the user to go through and try to navigate to find certain information, buttons, or pages. If the user failed to complete the task in 30 seconds or less, the task was marked as not completed.

The survey portion consisted of the following questions, using the numbers 1-5 ranked lowest to highest: 1) How much experience with web browsing do you have? 2) How easy-to-use was the website? 3) How interested were you in the material? 4) Overall, how would you rate the website?

The next few questions were: 1) What did you like about the website? 2) What didn’t you like about the website? 3) What are some features that you would like to be added?

#### 4.5 Test Users

For the study, adults and children were designated as the two types of test users. Five users of each user type were tested to be able to compare results.

In performing the navigation study, both user types were given identical instructions and was performed the same. In the survey portion, however, the adults were able to fill out the questionnaire on his/her own. For the children, the survey portion was given orally and responses were written down by the facilitator. This was decided upon to keep responses legible as well as help answer any questions along the way.

Originally, the children test users were ideally going to be tested at Eagle Bluff itself. Due to the lack of responses from affiliated schools that were contacted, this was unable to happen. The interface was instead tested on five 6<sup>th</sup> grade students at Winona Middle School.

#### 5. RESULTS

I did achieve beneficial feedback in my experience testing the website on children as well as adults. The results that were collected fall into two categories: 1) Participants’ task times and 2) Participants’ survey data and subjective feedback on the design. Since there were not enough test users to aggregate the data into averages, it is more practical to look at the results on a user-by-user basis.

To clarify on some of the later figures, the numbered tasks that were asked of each participant are as follows: 1. Find the current temperature of the river; 2. Go back to the monitoring page; 3. Find the amount of power produced by wind; 4. Find the current temperature outside; 5. Download the current weather data; 6. Download current river data; 7. Download current wind power data; 8. Go to the Eagle Bluff home page.

What follows is a presentation and explanation of the results, as well as graphs to show these results on a user-by-user basis.

##### 5.1 Children’s feedback

Figure 2 shows each child’s task times for the eight tasks that were presented during the study. Each shaded bar represents a different participant. One of the children, c2, for some reason had particular difficulty in navigating the site. It is worth noting that participant c2 ranked his experience in web browsing as a 3 on a scale from 1 to 5, with 5 being the most. All of the other participants ranked themselves with a score of 4 or higher. Participant c2’s task times were far greater than all of the other children and skewed the results to a degree.

Most of the participants other than c2 had little trouble completing tasks in 30 seconds or lower. One in particular stands out, however, and this would be participant c5’s time for task 5. This task was the first one that asked participants to download data, which required participants to find the download link on the same page they were currently on (weather page).

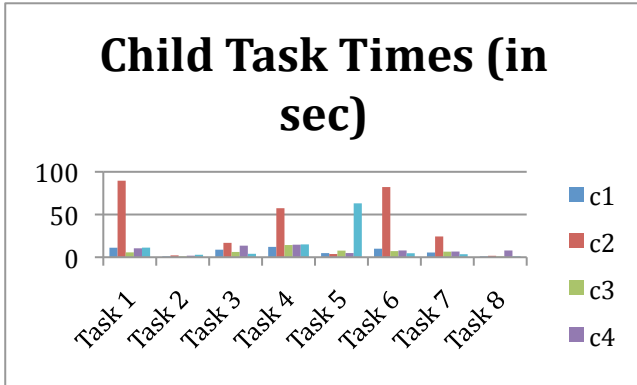


Figure 4. Child Task Times (in seconds)

In the survey portion, the children all seemed to like the use of pictures in the design. One child in particular liked the easy-to-understand buttons linking to each leaf page in the website hierarchy. Another one of the children participants agreed with this as well. One of the participants liked how the pictures were big and easy to see, that the website was organized, and also how the data would be current, or up-to-date.

What the children didn't like about the website was almost exclusively focused on the hard-to-find download link(s). One of the participants suggested that the download links could be made bigger to fix this. Another one of the participants had the good idea of grouping all of the download links into one place so the user can find them all in that spot.

## 5.2 Adults' feedback

Figure 3 is another graph of task times in seconds, except it is for the adult participant group. All of these task times were in a reasonable range and did not exceed 30 seconds to complete. However, it seems that task 4 took the longest to complete overall. Task 4 asked participants to find the current temperature outside. This task was meant to test the usability of the weather monitoring page.

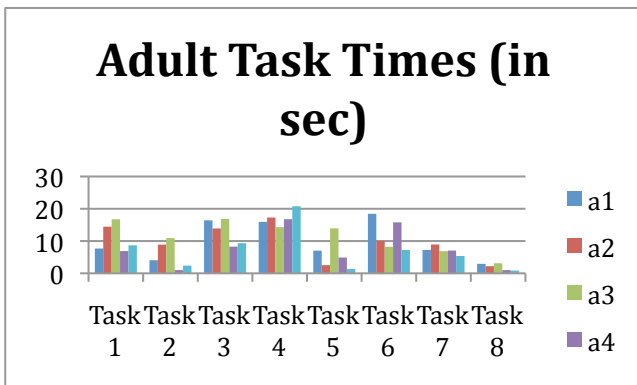


Figure 5. Adult Task Times (in seconds)

In the survey portion, adult participants were allowed to write their own thoughts on each of the questions, which also gave them more time to think on each question. This resulted in more thorough answers all-around, which benefited me more in the design process. Some participants also felt the need to talk to me about their thoughts after they filled out the survey and clarify what they were saying.

A common item of praise among the adult participants was the use of pictures in the website, not unlike the feedback from the children participants. The pictures were "big", "helpful", and "helped guide the eye." Another positive was, in fact, that the site was simple and easy to use. According to one user, a plus for the website was that it was "consistent" as well.

As for the cons the adult participants picked out, the download links were also reported as hard to find. Another dislike was the table layout for data on the weather monitoring page being "not as exciting" as the other pages. It was suggested that this be changed as it didn't fit well with the other monitoring pages. The labels for wind power were also stated as being confusing. One participant suggested that the "Back" button specify that it goes back to the monitoring home page and not the Eagle Bluff home page. Finally, the explanation of barometric pressure was suggested to indicate its effect on weather patterns as well.

The adult participants were able to think of lots of things that could be added to the website. One suggested more pictures to signify sunrise/sunset and moonrise/moonset values. Another suggestion given by two participants was adding predicted weather information to the weather page. Finally, a sidebar to be used for navigation was suggested.

## 6. ANALYSIS

### 6.1 Compare/Contrast feedback

As stated earlier, the amount of feedback was greater among adult participants, which I credit to the fact that they wrote down their own responses to the questions. This also gave the adults more time to collect their thoughts and give more thorough answers. In hindsight, this may have showed favor to the responses of adults over children and put less pressure on the adult participants when answering the questions.

The children participants did have plenty of feedback on the survey portion as well, but the most significant results came from the navigation study. The adult participants were able to complete all tasks in 30 seconds or less. As mentioned in the results, one of the children (c2) had trouble with most of the tasks and skewed the results, as is apparent in Figure 2. Almost all of the other children participants were able to complete the tasks in 30 seconds, except for c5. The task in question was task 5, which asked the user to download data. User c5 had trouble finding the download link and took over 30 seconds to complete, thus giving empirical support to the suggestions that the download links be made easier to see.

### 6.2 Implementation Implications

Based on the feedback given from both adult and children participants, several changes could be made to improve the design. The biggest flaw is the current location and visibility of the download links, which would most likely be changed into a button. The "Back" button would also be changed to specify that it goes to the monitoring home page. The next thing that would be changed is the weather monitoring page so it does not have a table and instead presents the data in a different way. The use of picture icons would then be used in a similar fashion as the river monitoring page.

## 7. CONCLUSIONS AND FUTURE WORK

Throughout the study, I did achieve beneficial feedback from working with children. This is mainly due to the results of the navigation study, but also because the children were helpful and

seemed to enjoy participating. However, I believe there wasn't a sufficient amount of data available to strongly support my original hypothesis.

The difficulty in obtaining valuable feedback from children may be due in part to the notion that they will tell you what you want to hear and may hold back telling you what they dislike about the design [7]. Although I had the children participants present their answers to the survey orally to maintain legibility in the results, any future design iterations would ideally let them write their own responses down on the survey, followed by an explanation of the responses. In addition, I would give them more time to come up with responses and stress that I need to know the drawbacks of the website to improve design. I believe both of these would have a positive effect on the amount of feedback given, which would further increase quality of responses.

Due to the availability of getting young students to participate, there were only 5 included in the study. If this study were continued, more participants would need to be included to achieve a broader grounding for results. More adult participants would also be included in the study for comparison purposes. Since the design I originally had was a low-fidelity prototype, future work on the design should ideally implement the suggested changes into a high-fidelity prototype and possibly start another iteration of testing. Based on the user feedback I acquired, the prototype was easy-to-use for the most part and got the job done well, save for some of the problems that were mentioned earlier. Therefore, not much extra testing would be needed for the design and is actually close to being implemented fully.

## 8. ACKNOWLEDGMENTS

Thanks goes out to my advisor Dr. Joan Francioni, the staff at Eagle Bluff Environmental Learning Center, my assistants Tom Caflisch and Sean Kioski, and Mrs. Christensen and her 6<sup>th</sup> grade homeroom students.

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# Porting the Lung Cancer Survivability Prediction Tool to the iPhone

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## ABSTRACT

The Lung Cancer Survivability Prediction Tool (LCSPT) is a web-based system that predicts the survival possibility of a lung cancer patient based on the status of a patient and the treatments provided. The statistical model used in this system was developed by a biostatistician at the Mayo Clinic in Rochester. Clinicians on different campuses at the Mayo Clinic are currently evaluating the system. In order to make the tool available to doctors in each department of the clinic, we present the new version of Lung Cancer Survivability Prediction Tool on the iPhone. To make browsing the webpage more efficient for users, we modified the web page layout to better fit into the small screen, and to save the download time the sever would only send out the data and the possibility curve would be generated at client side. We conducted a survey to test the usability of the new version on the iPhone, and the result show that the iPhone version could provide the same amount of information in an effective manner and users performances are not influenced by the platform switching.

## Categories and Subject Descriptors

D.3.3 [Information Interfaces and Presentation]: User Interfaces \_ evaluation/methodology.

## General Terms

Measurement, Performance, Design, Reliability, Experimentation

## Keywords

Web-based, lung cancer, mobile device, wireless, usability test

## 1. INTRODUCTION

The Lung Cancer Survivability Prediction Tool (LCSPT) is a web-based application, which takes a lung cancer patient status as input, and then calculates his/her survival possibility by using a bioinformatics model. The model was developed by bioinformatician in the Mayo Clinic. The output of the system has two parts: a chart with lines indicate the different possibility

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results in the following years when patients receive certain treatments, and a table with the possibility data listed to enable user to see the quantitatively differences between each treatment.

LCSPT was initially developed for doctors to make medical decisions, and after several months of evaluating the system, the Mayo Clinic decided that they would like to release the survivability prediction tool to patients on campus. To make this Lung Cancer Tool accessible to doctors and patients in different locations in the Mayo Clinic, it would be more efficient if users were allowed to browse the LCSPT pages by using a mobile device. The mobile device will enable user to access to web pages via a wireless connection. The research group chose the iPhone as a prototype mobile device.

Web browsing on mobile devices faces two major constraints [1, 2]. First, the data transportation causes inconveniences to users, because the loading time is usually longer than the PC browsing experience. Secondly, the layout of web pages on the small screen makes it difficult for users to find the essential information they need since the page is filled with medical information. The information displayed in the output is critical for both doctors and patients themselves since it gives a brief idea that how long the patient could survive in the future according to the statistics data collected before. It is important that the display of the information is done in an efficient and meaningful manner, which assures that the there is little chance that user may misinterpret the information.

## 2. RELATED RESEARCH

Facing several treatment choices for lung cancer patient, it is crucial for doctors to have a quantitative way of comparing the available treatments. LCSPT gives doctors a clear idea of the possibility that a patient could survive under certain treatment and health conditions. In order to make the tool more useful in a clinical setting, it is desirable for doctors to be able to get access to the results from the statistical models in real-time on a mobile device while they are making their rounds. This will provide them with a more convenient way of comparing treatments and making decisions.

LCSPT was developed in 2006 under the guidance of the Computer Science Department at Winona State University and the Health Science Research Department at the Mayo Clinic. It was a successful software implementation for doctors to compare survival possibilities of lung cancer patients under different treatments. The system was set up on a desktop computer at the Mayo Clinic. But in practice, however, the doctors often need the data at times when a desktop computer is not available. For

example, it is much more convenient to update the patients' information while they gathering it rather than waiting until later to enter it. Furthermore, studies have shown that better results can be observed in both health status and clinical outcomes when patients are provided with proper tools that enable involvement and active management of their illness [4] so it is expected that the LCSPT will be released to patients. Therefore, accessing the system with a mobile device is a logical next step.

The existing research suggests, however, that only about one-third of all mobile web users are satisfied with their experience [2]. This dissatisfaction is due to a number of factors, including that it is a more time consuming process [1] and it is more difficult to locate the content in long narrow page [3]. Thus, the current LCSPT needed to be adapted to overcome its shortcomings in these areas.

### 3. DESIGN

Porting a software application to a mobile device introduces a number of challenges. In this project, we mainly focused on two of them: speed of the data transfer and the display size of the LCSPT on a small screen.

Due to the transmission of the data over wireless connections, the amount of data that is transmitted needs to be minimized to ensure real-time response. Furthermore, the small screen size on mobile devices poses a problem with displaying the information in a useful and effective manner. In order to accelerate the loading process of the pages, we changed the way of generating the survival chart from the server side to client side. The data calculated by the bioinformatic model is now sent directly to the client side and the chart is generated locally, which saves a significant amount of time by eliminating the need to send a large image file of the chart. At the same time, we developed an algorithm to sample the most meaningful and useful data from the massive results data to help make effective treatment decisions.

Additionally, the user interface was modified and the information layout was changed for mobile device users who would have a relatively smaller screen.

The browsing experience on a mobile device is very different from that on a PC, and is often frustrating for users because it can be very time consuming and difficult to locate the content in long narrow page [3], resulting a longer waiting time. After the modification of LCSPT, users are

expected to receive the same level of satisfaction from the mobile device compared to PC.

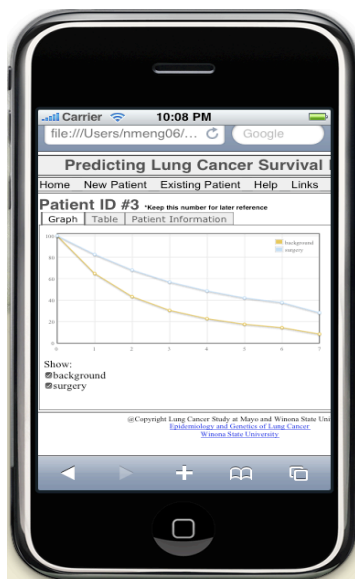


Figure 1. iPhone user interface of LCSPT

### 3.1 Page Layout

Since the mobile device has a smaller screen, it generally harder for user to find the information they need from a page filled with content. The long narrow layout is quite different from the layout on PC, which makes it even harder for most users to adapt to the application on an iPhone. In order to limit the time that a user spends searching for essential information on the screen, the layout of the page for iPhone version was modified to make the information clearly and effectively displayed. The new layout enables user to find information they need in a reasonable time without wasting time on scrolling down the page or aimlessly searching on the page. This improves the user experience when attempting to access critical information.

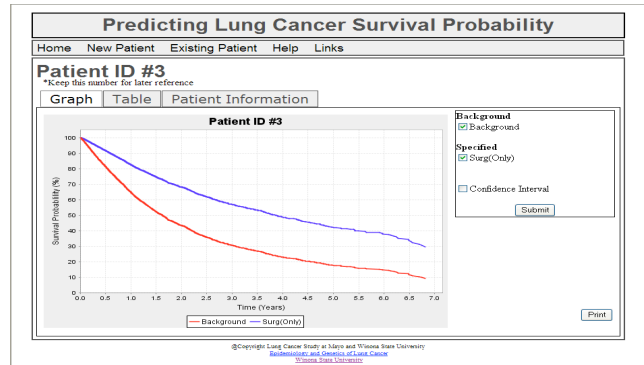


Figure 2. PC user interface of LCSPT

### 3.2 Survival Possibility Chart

The survival possibility chart is generated in a different way to minimize the loading time of the page, which further improves the user experience. The PC version sends a complete JPEG picture to the client side of the system as shown in Figure 3. For the iPhone version, only the calculated possibility data is sent and image is generated locally as shown in Figure 4. This saves a significant amount of time by reducing the amount of information that is transmitted across the wireless network. The image was generated locally using JavaScript and CSS. Because the client side generated image shortens the time required to transport data from the server to the mobile device as compared to directly sending the image, it enhances the user's experience.

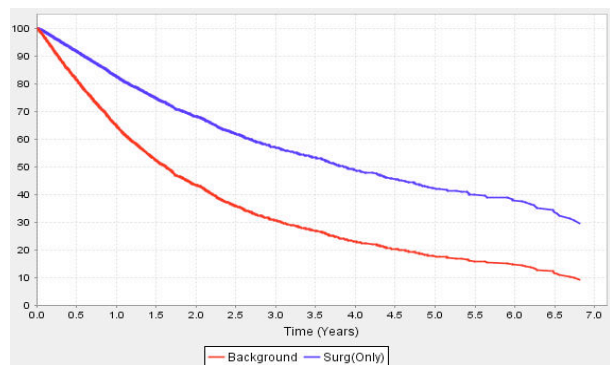


Figure 3. Survivability Chart generated in PC version of LCSPT



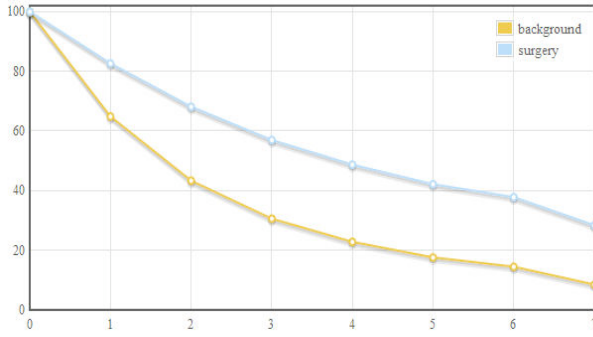


Figure 3. Survivability Chart generated in iPhone version of LCSPT

The graph was also changed to display interactively to the user, which also improved the user experience of the system [3, 4]. Users can get the detailed information about each treatment survival line by hovering over the lines on the image. The detailed information contains the estimated possibility for certain dot on the graph for the selected treatment, which resulted in a small window opening at that point on the graph. The window contained detailed information about the values at that point on the graph. Thus, there was no need to “guess” the values.

#### 4. USABILITY TEST

The usability test on iPhone platform was accomplished by using a simulator of iPhone, which is an application developed for developing and testing new iPhone applications. The simulator enabled subjects to experience using an iPhone to access LCSPT.

##### 4.1 PARTICIPANTS

Eighteen under-graduate and 2 post-graduate students from Winona State University took part in this evaluation. Eleven subjects were male and 9 were female. Each participant first gave a brief description about his or her background in using PC, as the Figure 5 indicates.

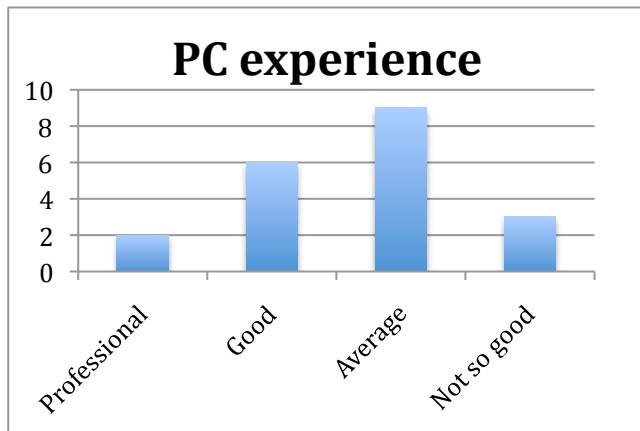


Figure 5. Participants’ PC experience background

Only one participant claimed to be a regular iPhone user and 4 participants said that they had used an iPhone a couple times, while the remaining subjects said that had not used an iPhone previously. From the 20 participants, 11 participants had mobile device web browsing experience as shown in Figure 6.

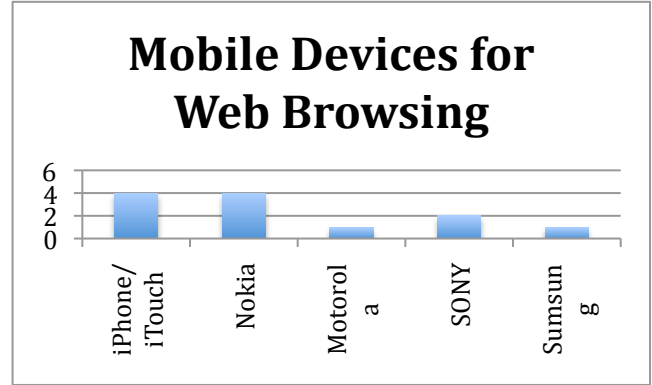


Figure 6. Participants’ web browsing experience on mobile devices

From the participants who had previous mobile browsing experience, they rated several major weaknesses of web browsing on mobile devices: harder to interact with the user interface, expensive data plan, smaller screen compare to computers, and slower in the speed to load pages. As Figure 7 shows, users appear to be most concerned with the expense of mobile device browsing and the loading speed. That it was harder to interact with a mobile device as compared to a PC and the screen size were less major concerns. The small screen and expensive data plan are constraints that are out of our control, but as web application developers, we can improve the loading speed and the interactive user interface design to give user a better user experience, which is the main focus of this project.

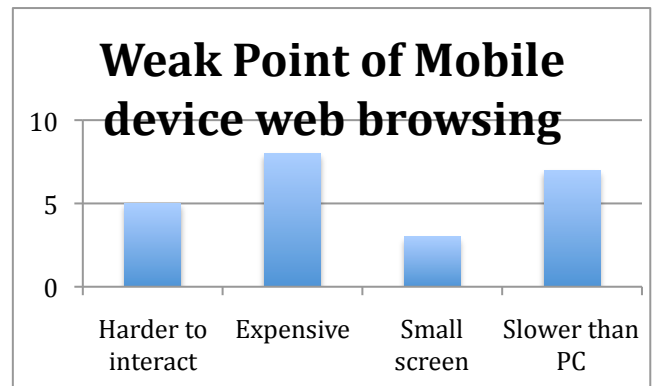


Figure 7. Participants’ rating on weak point of mobile device web browsing

##### 4.2 TASKS

Participants were asked to accomplish two tasks and then evaluate their user experience on both versions of the LCSPT system. In both tasks, participants were asked to find the survival possibility of a patient after 3.5 years from the charts shown on the page. In task one, participants were asked to create a new patient with specified information. In the second task, participants were asked to modify patient information for an existing patient and then get the result.

Participants were randomly divided into two groups, one group used the iPhone version first and then PC version; the other one used the PC version first then the iPhone version.

## 5. DATA ANALYSIS

### 5.1 TASKS PERFORMANCE

All the participants successfully finished the tasks and wrote down the survival possibility data they found from the charts on PC and iPhone version. From Table 1, we can see that the mean of the estimation from both versions was very close but there was a significant difference between the standard deviations. This data shows that PC version users may interpret data, which is much higher or lower than the average value, while the iPhone users were more likely to concentrate on a smaller estimation range. We could safely conclude that results from the iPhone version are in a smaller range and has little volatility about the survivability than those from PC version, which means that in real medical situations, doctors would be more likely to agree with each other when using the iPhone version more than the PC version.

Table 1. Tasks results

	Task I		Task II	
	PC	iPhone	PC	iPhone
<b>Mean</b>	58.025	57.269	66.585	64.963
<b>Standard Deviation</b>	4.948	1.158	2.712	1.266
<b>Range</b>	22	5	12	5

One of the advantages of the iPhone version is that the chart was interactive, providing its users with the data that was used to plot the line when they hovered over points on the graph. The iPhone users had more data to refer to when deciding the possibility of surviving, while the PC version only gives a chart which required users to measure the possibility by visually examining the graph to determine value associated with the Y-axis (the survival possibilities series), which lead to a wider range of values. Thus, iPhone users were less likely to make errors in reading the graph.

Since the estimated data from the model is not continuous on X-axis (the time series), there is no concrete answer to the survival possibility at some certain time, which requires user to estimate from the chart. But clearly iPhone version users would agree within a smaller range since it would give an upper and lower bound for user, also this feature could save time on measuring Y-axis (the survival possibility series) and improve accuracy of their estimation.

Most of the participants were satisfied with the layout of the iPhone version. When asked about the ease with which that could perform the tasks, 8 participants thought it is easy to accomplish, 11 said it took some time to figure it out but eventually they found everything in a reasonable time. Only 1 of them claimed that it was hard to finish the tasks on iPhone.

### 5.2 OVERALL USER EXPERIENCE

Nine subjects stated that they thought the iPhone version provided the same amount of information as PC version and 8 said that iPhone version actually gave more information than the PC version.

Only 3 users were not satisfied with the information provided on iPhone and their reasons were: the PC version had a clearer interface, the PC version had a larger screen, and the PC version is easy to control. The preference of the large screen of PC and the

ease of control likely had more to do with subjects prior PC experience as compared to their prior iPhone/mobile device experience. We expect that these preference will fade as users gain more experience with the mobile device interface.

Six people thought that iPhone version was better than PC version in the overall experience, 11 of them thought that both versions were about the same, while 3 claimed that the iPhone version was worse, as shown in Figure 8.

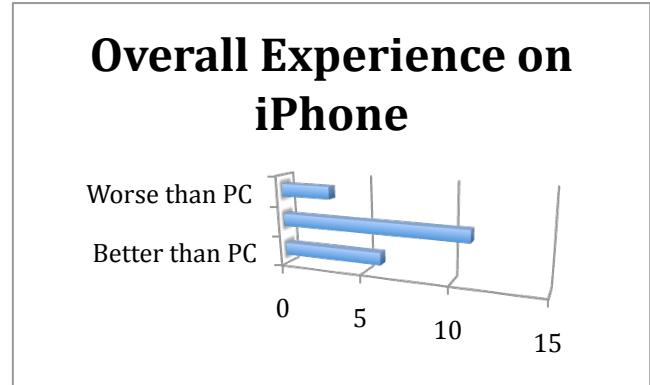


Figure 8. Participants' overall experience on the iPhone version of LCSPT

## 6. Conclusion

The LCSPT was a great success when first introduced to the Mayo Clinic on a PC platform. To make the access to the system more convenient and to further meet the needs for doctors, we made several modifications to the system and ported it to an iPhone platform. The modifications included changing the layout, moving the chart generation from the server-side to the client-side, and adding the hovering feature which provided the user with the data that was used to plot the chart. After completing the modifications to the LCSPT system, a usability test was conducted to ensure that the changes make the tool effective to use on iPhone. Based on the usability study, the iPhone version of LCSPT provides sufficient information for users to make medical decisions, most user were satisfied with the experience on iPhone compare to the PC version, and several actually stated that the iPhone version is better than the PC version.

Additional modifications will be made to the LCSPT system with the goal of making it a more effective and usable tool for doctors in a clinical environment. From the usability test, users still felt uncomfortable with the small screen and small font on iPhone version. The small font was one of the major complaints and we would further enlarge the font size to make it easier to use. When users try to decide the survival possibility of a patient, it is human nature to pick a time such as half year later, 2 years later, which increments by 0.5 not a random decimal number that we might have show in the chart. Thus, we need to provide more information for the first couple of years than we need for the last couple of years. We can further improve the performance of the LCSPT by restricting the amount of data that is transmitted. We are currently investigating such changes to the chart algorithm to optimize the data used to plot the survivability line in the chart, using one month as increment for the first year's data and half year for following years. Such modifications should further improve the usability of the LCSPT.

## 7. ACKNOWLEDGMENTS

I would specially thank my advisor Dr. Tim Gegg-Harrison and Dr. Mingrui Zhang, for their patient guidance and encouragement during the research. Also I am grateful to have the support from the faculty members and classmates of the Senior Seminar class. Finally I want to extend my appreciations to the evaluators for their time and patience, also the developer of the PC version of LCPST, Scott Olson.

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# Prediction of Home Automation Sensor State Utilizing Fourier Synthesis

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## ABSTRACT

Home automation systems of today currently lack the level of automation required to make them feasible as a wide spread public tool. They are typically complex and require time and motivation to learn how to utilize their manual, often wireless, controls and timers. In this research, we propose one important facet of home automation systems of the future. This is the prediction of home automation sensor states. In this research we implement a predictive system, utilizing Fourier Synthesis, based on periodic historical data and test prediction accuracy. Historical data is gathered from a typical household that is sensor equipped, predictions are made, and accuracies are calculated. This research paves the way for the development of smarter, friendlier, green households of the future.

## Categories and Subject Descriptors

D.3.3 [Sensor State Prediction]: Fourier Synthesis and Historical Sensor Data— generalized *Fourier series*, *Historical Data Extrapolation*.

## General Terms

Management, Measurement, Performance, Design, Economics, Reliability, Human Factors, Theory, Verification

## Keywords

Fourier Series, Fourier Synthesis, Home Automation, AI, Prediction, Data extrapolation, Sensor, Sensor State, Zigbee, iDigi Platform, Sinusoids, iDigi DIA, Green

## 1. INTRODUCTION

In today's world, we are faced with many challenges within our daily and lifetime journeys. These events are typically problems that are either too hard to see or have just become such a regular part of our daily routines that we have just accepted them to be a required part of our existence.

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Nuisances such as having to turn lights on and off, opening and closing window blinds, turning your shower on and off, all while managing your electrical and heat usage have added a considerable amount of unneeded steps to our daily routines. In the fast paced technologically increasing world that we live in, people are expecting more for less. In this research, we propose one very fundamental facet to the design of future home automation systems that make these very tasks obsolete. This is the prediction of the state of a sensor within a home automation system via a fast scalable algorithm.

Why is the prediction of sensor state so important? One of the main reasons why predicting the future state of a sensor is so important is for having environmental awareness not only in the past and present but for the future. By having an awareness of potential future events, a behaviorally controlled home automation system can make decisions not only based on the current state of the environment but also the predicted future state of the environment. For instance, if a set of lights is left on in a room, should a decision be made to shut them off or leave them on? This is totally dependent on whether or not someone is using them and if not how long before they will be using them again. If a system purely looked at the current state of the environment no decisions could possibly be made as to what should be done. But by predicting the future state of sensors, within a room, a decision can be made as to whether or not the lights will be unused for a sufficient enough time to deem shutting them off desirable.

## 1.1 MOTIVATION AND BACKGROUND

### 1.1.1 MANUAL AUTOMATION SYSTEMS

In the beginning of this research, we took a look at the current state of commercially available home automation systems. This was done to gain a better understanding of the state of the technology within this field and how we can improve upon it. We found that there are virtually no large-scale intelligent commercial home automation systems. The ones that exist, such as X10, typically provide sensors and devices that offer manual timers and wireless control [1]. This is far from the concept of an intelligent system because these timers have to be manually set and do not independently change their behavior based on their owners' own behavior. The wireless controls that they offer range from a wireless keypad to full online access from anywhere in the world. Although this may be more convenient in cases of travel, this solves none of the daily reoccurring nuisances described earlier.

### 1.1.2 INTELLIGENT AUTOMATION SYSTEMS

After we completed our exploration of commercial home automation systems, we began to explore more advanced intelligent home automation systems that are currently being developed. Examples such as a project dubbed “The Neural Net Home” were investigated. In this research, a home was equipped with sensors and a neural net was trained to balance human behavior and energy conservation [2]. Dimmable lights, with 15 levels of brightness, were installed in the house [2]. The neural net was conditioned using punishment based on whether a human changed the value of a sensor set by the computer. This means that lights could continually be dimmed until the human set the brightness to a different level. By doing this, the neural net was able to decide what the minimum amount of light was acceptable by a human within the room. This system was able to adapt to the behavior of the individuals within the system. If a human was detected to be within a room, a decision as to whether to turn the light on or off was made. The system would then be trained based on how the human reacted to this decision. As the human left the room, a decision to turn off the light was performed unless otherwise conditioned. But both of these cases were based on the current state of sensors within the home. Neither of these decisions were based on the predicted state of the environment at a future time period. Such a decision would have allowed the system to reason that the room is likely to not be occupied within a given future period of time and turn the light off. But more importantly, the neural nets have difficulty scaling and a neural net per home would most likely be required in a large-scale environment such as a city [3]. This neural net was also required to be at the premise of the home reducing its scalability further. This is a problem when imagining the future of home automation systems.

### 1.1.3 PERCEPTIONS OF THE FUTURE

The majority of this research was conducted while keeping in mind the ultimate desires that we have for home automation systems. When we think of what the future holds for home automation, we imagine all of our daily simple and even complex tasks being performed for us within our homes. We see this happening not only in the homes of the rich but also in the lives of the average homeowner. We imagine a system like this to be as naturally installed in a house as lights or sinks are. We also see that it not only has to be versatile and adaptive, in the home, but that new situations and technologies need to easily be incorporated into the environment. As a result, a service based home automation network needs to be developed to allow for all of these aspects. This is why an emphasis on scalability has been put on the design of this prediction algorithm.

## 1.2 SENSOR ENVIRONMENT

### 1.2.1 ZIGBEE MESHED SENSOR NETWORK

In this section, we will explain the basics of the sensor network along with the physical setup of the system. For this research, we decided to utilize a Zigbee meshed sensor network. We will briefly explain what Zigbee is and the advantages of taking this approach. Zigbee is a high-level communication protocol specifically designed for low-cost, low-power wireless devices [4]. Some of the applications that Zigbee is currently used in are home automation systems, ZigBee smart energy systems,

telecommunication applications, and personal home and hospital care systems. This is a mesh self-healing network consisting of a coordinator, routers and end nodes. Data is routed from one point to another through other routers. Routers can be devices themselves or purely just used to route traffic. The Zigbee protocol is self-healing in the sense that a node can be removed from the network and the topology of the network will automatically reconfigure, much like the Internet.

### 1.2.2 SENSOR TYPES

In this research, we utilized a total of five sensor types. These include light, temperature, humidity, electrical current, and motion. These sensors were wirelessly connected to a Digi ConnectPort X8 base device. This device was running the iDigi Dia framework, which is specifically designed for the ease of interacting with sensors within a meshed Zigbee network. The iDigi Dia also made it very easy to aggregate sensor data on a timed interval of one second to the iDigi Platform. The iDigi Platform is a commercially hosted infrastructure that manages the communication between enterprise applications and remote device assets. This technology is specifically designed with scalability and optimization for wireless technologies in mind. The use of this industrial level framework allows for a realistic exploration of practical intelligent home automation systems.

### 1.2.3 PERIODIC TENDENCIES

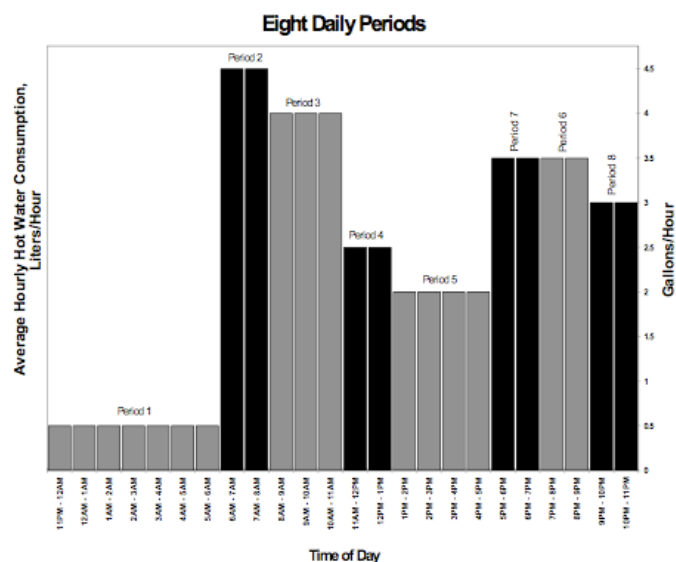


Figure 6. Eight Daily Periods [5]

Some research was done initially to show that there is at least some periodic tendencies that can be found across multiple home sites. By doing this research we are able to say that there are periodic tendencies in a home environment and if that is the case our technique should then be able to find these periodic tendencies across more diverse home settings. In Figure 1, we present a graph, courtesy of the Energy and Environment division of Ernest Orlando Lawrence Berkley National Lab, that shows there are

indeed periodic tendencies within homes. They did research that studied the periodic nature of hot water usage within homes. This graph shows that there are indeed sets of periodic events that occur within the home. This simple research gave us hope that there are at least some periodic tendencies to be discovered.

## 2. Hypothesis

Our hypothesis for this research deals with the ability to predict sensor state within a home environment utilizing Fourier synthesis. We made a few assumptions to simplify and narrow our research for this specific experiment. Due to time constraints we assume that predictions will be based on sensors that return back 3 state responses. This means that we will either be able to answer with true, false, or your guess is as good as mine. What this translates to is whether or not situations are occurring in the environment. We will be able to predict if the bathroom is being used and if so is a shower taking place or some other task, along with predicting the state of a TV. Our hypothesis states that we will be able to predict the state of these described events with accuracy greater than 60% for data consisting of a threshold periodic tendency.

## 3. Methods

### 3.1 Exploration of Prediction Techniques

We investigated a few different possibilities of data extrapolation and prediction. We knew we needed something fast and scalable with a sufficient amount of accuracy. Our first inclination was to use a traditional AI system to perform this task. We investigated techniques such as genetic AI, fuzzy logic, and neural nets. It became obvious early on that a neural net seemed to be one of the best techniques for this type of problem. With its ability to learn and adapt to a situation and a unique environment it seemed like a promising avenue. But many problems arose when investigating further. We realized that neural nets are typically slow in comparison to some other algorithms. Slow in the sense of their runtime speed but more importantly their training and conditioning periods. Most importantly we found that neural nets have a very difficult time scaling. This is a very important requirement set out from the beginning due to the perceived notions of making a practical intelligent home automation system. We also were hesitant to use them due to the fact that our prediction algorithm is merely a piece of a bigger system that utilizes fuzzy logic to make behavioral decisions. These requirements led us to a more mathematically based algorithm.

### 3.2 Fourier Series

Due to research that has shown periodic tendencies in human household behavior, we decided to use a technique that extracts and can extrapolate these assumed periodic tendencies. The Fourier series decomposes a periodic signal into a sum of simple oscillating functions, namely sines and cosines [6]. The simple oscillating functions represent the periodic tendencies in the data. The size of a coefficient on a specific simple function represents its periodic strength. We are then able to set a threshold value for eliminating the weak periodic simple functions. These weak functions represent the noise in the data, more specifically the chaotic events that happen in the data. But more interestingly, if

we have a week of data and periodically related events occur on Monday, Wednesday, and Friday while uniquely differently periodic related events occur on Tuesday and Thursday, we are able to extract out the periodic noise from Tuesday and Thursday if we are trying to make a prediction on Friday. Therefore noise is not only non-periodic tendencies but also the removal of periodic tendencies that are unrelated to the specific date and time in question. This is much more complex to do than just the static removal of weak functions.

We found this technique rather interesting because we have not found it used in other research on sensor state prediction. It was also very interesting to see how versatile and powerful this process is by exploring some of the practical applications, such as audio content-recognition software, EEG, MRI, image processing, cryptography, and compression. We were initially going to use a Discrete Fourier Transform but due to its runtime complexity, we decided to implement the Fast Fourier Transform which essentially does the same thing in  $O(n \log n)$  time [6].

## 4. Tests and Results

In our testing section, we decided to limit the amount of historical data that we based our predictions on. This was due to the fact that we really wanted to see if the Fourier Series would pull out periodic tendencies in a limited data set. We recorded data from a TV electrical current and Bathroom light sensor. The data gathered from each sensor was used for performing tests on two different sub environments of a home. This data was recorded on a Monday, Tuesday, and Wednesday. The data from these sensors was taken over intervals of one second. We then performed a Fast Fourier Transform which essentially creates a curve that represents the periodic tendencies in the data. The Fast Fourier Transform produces an equation. We can then use this equation and input any given time to see the predicated state of any given sensor in the past, present, or future.

Figures 2 and 3 within the index represent the sensors recorded data and the Fast Fourier Transform. The dots are the actual recorded values at a given time. Whereas the curve is the Fast Fourier Transform of the data. The x axis is in units of seconds from 1970 (Basic Unix Timestamp).

In Figures 2 and 3, three days of actual data with a Fast Fourier Transform superimposed on the data points as a curve is presented. If you visually cut the graphs into thirds, you can see periodic tendencies within the data. For instance, in the TV electrical current data, we notice that the TV is always on in the mornings, and typically in the afternoon and evening periods. For the bathroom light, we can see one major periodic event with a few minor ones. By cross-referencing this light data with humidity data we can realize that these are actually showering events taking place. This makes sense because showers tend to be periodic as was shown via the previous graphs on the periodic nature of hot water usage within homes (see Figure 1).

The dark curve that represents our Fourier Transform, is actually a mathematical equation composed of many sines and cosines with different coefficients. By looking at Figures 4 and 5, within the index, we can see our actual test scenario. In these graphs we display actual values of the TV current and bathroom light sensor as dots and the predicated state of these sensors as a more continuous set of dots. The predicted state of the sensor was generated via the equation that was derived from our historical data.

Although we may at first not see a striking similarity between the predicated values and the actual values, we began to when we set a threshold value for the sensors' state. If we analyze data and determine what it means for a light and TV to be on and off, we can compare the predicated values to their associated actual value and determine accuracy.

Surprisingly, the accuracy of predicting the state of the TV electrical current and light sensor was 90% and 77% respectively. These tests were performed solely on three days of historical data and predictions were made about the fourth day before it occurred.

## 5. Conclusion and Future Work

We were able to successfully predict the state of a sensor, based on limited historical data, with greater accuracy than we had believed was possible in our hypothesis. More importantly than proving our hypothesis, our research has shown that the Fourier Series has the potential in finding and predicting periodic tendencies in home environmental state data. We imposed many limitations on our Fourier algorithm, such as limiting our historical data set and also not exploiting many of the potential more complex ways to do Fourier Synthesis. This simple, scalable, fast algorithm has shown us that its strength has the potential to start the future of service based home automation systems.

In our future work, we intend to continue our investigation by implementing a more complex form of our Fourier Transform algorithm. Once this is completed we can then do a larger study across multiple home sites to test periodic tendencies in a more diverse environment. This is very important because the major flaw in this research was our ability to show that our algorithm actually could find and predict periodic tendencies across a wide varying home environment. Another very interesting avenue we wish to investigate is finding relationships and patterns between events that occur across multiple sensors. We found compelling data that suggested that patterns or sequences of events across multiple sensors were likely to occur. By eliminating the direct need of making predictions based off of time, we would then be

able to predict user actions based on the patterns found between multiple sensors. Therefore we could use our algorithm to not only find periodic tendencies between individual sensors but also find more complex periodic tendencies between the events that occur on multiple sensors.

## 7. ACKNOWLEDGMENTS

I would like to thank the Winona State Math department for their help with understanding Fourier Synthesis. I would also like to thank employees at Digi International for assisting me with equipment acquisition and also all of my fellow students for helping me weed out many of the problems I encountered. I would also like to thank all of my professors for being there when I had questions and helping me learn and grow throughout this process.

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# Appendix

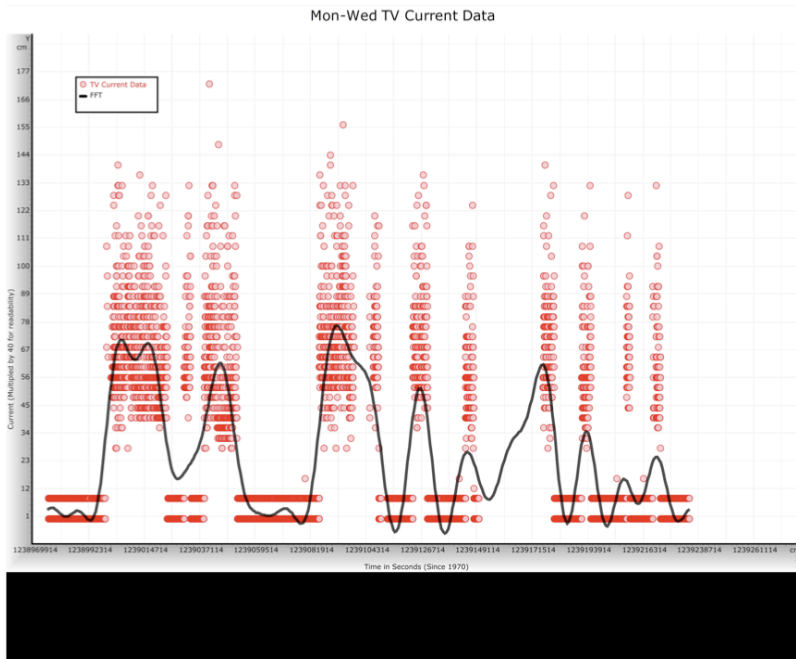


Figure 7. Monday - Wednesday TV Current Data (With FFT)

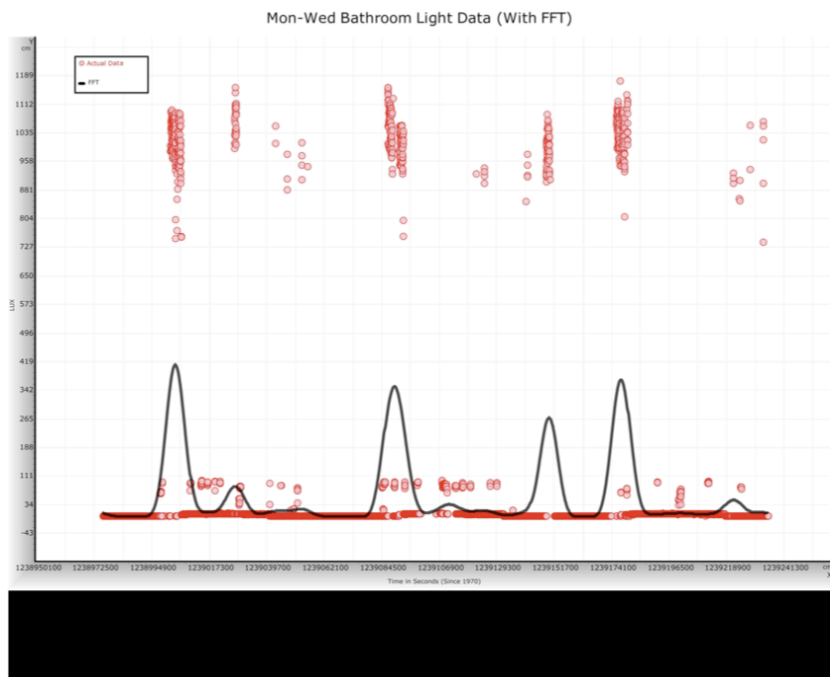


Figure 8. Monday - Wednesday Bathroom Light Data (With FFT)



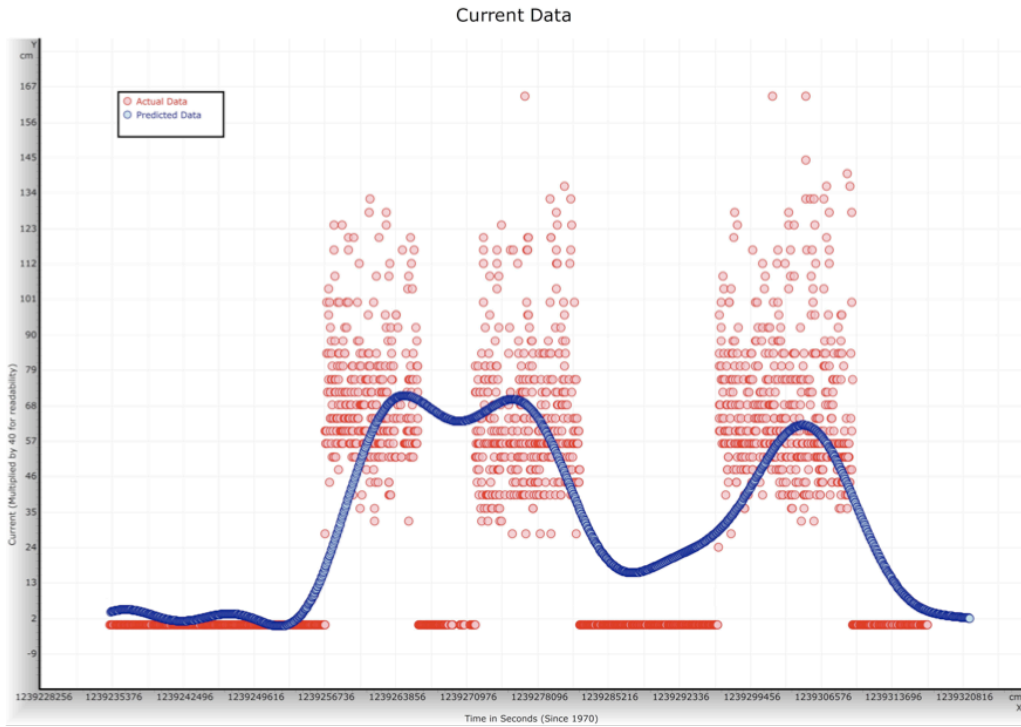


Figure 9. Thursdays Predicted(Curved Line) and Actual(Dots) TV Current Data

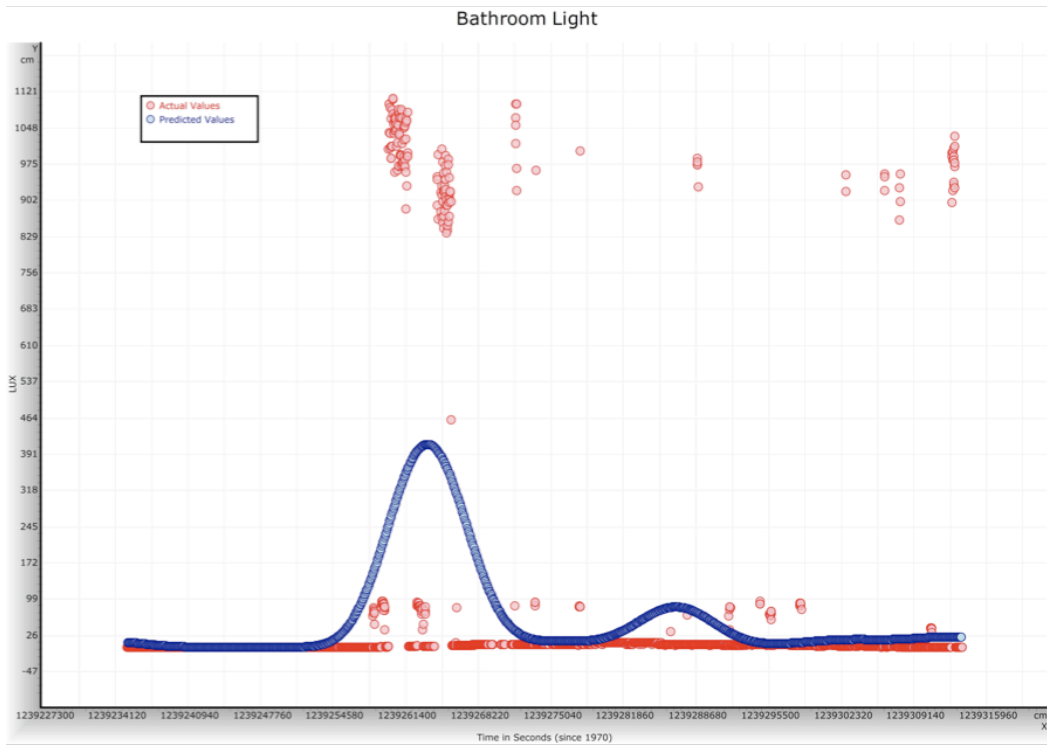


Figure 10. Thursdays Predicted(Curved Line) and Actual(Dots) Bathroom Light Data

# A Classroom Testing Solution for Laptop Universities

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## ABSTRACT

Universities which incorporate laptop programs can benefit from a classroom testing solution which utilizes student and faculty laptops. Such a system would not require additional hardware and would therefore be a more cost effective solution than existing systems. Another benefit is that this system could be an “all in one” solution, meaning that it has the potential to replace Scantron tests and CPS clickers. Our proposed system will allow instructors to create tests for their classes and students to answer questions using their laptops. This system will take precautions to prevent students from cheating on tests. The Respondus browser is an existing program which locks down laptops and allows students to take a test. We demonstrate that, it is possible to write a program which can display information to the user even when the Respondus browser is locked down. Our system is intended to be a proof of concept; however, it is possible that this system could be incorporated into D2L which would greatly increase the ease of integrating this system into classrooms.

## General Terms

Management, Security, Human Factors, Standardization

## Keywords

Electronic Classroom Testing, Laptop Universities

## 1. INTRODUCTION

Universities which incorporate a laptop program could benefit from a testing system which utilizes the student and faculty laptop computers. Once a student’s test is submitted any multiple choice questions are instantly graded. Grades can then be viewed online by both the instructor and students after an exam. There are existing systems that universities can purchase which allow large classes to take tests with remote devices. However, these systems can be expensive for both the students and the university. For example the CPS (Classroom Performance System) by eInstruction allows students to use a remote handheld device to answer questions [1]. The CPS solution requires additional hardware which is unnecessary for a laptop university. A system which utilizes existing laptops would therefore benefit both the students and the university by providing a more cost effective solution.

A major concern with using laptops for test taking is cheating. Students should not be able to open other programs and

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documents or use the Internet while taking a test. This is why there is a client program which needs to be run on a student’s computer to take a test. When the client program is executed it will open a full screen window so nothing but what the client program displays will be visible. The client will not allow any other window to be moved on top of it. This includes trying to minimize the full screen window or navigating to others by using the keyboard. If the user closes the client program they will not be allowed to continue the test. Communication between the client and server is encrypted to prevent anyone from attempting to view answers on the network.

The Respondus browser is an existing program which locks down laptops and allows students to take a test.[8] However, we demonstrate that it is possible to write a program which can display information to the user even when the Respondus browser is locked down. This was done using the same method in which our proposed solution prevents other windows from being visible above it and therefore the proposed solution would not have the same vulnerability. Attempting to use this method against our proposed solution would essentially render both programs unusable since they would be “fighting” to stay visible above each other.

The goal of this project was to create a testing system designed for use with laptops to benefit universities with a laptop program. The system prevents students from being able to cheat while taking exams. The system allows instructors to create tests and students to be able to submit answers using their laptops.

## 2. HYPOTHESIS/QUESTIONS

We hypothesize that it possible to create a testing system for a classroom environment which utilizes student and faculty laptops while ensuring that the students’ laptop can be locked down while taking an exam.

## 3. METHODS

### 3.1 System Overview

Our client program was developed in Java which made it easier to develop the program for both the Windows and Mac OS platforms. The Eclipse IDE was used for java development. Our server consists of an eXist database and an Apache Tomcat web server. JavaServer Pages (JSP) was used for writing web pages and communicating with the database. The Apache MINA network application framework was used for the communication between the clients and the server. MINA was used because there are potentially thousands of clients which will need to communicate with the server simultaneously. MINA also supports SSL which allows all communication between the clients and the server to be encrypted. Figure 1 shows a high level view of the system.

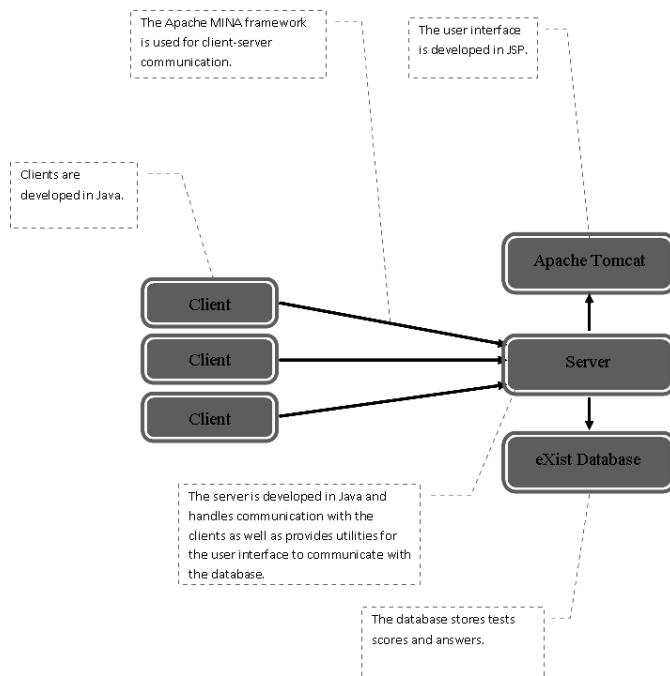


Figure 11. High level view

### 3.2 System Functionality

Our proof of concept system provides basic functionality to distribute a test to a set of students. Tests can be imported using a web based user interface. The import format provides support for creating a test with multiple choice questions, short answer questions or essay questions. For the multiple choice and short answer questions the correct answer can be provided for automatic grading. The import format used for this system is the same format which Desier2Learn (D2L) uses. D2L is a system which many universities use for managing classes. D2L allows instructors to post information about a course, create an online quiz, post grades and other class management activities. When a test is first imported, it needs to be enabled before the client program is able to display the test. The test can then be disabled or enabled again at a later time. When importing a test the instructor has an option to either send the test questions and the answer choices to the student or to only send an “answer sheet” to the student. In the latter case the scenario would be similar to using a Scantron sheet where the instructor provides the test and the students fill out the Scantron. The web UI also provides a way to create a single multiple choice question and send it to a class. This is useful for sending questions during a lecture and viewing instant results as students answer. In this case the instructor has the option of not locking down students’ laptops in case they should be allowed to use other resources. Once a test has been imported or a question has been created, students can login to the class which the test or question has been created for. After logging in the students will see a list of tests which are enabled for that class. They can then pick a test and begin answering questions. Figure 2 shows the client program after a student has logged into a class. Figure 3 shows a test in progress with the screen locked down. After a student is finished he/she can then submit the test

and any multiple choice and short answer questions will automatically be graded. The score can then be viewed using the web UI.

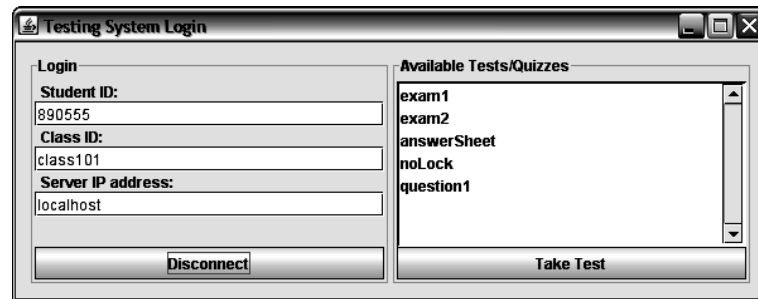


Figure 12. Logging In and Selecting a Test

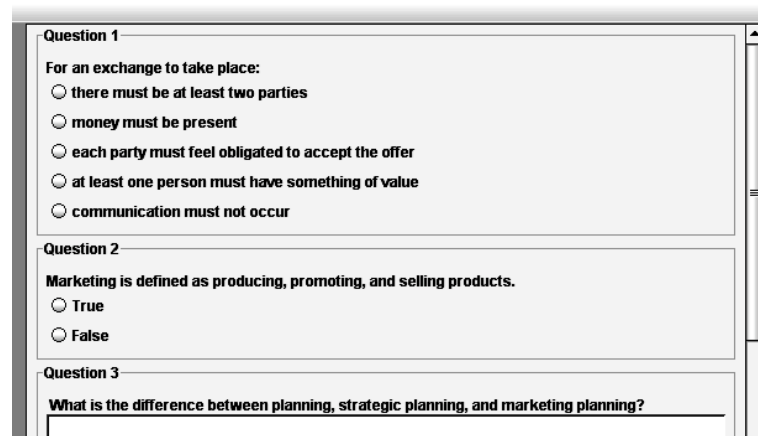


Figure 13. Taking a Test

### 3.3 System Implementation

Since the focus of this project is to lockdown a student’s laptop and display a test, this section will focus on the implementation details of the lockdown features.

#### 3.3.1 Lockdown With Only Java

The first method for locking down a laptop is done using only Java. When the client program enters into lockdown mode a full-screen window is created using Java’s Full-Screen Exclusive mode. Full-Screen Exclusive mode is designed to suspend the operating system’s windowing system and allow a program to render directly to the graphic device’s frame buffer. Using Full-Screen Exclusive mode provides a lot of power which is not necessary for this system; however it may help to keep the client program in control of the screen in some operating systems.

Locking down the client program is accomplished by detecting if the full-screen window is being minimized, losing focus, etc.. If one of these events is detected the current window is disposed and then a new one is instantly created to replace it. This effectively forces the operating system to create a new full-screen window which is displayed above all other windows. This is implemented by adding event listeners to the full-screen window and recreating the window when ever certain events occur. This method is also used to notify the server if the client program has detected if the

user or some other program is attempting to minimize or gain focus over the full-screen window. If the server is notified it display a message next to the students score that this event has been detected. Figure 4 shows an example of this.

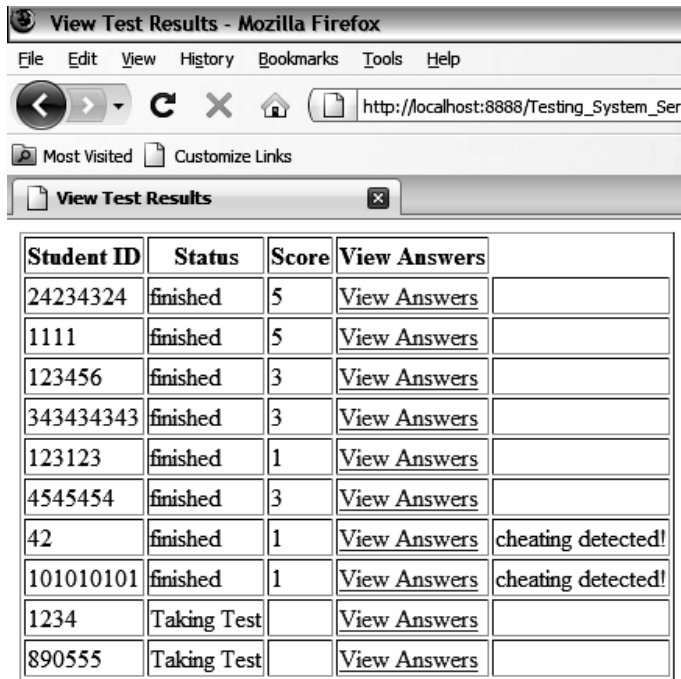


Figure 14. Viewing Test Results

### 3.3.2 OS Specific Lockdown Using the JNI

The second method for locking down the client program is operating system specific. For example in Windows the Task Manager or CTRL+ALT+DEL can be disabled. This is done using the Java Native Interface which allows a Java program to call methods compiled for a specific platform. Our system uses C functions which edit the Windows registry to disable the Task Manager in Windows XP. This method can be used to disable other keys such as the TAB key or the Windows key. Since different C functions have to be written for different operating systems this has only been implemented for Windows XP. However at this point locking down other things is just a matter of looking up what needs to be edited for a specific OS and then recompiling the C code. The C code consist of two functions: lock() and unlock(). As their names suggest the lock() function applies all of the OS specific lockdown features and unlock() reverses them. Apdx 1 shows the C code used to lock the task manager on Windows XP.

## 4. RESULTS

The lockdown features of our system were tested on three different operating systems. The operating systems were Windows XP, Windows Vista, and Mac OS X Leopard. The lockdown features were successful on all of these systems. The lockdown features which were implemented in Java were sufficient to keep the locked window on top of all others; however the operating system specific lockdown features provide another layer of defense. In Windows XP there is a noticeable flicker when there is

an attempt to minimize the full-screen window which was not seen when running on OS X Leopard.

The Respondus Lockdown browser was also analyzed to see if there was a way to break its lock down functionality. By using the method of recreating a window when a certain window event occurs enabled us to display alternate content after the Respondus browser was opened.

## 5. ANALYSIS

The Respondus browser seems to only lockdown its window by disabling keys on the keyboard. Since we are able to write a program in Java which can be displayed after the Respondus browser has been opened this allows someone to put lecture notes or other content in this window and view them while using the browser. This would not work in our proposed system since it actively keeps its window above all others. The proposed solution provides a much better solution for locking down a laptop since it uses a more active method of keeping its window above all others. The Respondus browser only attempts to prevent the user from switching to a new window or minimizing the browser.

Our system was tested on Windows XP, Windows Vista, and Mac OS X Leopard. However it is possible that someone may try to run the client on a system which has not been tested. There may be an operating system in which the client program does not lock down as expected allowing the user to bypass the lockdown features. Another possibility is that someone could run the client in a virtual machine. In this case the virtual machine could be minimized while using the host operating system to view alternative content. Both these issues could be avoided by detecting the operating system that the client is running on. If an unsupported operating system or virtual machine is detected then the client program would not run. This would prevent anyone from using an unsupported operating system or virtual machine to cheat on an exam.

Our proposed solution also provides more functionality than current solutions. The Respondus browser only allows the instructor to create an exam ahead of time and view the results later. Our proposed solution has the ability to create a question using the web UI and then see instant results after students have submitted their answers. CPS clickers are useful for creating questions during lectures and seeing instant results but they are not as easy to use and do not take advantage of student laptops. Also the CPS clickers are not integrated with D2L so any exam scores need to be manually transferred. The Proposed solution could be integrated into D2L to make this automatic. The proposed solution could also effectively replace Scantron tests since the instructor can opt to only send an "answer sheet" and then hand out the test in class. In this case the student's tests would be instantly graded and there would be no need to purchase Scantron sheets or the Scantron grading machine.

Many universities already use D2L. This would make integrating our system into classrooms much easier since instructors would not need to learn many new things. The same format for creating D2L tests could be used for our system. Students would only need to run the client program on their laptop when taking a test. Another option may be to use Java Web Start to download the program from a browser when the student needs to use it.

## 6. CONCLUSION

Our proof of concept system has shown that it is possible to lockdown a laptop and to use it for taking exams. We have shown a way to work around the Respondus browsers' lockdown features and that our proof of concept system is more secure. Also our system provides more functionality in one system. It has the potential to replace the Respondus browser, CPS clickers, and Scantron tests. If this system were integrated with D2L instructors would not need to learn how to use a completely new system to create and distribute tests

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# A Behavior Driven Intelligent Home Automation System

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## ABSTRACT

A home automation system enables automatic control of devices in a house. There have been a lot of researches and implementations of home automation systems. All these systems require users to interact with a computer to control and command systems. There is a need for an intelligent home automation system that makes decisions like a normal human being and as a result lowers energy consumption. In this paper, we propose a prototype system that can make appropriate decisions to maximize the comfort level of a user and save energy at the same time. This system takes in predicted human activity, monitors temperature, light and motion sensors, and uses its intelligence to determine appropriate actions. We did a quantitative analysis of this system on a prototype room. The result suggests that the energy consumption was lowered by 5% along with an automated lighting and thermostat control system.

## Categories and Subject Descriptors

D.3.3 [Programming Languages]: Java, Fuzzy Logic.

## General Terms

Design, Algorithms, Management, Experimentation, Human Factors, Standardization.

## Keywords

Fuzzy Logic, Home Automation, Zigbee, Digi Smart Plug, Green System, Energy Management.

## 1. INTRODUCTION

The advancement of technology is undoubtedly changing peoples' lifestyles. Everything is being automated these days. Home automation systems developed in recent years are capable of turning on/off, changing settings or rebooting any electronic device with just a click of a button. These systems can help users optimize their energy consumption by turning off unnecessary appliances remotely. These systems are more like home-management systems, where users have to be constantly involved. In addition to home automation systems available currently, smart home automation systems that can make decisions on their own are required [1, 2, 3]; a system that can predict the decisions a normal human being would make.

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Therefore, we proposed a system that is capable of making appropriate decisions and lowering costs at the same time. The system is *smart* enough to use predicted human activity data, motion, light and temperature sensors, etc to generate a situation model. Using this situation model, it makes decisions and hence minimizes the involvement of a user. This system also saves a user's time spent on operating electronic devices manually. This not only maximizes the comfort level of a user, but also minimizes unnecessary consumption of energy. To provide a user with more flexibility, this system offers a highly interactive website where a user can view statistical usage data of appliances installed in their house.

The main focus of this study is to determine the possibility to develop this intelligent system along with a lower consumption of energy. This research demonstrates a prototype of an intelligent home automation system represented through a room setting using wireless Zigbee modules, sensors and a user friendly web user-interface. This study basically serves to build a foundation for a wide variety of users and buildings.

Following is the summary of our contribution:

- This system enables a truly intelligent home automation system and saves energy without a user being constantly involved.
- This system not only automates the appliances in a house but also provides statistical data of energy usage in the past or can predict the use of energy in the near future.
- This prototype creates a platform where many complex home automation system can be developed. For ex. A system that monitors humidity sensor, knows when a user is taking shower and hence can automatically turn on an exhaust fan.

## 2. HYPOTHESIS

Provided a pattern of human activity and data from temperature, light and motion sensors, it is possible to lower energy consumption by 5% and implement an automated lighting and thermostat control system that does not require the user to be constantly involved.

## 3. METHODS

### 3.1 Overview

Zigbee is a low powered and low cost wireless mesh-networking device. Mesh networking are self-healing in nature, which makes a network reliable [4]. We setup a prototype room to perform this experiment. The prototype room was equipped with two light bulbs, motion, temperature and light sensors. We used Digi smart plug, which is basically a relay, to turn on and off a light. Digi

Zigbee enabled light, temperature and motion sensors were used to collect data from the room. This data along with a predicted human activity pattern was sent as an input to our system and the system made appropriate decisions. These sensors push data into an iDigi Server, a remote device management tool, and sleeps for a second. As soon as it wakes up it pushes data into the server and sleeps again.

### 3.2 Input and Output

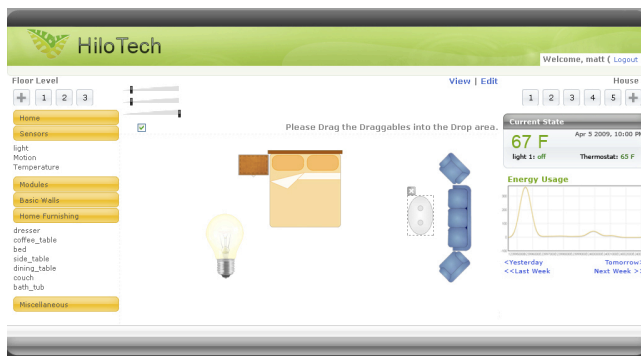
Inputs to this system were collected from the iDigi Server and outputs were the state of light bulb and the state of the thermostat. Following is the list of valid input and output to and from the system respectively.

**Table 1. List of valid input and output**

Input	
Light	0 lux – 32000 lux
Temperature	0 <sup>0</sup> F - 100 <sup>0</sup> F
Motion	0 - 150
Output	
Light_out	0 – 40
Thermostat	20 F – 100 F

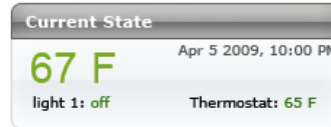
### 3.3 Website

We implemented a website where a user can just drag and drop sensors and other home furnishing objects to create a layout of the user’s house. We realized that energy saving could be measured better by implementing a website that can be used to monitor activity and energy usage of devices [5]. Using this website a user can monitor the activity of devices installed in his/her house. This enables a user to easily get a summary of an activity of all devices installed in his/her house. A user could even click at the light bulb to turn on/off the bulb manually. Following is the screen shot of the website.



**Figure 1. Screenshot of the web user Interface.**

At the right top is the current state section. This section basically contains the information about the current temperature of the room, state of light and thermostat. The screen shot of the current state is shown in figure 2.



**Figure 2. State of devices installed in a house**

The website can be used to track the amount of energy used in the past or to predict the amount of energy that will be used in future. Flot, an open source javascript graph-plotting library, was used to plot graph of energy consumed or energy usage predicted. Figure 3 shows a way one can get a view of energy usage of past or future.



**Figure 3. Energy usage data**

### 3.4 Fuzzy Logic

Fuzzy Logic was used to predict human behavior. Fuzzy logic enables a computer to use linguistic terms and rules to take certain actions [6]. For instance, if we were to instruct someone to equalize a sound, we would ask him/her to set the bass to high or set the treble to low. These terms like max and low are vague linguistic terms, which a human being would understand. A fuzzy system enables a computer to understand linguistic terms and rules made up of linguistic terms.

There are basically three steps in a fuzzy system: fuzzification, fuzzy rule and defuzzification. Fuzzification is the process of converting crisp data into linguistic terms. Fuzzified data is run across a set of linguistic rules to get an output. The output is then defuzzified—converted into a crisp value.

#### 3.4.1 JFuzzyLogic

JFuzzyLogic is an open source package written in Java to implement a fuzzy system. JFuzzyLogic basically makes solving problems using fuzzy logic real simple. It takes in a standardized notation of fuzzy system called Fuzzy Control Language, which describes the input and output variables, fuzzification methods and a set of rules.

#### 3.4.2 Fuzzification

The data read from the sensors were fuzzified and converted into linguistic terms. Using fuzzy sets we can assign data to a degree of linguistic term. For example, if the temperature reading is 55 degrees, fuzzy sets enable us to say that its is 35% low and 65% medium.

Following is the linguistic representation of membership of input where temperature has been categorized into very low, low, medium, high and very high; motion has been categorized into low, medium and high; and light has been categorized into low medium and high.

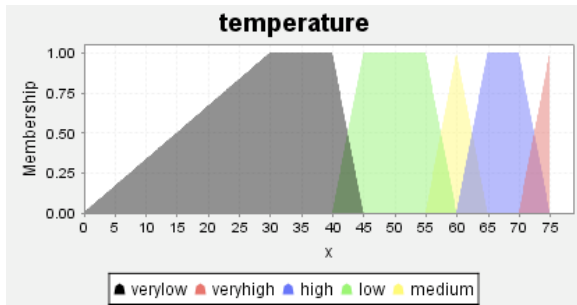


Figure 4. Fuzzification of data from temperature sensor.

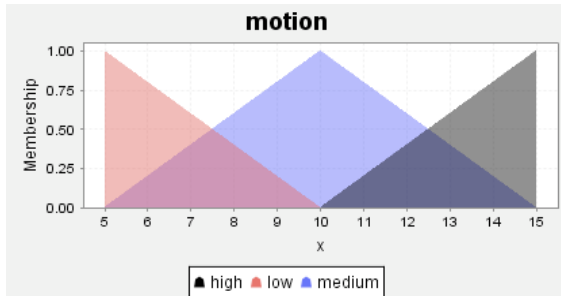


Figure 5. Fuzzification of data from motion sensor.

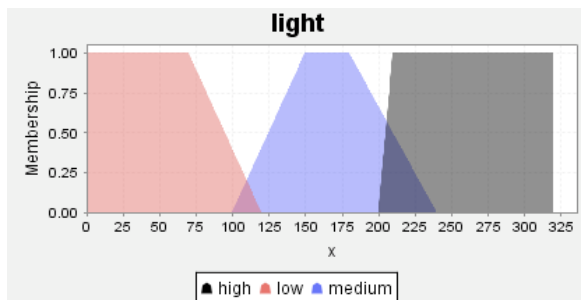


Figure 6. Fuzzification of data from light sensor.

### 3.4.3 Fuzzy Rules

These data were run across rules formed by combination of linguistic terms. Some of the rules are given below:

RULE 1 : IF temperature IS very low AND motion is low THEN thermostat IS low;

RULE 2 : IF temperature IS very low AND motion is medium THEN thermostat IS medium;

RULE 3 : IF temperature IS very low AND motion is high THEN thermostat IS medium;

RULE 4 : IF temperature IS medium AND motion is high THEN thermostat IS medium;

RULE 5 : IF temperature IS high AND motion is low THEN thermostat IS very low;

RULE 6 : IF temperature IS high AND motion is medium THEN thermostat IS low;

RULE 7 : IF temperature IS high AND motion is high THEN thermostat IS low;

RULE 8 : IF temperature IS very high AND motion is low THEN

thermostat IS very low;

...

RULE 16 : IF light IS low AND motion is low THEN light\_out IS off;

RULE 17 : IF light IS low AND motion is medium THEN light\_out IS on;

RULE 18 : IF light IS low AND motion is high THEN light\_out IS on;

...

### 3.4.4 Defuzzification

We get the result in the form of linguistic terms. The result was then defuzzified, converted into crisp values, to make decisions.

Following is the linguistic representation of membership of output where light\_out has been categorized into on and off; and thermostat has been categorized into very low, low, medium and high.

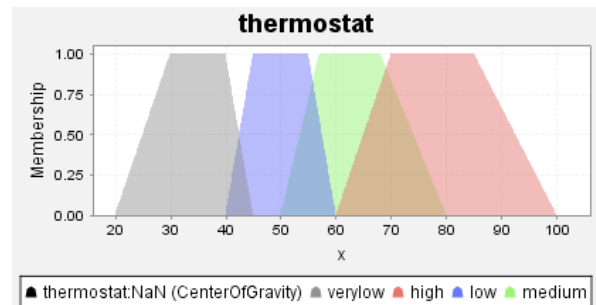


Figure 7. Defuzzification of thermostat state.

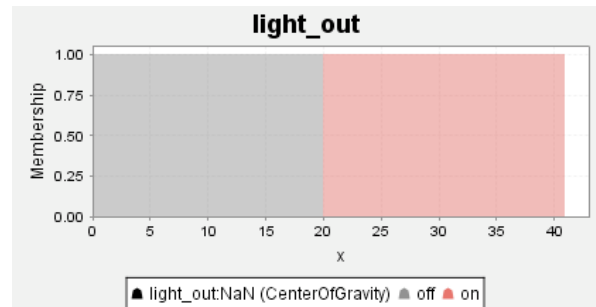


Figure 8. Defuzzification of light bulb state.

We performed this experiment for a week. We collected the usage data of sensors and light bulb for April 4, 2009 from sensors without using this system, which is shown in Figure 9. We then enabled this system and collected usage data for April 5, 2009 along with decisions our system made are shown in Figure 10.

## 4. RESULT

We tested this system and the results from fuzzy logic show that it produced the expected output. The system detected the presence of a user in the room and turned on the light automatically. The light was turned off as soon as the user left the room. It also identified the state when people were sleeping in a room and set back the thermostat by 3 degrees. As a result, this system enabled users to save energy.



Furthermore, the system was also able to generate a summary of the state of devices, display the energy usage in the past and also predict the usage of energy in future.

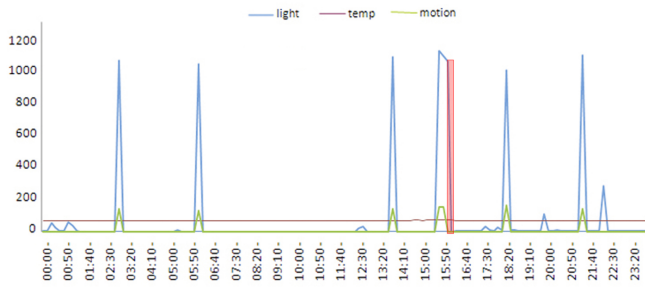


Figure 9. Actual usage data of electronic appliance.

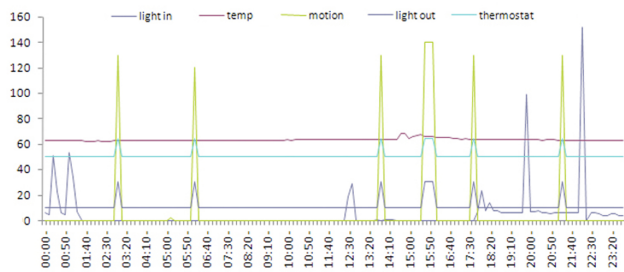


Figure 10. Usage of electronic appliance along with decisions our system made.

## 5. ANALYSIS

Usually people don't always turn off the light when they leave a room, turn on more lights than required, or turn on the light for the entire night. These are the results of forgetfulness and laziness of human beings. Since this system immediately turns off the light and lowers the thermostat when there is no one in the room, it enables a user to save energy. All Zigbee sensors we used in this system are extremely low powered. According to Zigbee Alliance, a sensor can run for years with a pair of batteries [4]. Since, it has a long battery life, we didn't factor out this in our analysis.

### 5.1 Light Bulb

We monitored the state of motion and light for a week as shown in Table 2. We then selected only those entries without motion but with the light turned on. The area highlighted in Figure 9 implies that the light was left on in the absence of people. We calculated the total amount of time the light was on and obtained the total energy consumed. Following is the mathematical approach to find the total energy consumed in the absence of people.

Total minutes light turned on ( $M_T$ )= 63.5 min

Total minutes light turned on in the absence of people ( $M_W$ ) = 7.28 min

Total watt consumed =

$$\begin{aligned}
 &= ((M_T/60 * \text{no of bulbs} * \text{watt of each bulb}) \\
 &= ((M_T/60 * 2 * 60) \\
 &= 127 \text{ Wh}
 \end{aligned}$$

Total watt consumed in absence of people

$$\begin{aligned}
 &= ((M_W/60 * \text{no of bulbs} * \text{watt of each bulb}) \\
 &= ((M_W/60 * 2 * 60) \\
 &= 14.56 \text{ Wh}
 \end{aligned}$$

Total percentage of energy saved = (Total watt consumed / Total watt consumed in absence of people) \* 100

$$= 14.56/127 * 100 = 11.4 \%$$

On average people did not turn off the light at least 1 night per month.

Total watt consumed = (days \* no of Hours turned on \* no of bulbs \* watt of each bulb)

$$\begin{aligned}
 &= (1 * 8 * 2 * 60) \\
 &= 960 \text{ Wh}
 \end{aligned}$$

Total watt consumed per month = 127 \* 30 + 960

$$\begin{aligned}
 &= 3840 + 960 \\
 &= 4800 \text{ Wh}
 \end{aligned}$$

Using this system, situations like this can easily be prevented and hence save energy.

Total energy saved using our system = 960 + (14.56 \* 30)

$$= 1396 \text{ Wh}$$

Our study shows that 0.0145 Kwh energy can be saved per day per room using this system. Also if a user forgets to turn off the light for a whole night, the light will consume 0.96 Kwh of energy.

### 5.2 Thermostat

Rules in fuzzy logic would only increase the heat in thermostat when there was some motion detected. Assuming the outside temperature to be less than 10F (winter), thermostats were also set back by 3 degrees during the night when everyone is sleeping. This would indeed lower a lot of energy consumed.

Total Energy Saved = (BTU per square foot

$$\begin{aligned}
 &* \text{total square foot} * \text{total hours})/3400 \\
 &= (3 * 150 * 6)/3400 \\
 &= 0.92 \text{ Kwh per night}
 \end{aligned}$$

An average user could save around 0.92 Kwh per night if the thermostat was lowered by 3 degrees. This would add up to 27.6 Kwh of energy per month.

Using a similar strategy, when people are at work during the day would save another 0.92 Kwh per day, which is definitely a significant amount of saving. This would add up to 55.2 Kwh of energy per month, which can actually power a 60-watt light bulb for 38 days. This is a result for a single room. If this system was installed in a whole house the saving would be 4-5 times greater than this.

## 6. CURRENT ISSUES

We experienced a couple of issues with this system. As this system was a prototype and only confined to a room, we were able to eliminate a lot of problems. We were still having an issue with our motion sensor. It was an ultra sonic sensor, which did not work well. The sensor would say the room was unoccupied when someone in the room didn't move at all; however we were still able to get results with a good accuracy.

## 7. CONCLUSION

Our goal was to implement a truly intelligent home automation system, which would make decisions itself and lower energy consumption by 5%. Based upon our quantitative analysis, it seems that our hypothesis was supported. Our simple analysis with some basic usage assumptions show that we can reduce lighting energy usage by at least 5%. While we showed we could reduce heating energy use, we did not have enough data to quantify the percentage. We implemented a highly interactive website to monitor the activity of devices and energy usage. We also used fuzzy logic to determine the state of the room and make decisions.

## 8. FUTURE WORK

This prototype basically establishes a platform for more complex home automation systems. For ex. a system where a user could install a sensor or a module seamlessly. Users could buy a module; turn it on and simply click at a button on the web interface. This would automatically discover the new device and integrate it into the system.

Future work would include building blocks on top of this prototype by integrating this system with other sensors like smoke detectors, fire alarms, smell detectors, humidity sensors, etc. One could automate other electronic equipment used in a house. For instance opening and closing window blinds, turning on/off home entertainment systems and alarm clocks.

Some other future work would be a fully customizable web interface. Every one has a different temperature they feel comfortable with. 65 degrees might be cold for one person while at the same time it might be perfect for another. So, there is a need

of a system where a user could basically choose one's preference regarding the temperature he/she feels comfortable with.

It would be nice to get this system working in a whole house instead of just one room. We can have sensors in every room and not only predict energy usage but also predict events occurring by analyzing readings from all sensors.

## 9. ACKNOWLEDGMENTS

Our thanks to Christopher Popp and Digi International for providing us with equipments. We would also like to thank the Winona State University Computer Science Department, Dr. Gerald Cichanowski, Dr. Joan Francioni, and Dr. Tim Gegg-Harrison for guiding us throughout the research.

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# Appendix

**Table 2. Input and output data obtained from this system for April 5, 2009.**

		Input			Output						
Time	light in	temp	motion	light out	thermostat	07:00 - 07:10	0.0	62.47	0.0	9.98	50.0
00:00 - 00:10	6.0	62.91	0.0	9.98	50.0	07:10 - 07:20	0.0	62.62	0.0	9.98	50.0
00:10 - 00:20	4.7	62.95	0.0	9.98	50.0	07:20 - 07:30	0.0	62.43	0.0	9.98	50.0
00:20 - 00:30	50.8	62.78	0.0	9.98	50.0	07:30 - 07:40	0.0	62.76	0.0	9.98	50.0
00:30 - 00:40	22.75	62.78	0.0	9.98	50.0	07:40 - 07:50	0.0	62.72	0.0	9.98	50.0
00:40 - 00:50	6.0	62.89	0.0	9.98	50.0	07:50 - 08:00	0.0	62.49	0.0	9.98	50.0
00:50 - 01:00	4.7	62.76	0.0	9.98	50.0	08:00 - 08:10	0.0	62.76	0.0	9.98	50.0
01:00 - 01:10	53.7	62.96	0.0	9.98	50.0	08:10 - 08:20	0.0	62.66	0.0	9.98	50.0
01:10 - 01:20	33.55	62.76	0.0	9.98	50.0	08:20 - 08:30	0.0	62.72	0.0	9.98	50.0
01:20 - 01:30	7.2	62.76	0.0	9.98	50.0	08:30 - 08:40	0.0	62.76	0.0	9.98	50.0
01:30 - 01:40	0.0	62.57	0.0	9.98	50.0	08:40 - 08:50	0.0	62.74	0.0	9.98	50.0
01:40 - 01:50	0.0	62.04	0.0	9.98	50.0	08:50 - 09:00	0.0	62.81	0.0	9.98	50.0
01:50 - 02:00	0.0	62.02	0.0	9.98	50.0	09:00 - 09:10	0.0	62.80	0.0	9.98	50.0
02:00 - 02:10	0.0	62.09	0.0	9.98	50.0	09:10 - 09:20	0.0	62.81	0.0	9.98	50.0
02:10 - 02:20	0.0	62.35	0.0	9.98	50.0	09:20 - 09:30	0.0	62.76	0.0	9.98	50.0
02:20 - 02:30	0.0	62.02	0.0	9.98	50.0	09:30 - 09:40	0.0	62.76	0.0	9.98	50.0
02:30 - 02:40	0.0	61.92	0.0	9.98	50.0	09:40 - 09:50	0.0	63.02	0.0	9.98	50.0
02:40 - 02:50	0.0	62.28	0.0	9.98	50.0	09:50 - 10:00	0.0	62.76	0.0	9.98	50.0
02:50 - 03:00	0.0	62.41	0.0	9.98	50.0	10:00 - 10:10	0.0	63.11	0.0	9.98	50.0
03:00 - 03:10	0.0	62.35	130.0	29.98	64.31	10:10 - 10:20	0.0	63.04	0.0	9.98	50.0
03:10 - 03:20	0.0	62.41	0.0	9.98	50.0	10:20 - 10:30	0.0	63.11	0.0	9.98	50.0
03:20 - 03:30	0.0	62.41	0.0	9.98	50.0	10:30 - 10:40	0.0	63.19	0.0	9.98	50.0
03:30 - 03:40	0.0	62.35	0.0	9.98	50.0	10:40 - 10:50	0.0	63.17	0.0	9.98	50.0
03:40 - 03:50	0.0	62.37	0.0	9.98	50.0	10:50 - 11:00	0.0	63.24	0.0	9.98	50.0
03:50 - 04:00	0.0	62.41	0.0	9.98	50.0	11:00 - 11:10	0.0	63.19	0.0	9.98	50.0
04:00 - 04:10	0.0	62.35	0.0	9.98	50.0	11:10 - 11:20	0.0	63.32	0.0	9.98	50.0
04:10 - 04:20	0.0	62.58	0.0	9.98	50.0	11:20 - 11:30	0.0	63.21	0.0	9.98	50.0
04:20 - 04:30	0.0	62.35	0.0	9.98	50.0	11:30 - 11:40	0.0	63.34	0.0	9.98	50.0
04:30 - 04:40	0.0	62.54	0.0	9.98	50.0	11:40 - 11:50	0.0	63.30	0.0	9.98	50.0
04:40 - 04:50	0.0	62.43	0.0	9.98	50.0	11:50 - 12:00	0.0	63.17	0.0	9.98	50.0
04:50 - 05:00	0.0	62.35	0.0	9.98	50.0	12:00 - 12:10	0.0	63.46	0.0	9.98	50.0
05:00 - 05:10	0.0	62.35	0.0	9.98	50.0	12:10 - 12:20	0.0	63.19	0.0	9.98	50.0
05:10 - 05:20	0.0	62.53	2.0	9.98	50.0	12:20 - 12:30	0.0	63.48	0.0	9.98	50.0
05:20 - 05:30	0.0	62.49	0.0	9.98	50.0	12:30 - 12:40	19.2	63.32	0.0	9.98	50.0
05:30 - 05:40	0.0	62.35	0.0	9.98	50.0	12:40 - 12:50	29.1	63.61	0.0	9.98	50.0
05:40 - 05:50	0.0	62.35	0.0	9.98	50.0	12:50 - 13:00	0.0	63.61	0.0	9.98	50.0
05:50 - 06:00	0.0	62.35	0.0	9.98	50.0	13:00 - 13:10	0.0	63.59	0.0	9.98	50.0
06:00 - 06:10	0.0	62.35	0.0	9.98	50.0	13:10 - 13:20	0.0	63.53	0.0	9.98	50.0
06:10 - 06:20	0.0	62.41	120.0	29.98	64.31	13:20 - 13:30	0.05	63.59	0.0	9.98	50.0
06:20 - 06:30	0.0	62.47	0.0	9.98	50.0	13:30 - 13:40	0.05	63.28	0.0	9.98	50.0
06:30 - 06:40	0.0	62.35	0.0	9.98	50.0	13:40 - 13:50	0.45	63.67	0.0	9.98	50.0
06:40 - 06:50	0.0	62.58	0.0	9.98	50.0	13:50 - 14:00	0.0	63.53	130.0	29.98	64.31
06:50 - 07:00	0.0	62.35	0.0	9.98	50.0	14:00 - 14:10	1.0	63.40	0.0	9.98	50.0
						14:10 - 14:20	1.0	63.61	0.0	9.98	50.0

14:20 - 14:30	1.0	63.32	0.0	9.98	50.0	19:40 - 19:50	6.0	63.30	0.0	9.98	50.0
14:30 - 14:40	0.0	63.40	0.0	9.98	50.0	19:50 - 20:00	99.15	63.42	0.0	9.98	50.0
14:40 - 14:50	0.0	68.09	0.0	9.98	50.0	20:00 - 20:10	7.4	63.19	0.0	9.98	50.0
14:50 - 15:00	0.0	67.97	0.0	9.98	50.0	20:10 - 20:20	6.8	63.26	0.0	9.98	50.0
15:00 - 15:10	0.0	64.43	0.0	9.98	50.0	20:20 - 20:30	7.7	63.26	0.0	9.98	50.0
15:10 - 15:20	0.0	65.68	0.0	9.98	50.0	20:30 - 20:40	6.0	63.04	0.0	9.98	50.0
15:20 - 15:30	0.0	66.39	0.0	9.98	50.0	20:40 - 20:50	6.0	63.26	0.0	9.98	50.0
15:30 - 15:40	0.0	67.09	0.0	9.98	50.0	20:50 - 21:00	5.6	63.32	0.0	9.98	50.0
15:40 - 15:50	0.0	66.06	140.0	29.98	64.11	21:00 - 21:10	6.0	63.24	0.0	9.98	50.0
15:50 - 16:00	1012.0	65.76	140.0	29.98	64.11	21:10 - 21:20	6.0	63.04	0.0	9.98	50.0
16:00 - 16:10	1004.0	65.69	140.0	29.98	64.11	21:20 - 21:30	6.0	62.81	130.0	29.98	64.31
16:10 - 16:20	0.0	65.17	0.0	9.98	50.0	21:30 - 21:40	6.0	62.82	0.0	9.98	50.0
16:20 - 16:30	0.0	64.87	0.0	9.98	50.0	21:40 - 21:50	6.0	62.76	0.0	9.98	50.0
16:30 - 16:40	0.0	64.87	0.0	9.98	50.0	21:50 - 22:00	5.9	62.82	0.0	9.98	50.0
16:40 - 16:50	0.0	64.62	0.0	9.98	50.0	22:00 - 22:10	6.0	62.82	0.0	9.98	50.0
16:50 - 17:00	0.0	64.22	0.0	9.98	50.0	22:10 - 22:20	263.85	62.87	0.0	9.98	50.0
17:00 - 17:10	0.0	63.96	0.0	9.98	50.0	22:20 - 22:30	5.9	62.89	0.0	9.98	50.0
17:10 - 17:20	0.0	63.69	0.0	9.98	50.0	22:30 - 22:40	5.9	62.82	0.0	9.98	50.0
17:20 - 17:30	0.0	63.98	0.0	9.98	50.0	22:40 - 22:50	6.0	62.95	0.0	9.98	50.0
17:30 - 17:40	0.0	63.65	0.0	9.98	50.0	22:50 - 23:00	5.5	62.72	0.0	9.98	50.0
17:40 - 17:50	910.3	63.61	130.0	9.98	64.31	23:00 - 23:10	4.0	62.80	0.0	9.98	50.0
17:50 - 18:00	7.1	63.65	0.0	9.98	50.0	23:10 - 23:20	4.1	62.76	0.0	9.98	50.0
18:00 - 18:10	23.8	63.61	0.0	9.98	50.0	23:20 - 23:30	5.3	62.76	0.0	9.98	50.0
18:10 - 18:20	8.0	63.59	0.0	9.98	50.0	23:30 - 23:40	5.3	62.82	0.0	9.98	50.0
18:20 - 18:30	924.0	63.61	0.0	9.98	50.0	23:40 - 23:50	4.1	62.76	0.0	9.98	50.0
18:30 - 18:40	7.9	63.59	0.0	9.98	50.0	23:50 - 00:00	4.0	62.76	0.0	9.98	50.0
18:40 - 18:50	8.0	63.55	0.0	9.98	50.0						
18:50 - 19:00	6.6	63.38	0.0	9.98	50.0						
19:00 - 19:10	6.0	63.19	0.0	9.98	50.0						
19:10 - 19:20	6.0	63.24	0.0	9.98	50.0						
19:20 - 19:30	6.0	63.61	0.0	9.98	50.0						
19:30 - 19:40	6.0	63.50	0.0	9.98	50.0						

# Comparison of Fuzzy C-Means Algorithms Using Correlation Metrics versus Euclidean Distance Metrics

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## ABSTRACT

Fuzzy clustering algorithms work by assigning a set of genes to a given number of clusters such that each gene potentially belongs to more than one cluster with varying degrees of membership. In most applications, a fuzzy c-means (FCM) algorithm is equipped with an objective function that is based on Euclidean distance metrics. Recently, an alternative way to cluster genes using an FCM algorithm using Pearson correlation distance as a metric was proposed. The algorithm produces more clusters and assigns more genes to functional groups than using Euclidean distance metrics. In this paper, we provide empirical evidence of the effectiveness of the FCM algorithm using Pearson correlation distance by comparing it to an FCM algorithm using Euclidean distance metrics on a set of lung cancer datasets that were gathered from some experiments that were conducted at the National Cancer Institute and Harvard University.

## Keywords

Fuzzy C-Means Algorithms, Correlation metrics, Euclidean distance metrics.

## 1. INTRODUCTION

Clustering methods are often used when we analyze gene expression data. The goal of clustering is to subdivide a set of genes so that the genes that represent similar features fall into the same cluster [4]. Fuzzy clustering algorithms work by assigning a set of genes to a given number of clusters such that each gene may belong to more than one cluster with different degrees of membership [1]. During this process, the algorithm minimizes an objective function.

Gene expression profiles in microarray experiments may correlate positively or negatively. They should be clustered into one group regardless of their expression values. In most applications, Euclidean metrics have been assumed by default in objective function. However, a FCM algorithm using Euclidean metrics may fail to cluster those genes that are the same except that they correlate positively or negatively.

The genome is similar to a jigsaw puzzle. The pieces can be grouped into classes. Groups are then organized by interaction. One group of genes is called a gene cluster. A gene cluster is a set

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of two or more genes that serve to encode for the same or similar products. It is useful in biological and medical research in order to identify each gene's function.

Both a FCM algorithm using Pearson correlation distance as a metric in the objective function and FCM software have been created recently [7]. The FCM software uses both algorithms to process the gene expression data and cluster them. In this paper, we will evaluate both algorithms with three different microarray datasets based on one internal measure: WCSS (Within Cluster Sum-of-Squares) [5]. We found that the FCM algorithm with correlation metrics produces more functionally significant clusters than the FCM algorithm with Euclidean distance metrics.

## 2. METHODS

This study consists of three steps. In the first step, we normalized the raw file of lung cancer datasets which were the result of experiments from NCI (National Cancer Institute) and Harvard University in order to make the distributions identical across arrays. After normalization, the gene data was summarized into expression measures, so that the result was a single expression measure per chip.

In the second step, we converted Affy ID (Affymetrix Probe Set ID) to UID (UniGene ID). The Affymetrix Probe Set ID is a unique identifier generated by Affymetrix, and the recommended primary identifier for analyzing data generated on Affymetrix arrays. However, different organizations use different Affy IDs to identify the same gene which can introduce ambiguities when merging the datasets from different organizations. Therefore, we used the UID which was created through automatic partitioning of GenBank sequences, and each gene was represented by one UID instead of the Affy ID as a key to merge the two lung cancer datasets from two different organizations. The merging resulted in a matrix, in which each row corresponded to an element to be clustered and each column to an experimental condition. This matrix was in the proper form to be processed by FCM software to cluster genes. Table 1 shows an example of gene expression for genes Hs.23175, Hs.53472, and Hs.364964 for four different conditions.

TABLE 1. GENE EXPRESSION.

UID	NAME	GWEIGHT	AD1	AD2	AD3	AD4
EWEIGHT			1	1	1	1
Hs.23175	GABRA3	1	7.862	7.512	7.526	7.832
Hs.53472	OMD	1	7.816	7.77	7.659	8.2
Hs.364964	GS3686	1	9.444	9.159	8.838	9.505

In the third step, we ran the FCM software to process the merged dataset and two other datasets, lung cancer II and yeast, on the two FCM algorithms. The output was two files: mb file and fct

file which was used for further analysis to identify the correct number of clusters. These files are summarized in Tables 2-3. Table 2 is an example of mb file type which containing the membership between genes and clusters. For example, the gene Hs.23175 is 0.967416 (96.7416%) belong to Node 0 (Cluster 0). Table 3 is an example of fct file type which represents the fuzzy centroids.

TABLE 2. OUTPUT OF MB FILE.

UID	NAME	GWEIGHT	Node 0	Node 1
Hs.23175	GABRA3	1	0.967416	0.032584
Hs.53472	OMD	1	0.121146	0.138397
Hs.364964	GS3686	1	0.100486	0.093633

TABLE 3. OUTPUT OF FCT FILE.

CENTROID	NODE	GWEIGHT	AD1	AD2	AD3	AD4
0	Node 0	1	8.227885	8.142764	8.321743	8.910777
1	Node 1	1	7.4861	7.368448	7.564759	7.746347

### 3. DATASETS

The result of merging the NCI and Harvard University’s lung cancer datasets was a  $671 \times 125$  data matrix where each row corresponded to a patient’s expression data and each column to a gene. In addition to these datasets, we also used two datasets to compare the FCM algorithms described in the previous section.

Yeast: The dataset is part of that studied by Spellman et al. [6] and it is a  $698 \times 72$  data matrix, where each row corresponds to an experiment consist of genomic expression data and each column to a gene. There are no a priori known classes for this dataset.

LungCancer II: The dataset of 7,129 genes has 86 lung tumors and 10 normal lung samples [2]. Before the clustering algorithm was applied, quartile normalization had been performed using dChip (biosun1.harvard.edu/complab). Gene expression values were transformed to log2 based values, and the FCM clustering ( $m=1.2$ ) was applied.

### 4. ANALYSIS

We analyzed the results with one intrinsic evaluation method, WCSS. The WCSS evaluation method measures cluster quality based on how “tight” the clusters are. It measures the overall compactness of fuzzy clusters, and the amount of overlap between fuzzy clusters with the inclusion of fuzzy membership. “Tightness” is a measure of how close the genes are to the centroid of the cluster to which they belong. If the cluster is “tight,” the absolute value of slope of the WCSS curve is small.

#### WCSS Evaluating Euclidean Distance

The WCSS evaluation method using Euclidean distance metrics measures the sum of Euclidean distance of each gene and the centroid of the cluster the gene belong to. If the result is smaller, it means that the clusters are tighter.

In the equation for WCSS, the cluster centroids of Node 0 and Node 1 are denoted by  $C_0$  and  $C_1$ , respectively, and the genes are denoted by  $g_j$ .

$$D_r = \sum_{j \in C_r} d(g_j, C_r)^2 = \sum_{j \in C_r} \|g_j - g_r\|^2 \quad (1)$$

where  $\|g_j - g_r\|^2$  is Euclidean distance. The WCSS evaluation method using Euclidean distance metrics is based on the following formula:

$$WCSS(k) = \sum_{r=1}^k D_r \quad (2)$$

where  $k$  is the total number of clusters and  $D_r$  is a measure of within-cluster compactness. To compute  $D_0$ , we need decide if a gene is clustered to Node 0. How do we determine if a gene belongs to a Node (or a cluster)? We need look at the mb file. From Table 2, we can see that A28102\_at belongs to Node 0 by 0.967416 and to Node 1 by 0.032584. Thus, we A28102\_at belongs “more” to Node 0 than Node 1. If we assume that A28102\_at and AB000115\_at both belong to Node 0 then  $D_0 = [(7.862-8.227885)^2 + (7.512-8.142764)^2 + (7.526-8.321743)^2 + (7.832-8.910777)^2 + (9.444-8.227885)^2 + (9.159-8.142764)^2 + (8.838-8.321743)^2 + (9.505-8.910777)^2]$  using the data derived in Tables 1-3.

#### WCSS Evaluating Correlation

The WCSS evaluating correlation measures the sum of correlation-based distance of each gene and the centroid of the clusters to which the gene belongs. If WCSS is smaller, the clusters are tighter. The WCSS for correlation-based FCM is:

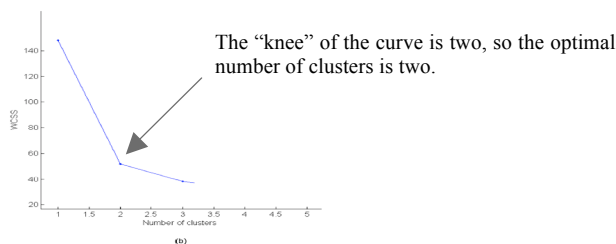
$$D_r' = \sum_j u_{jr}^m d(x_j, C_r) = \sum_j u_{jr}^m [-corr(x_j, C_r)] \quad (3)$$

where  $[-corr(x_j, C_r)]$  is the correlation-based distance. The fuzzy membership  $u_{jr}^m$  represents the membership of gene  $j$  to the cluster  $C_r$ , where  $m$  is the fuzziness index. The  $corr(x_j, C_r)$  is the correlation between a gene  $x_j$  and the cluster centroid  $C_r$ , which we computed using Matlab. The WCSS evaluation method using Pearson Correlation metrics is based on the same formula (2) except that we are using the distance calculation as the one that used for  $D_r'$ :

$$WCSS(k) = \sum_{r=1}^k D_r' \quad (4)$$

where  $k$  is the total number of clusters,  $D_r'$  is a measure of within-cluster compactness.

Good clustering yields clusters where genes have small within cluster sum of squares  $WCSS(k)$ . On the WCSS curve, the “optimal” number of clusters by predicted as the abscissa closest to the “knee” of the curve.



Sometimes it is difficult to identify the precise location of the “knee”. Therefore, we defined a function to formalize the location of the “knee” and thereby identify the “optimal” number of clusters.

$$N(i) = \frac{WCSS(i-1) - WCSS(i)}{WCSS(i)} \quad (5)$$

$WCSS(i)$  is the value of WCSS for number of cluster  $i$  on the WCSS curve. If  $N(k)$  is the closest  $N(i)$  to 0.3 which is a critical number that the clusters can be considered as “tight,” then  $k$  is the “optimal” number of clusters.

We performed fuzzy clustering over three microarray datasets: lung cancer I, lung cancer II, and yeast. To make a fair comparison, the FCM clustering algorithm was randomly initialized and the fuzziness index  $m$  was set to 1.2 according to [3].

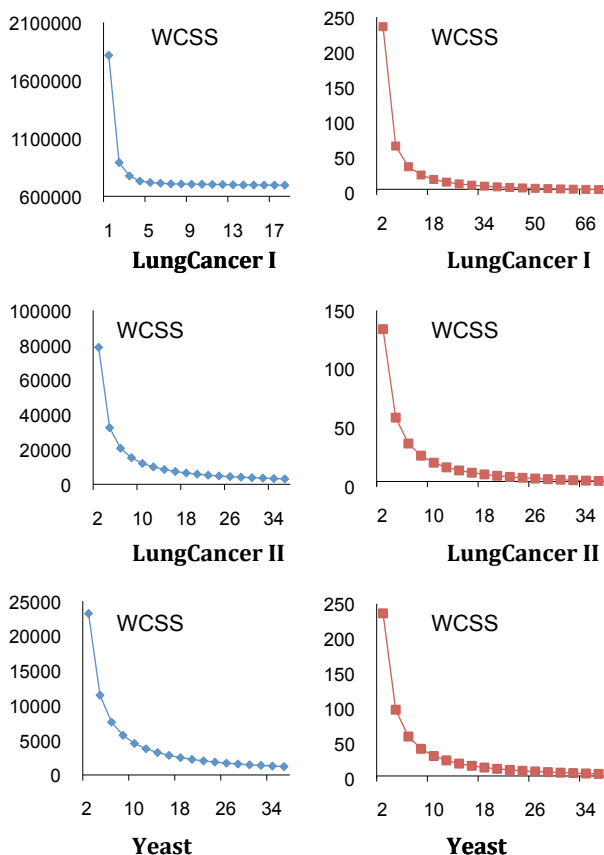


Fig.1. Validity measures calculate on lung cancer and yeast datasets

From the curves above we can see that clusters clustered by the FCM using Correlation Metrics is “tighter” than the ones clustered

by using Euclidean distance metrics. This observation is confirmed by our “knee” identifying function (5). The “optimal” number of cluster for each of the datasets is summarized in table 4.

TABLE 4. NUMBER OF CLUSTERS.

Data Sets	WCSS_Euclidean	WCSS_Correlation
Lung Cancer I	8	15
Lung Cancer II	7	8
Yeast	6	8

### P-values of Hypergeometric Probability Distribution

One downfall of the Fuzzy C-Means (FCM) clustering algorithm is the inability to assess the quality of the clusters after the cluster refinement process. To address this issue, the p-values of hypergeometric probability distribution can be calculated based on the distribution of associated genes with respect to the each functional category in a cluster.

Not only did the FCM using correlation metrics cluster more “optimal” clusters than the FCM algorithm using Euclidean distance metrics, the FCM algorithm with a correlation-based distance metric also produced more meaningful clusters.

TABLE 5. RESULTS BASED ON THE EUCLIDEAN DISTANCE METRICS.

Ck	Functional category	Mk	nk	Mk	p-Value
20	cell communication	136	41	6	0.00148611
75	homeostasis	78	41	4	0.00575199
4	sexual reproduction	68	36	3	0.017805286
66	response to abiotic stimulus	215	69	8	0.018864246
66	response to stress	263	69	9	0.021242483
66	regulation of gene expression	42	69	3	0.027838513
4	regulation	36	36	2	0.034842226
75	cell communication	136	41	4	0.037257344
75	morphogenesis	83	41	3	0.041907549
26	regulation	36	41	2	0.044207224
35	regulation	36	41	2	0.044207224
78	regulation	36	41	2	0.044207224
58	filamentous growth	51	30	2	0.047132831

TABLE 6. RESULTS BASED ON PEARSON CORRELATION-BASED METRICS.

Ck	Functional category	Mk	nk	Mk	p-Value
18	conjugation	67	29	8	6.59E-09
18	sexual reproduction	68	29	8	7.44E-09
18	reproductive physiological process	117	29	8	5.55E-07
42	localization	723	134	45	7.19E-07
6	response to abiotic stimulus	215	35	10	4.17E-06
18	cell adhesion	15	29	3	0.00011314
87	response to abiotic stimulus	215	35	7	0.00130195

61	response to abiotic stimulus	215	27	6	0.00163644
6	conjugation	67	35	4	0.0018438
6	sexual reproduction	68	35	4	0.00194796
79	regulation	91	89	7	0.00230813
18	response to abiotic stimulus	215	29	6	0.00241389
58	conjugation	67	19	3	0.00279511
58	sexual reproduction	68	19	3	0.00291608
30	response to stress	263	33	7	0.00300689
48	response to stress	263	33	7	0.00300689
99	morphogenesis	83	34	4	0.00362765
93	homeostasis	78	18	3	0.0036734
64	regulation	91	76	6	0.00467249
30	response to abiotic stimulus	215	33	6	0.00477585
50	homeostasis	78	43	4	0.00682381
68	death	26	23	2	0.00796575
	...	...	...	...	...

#### Correlation vs. Euclidean Distance

Tables 5 and 6 summarize the results from the applications of FCM algorithm to the yeast microarray dataset. In the first experiment (which is shown in Table 5), the FCM algorithm is initialized randomly and the Euclidean distance metrics used. In the second experiment (which is shown in Table 6), the algorithm is also initialized randomly, but, a correlation-based metrics is in place. The algorithm is set to make 100 clusters, and 1.2 is chosen for the fuzziness index  $m$ . It is evident that an FCM algorithm with a correlation-based distance metric produces more meaningful clusters. With Pearson correlation, there are 24 functional categories being significantly enriched across each cluster ( $p$ -values  $< 0.05$ ), as compared to 13 with Euclidean distance. The correlation based algorithm is able to identify genes with  $p$ -values  $< 10^{-4}$ , but, they are completely missed by an algorithm with Euclidean distance metrics.

## 5. CONCLUSION

We have compared a Fuzzy C-Means algorithm using correlation metrics with one using Euclidean distance metrics. Tables 4–6

show that not only did the FCM using correlation metrics cluster more “optimal” clusters than the FCM algorithm using Euclidean distance metrics, the FCM algorithm with a correlation-based distance metric also produced more meaningful clusters. Therefore, an FCM algorithm using Pearson correlation distance to cluster genes is better than the one using Euclidean distance.

## 6. ACKNOWLEDGMENT

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