WERC Design Contest 2014

Task 1: Open Task - CircuiTree Decay Detector– Design of a Hybrid and Cost-Effective System to Measure Structural Integrity of Trees

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TASK 1

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CIRCUITREE DECAY DETECTOR – DESIGN OF A HYBRID AND INEXPENSIVE SYSTEM TO MEASURE STRUCTURAL INTEGRITY OF TREES

EXECUTIVE SUMMARY

This report presents a solution to Task 1, Open Task, for the 2014 Environmental Design Contest sponsored by New Mexico State University's Institute for Energy and the Environment. As stated in the Task 1 description, the proposed problem identification and solution should respond to a current issue of national importance using an innovative and economically feasible approach.

To address the Task 1 directive, the Environmental Engineering for Tree Safety (EETS) Consulting Group proposes CircuiTree Decay Detector. CircuiTree is a safe, non-invasive and easy-to-use system for the homeowner or small nursery business to test the structural integrity of trees on their property. Using an innovative hybrid sensor system, an impact mallet and a hand held mobile device, frequency and time of flight measurements are gathered and analyzed. From these readings the health of the tree is assessed, and results are reported to the user through a custom designed mobile app as well as recorded with the USDA's International Tree Failure Database.

The motivation for this product responds to the destruction caused by tropical storms and hurricanes frequently experienced along the northeast coast of the United States. In Hurricane Sandy alone, property claims exceeded 19 billion dollars, property losses 65 billion dollars and 20 individuals were killed as a direct result of a falling tree.

The CircuiTree Decay Detector will be marketed through a licensing partnership targeting approximately 60,000 households and 1,000 small nurseries in the northeast. The full scale commercialized cost to manufacture the device is approximately \$20 dollars while the bench scale cost of the device is \$49 dollars. A retail price for the system is suggested at \$49.99 for a total profit to the consulting group of \$305,000 in this first year of licensing. An outreach plan is proposed that collaborates with several organizations with already established public communication channels. These organizations include: the USDA Forestry Services - Hazard Tree Management Program, The International Society of Arboriculture (ISA), The Tree Care Industry Association (TCIA) and state Agriculture Extension Offices.

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1 INTRODUCTION

1.1 Background Discussion

Trees provide a number of essential benefits to the environment, our ecosystems and economy. Energy usage, noise and air pollution reduction, and quality of life are all impacted positively by trees. Trees lessen storm water runoff, absorb carbon dioxide, and provide oxygen in addition to cleaner air. They also contribute to the aesthetics of cities, generate building materials, and increase homeowner property values. Furthermore, "an average-sized tree provides an estimated $7 savings in annual environmental benefits, including energy conservation and reduced pollution…and produces approximately 260 pounds of oxygen per year."[1] The USDA's most recent Forest Industry Inventory estimates that there are approximately 247 billion trees with at least a one inch diameter in the United States.[2]

Trees provide great benefits but as is evidenced during wind storms and hurricanes, trees can cause significant damage to property and even cause death. Hurricane Sandy, reaching landfall in the Northeast as a tropical storm on October 29, 2012, is a case in point. In this storm, New York City alone lost approximately 10,000 trees, many of them causing significant property damage or bodily harm.[3] In total, estimates for tree loss due to the storm in New York State top 20,000.[4] Even today, in Brooklyn, New York, the Parks Department is in the process of removing over 2,000 trees as a preventative measure to avoid possible liability due to Hurricane Sandy. The root systems of these trees were killed from salt-water saturation.[5]

The economic impact of property and casualty losses from catastrophic events such as hurricanes is staggering. In areas where natural disasters are common, namely states on eastern coastline, the value of insured coastal properties is in excess of $8.9 trillion dollars.[6] In the Northeast, New York's insured coastal property exceeds $2.9 trillion and represents 62% of all insured property value within the state. The percentage of Connecticut, Maine and Massachusetts coastal insured property all exceed 50% of the state's total insured property.[7] When damage does occur to property during windstorms and hurricanes it is most often due to flying or falling debris. Figure 1 shows a typical scenario of property damage due to a fallen tree.

Figure 1 Property Damage from Fallen Tree

Reviewing property claims, Hurricane Sandy proved to be the third most costly catastrophic storm in 2013 dollars with total claims of over 19 billion dollars and property losses exceeding 65 billion dollars.[8,9] Even with new national building compliance codes instituted in part as a result of Hurricane Katrina, the human and property loss associated with Sandy due to falling or flying debris was substantial. In total, 106 individuals died as a result of the storm with 19% or 20 individuals dying directly because of fallen trees. Figure 2, Causes of Death Due To Hurricane Sandy, shows the breakdown of loss of life due to the storm.[10]

In a review of thousands of downed trees as a result of the storm, one recurring condition appeared to be present in the majority of the trees: diminished structural integrity due to rot. In most cases, the outward appearance of the trees was unblemished, yet internally, varying degrees of rot contributed to a weakened tree state.

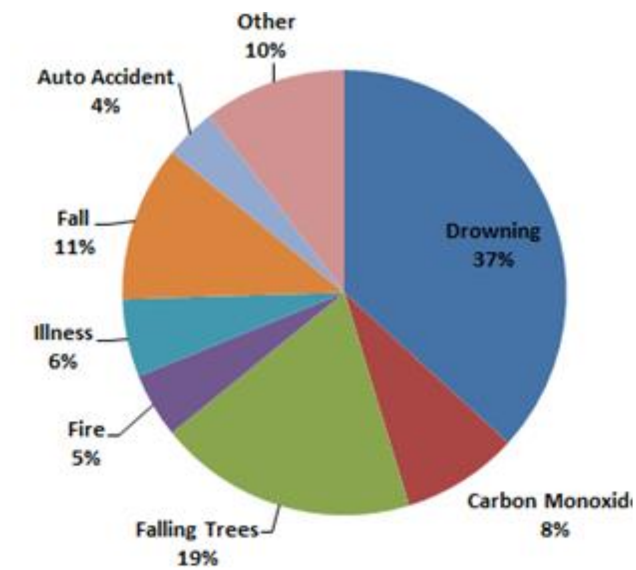


Figure 2 Causes of Deaths Due To Hurricane Sandy

1.2 Why Trees Fail

There are two failure modes associated with the structural integrity of trees. The first is trunk and branch breaking due to internal rot and the second is failure due to shallow root systems. According to the International Tree Failure Database cataloging over 6,000 failures, approximately 65% of trees fail due to trunk and branch snaps and 35% fail due to shallow root systems.[11] When a shallow root system fails, the tree topples pulling out the root ball as it falls.

Of trees that fail due to trunk or branch rot, the majority are a variety of pines.[12] Figure 3 show an examples of a downed tree with internal trunk rot. The U.S. Forest Service estimates that approximately 20% of all pines have some degree of internal rot.

Figure 3 Example of Trunk Rot

Wood decay is a stage of a tree's life cycle. But sometimes decay can occur sooner in some trees causing tree failure. Decay starts in living trees through some sort of wound. Broken limbs, leaf blight, fire scars, insects, fungi, and human destruction are some of the main causes of wounds. Once a tree is wounded, insects and fungi can enter the tree and cause further decay. Once fungi starts growing on a tree it replicates and spreads. While most fungi do not actually affect the health of the tree, they all contribute to a cause of structural weakness by the decay they cause.

Presently, there are no inexpensive, easy to use systems targeted to the homeowner or small nurseries that assess the structural integrity of trees. Therefore, to address this gap while responding to a need of national importance due to economic, legal, health and safety ramifications, we propose CircuiTree Decay Detector.

2 DESIGN SOLUTION

The CircuiTree Decay Detector is an elegant, simple and cost effective system to test tree trunks for evidence of internal tree rot. The user strikes the tree specimen with the impact device and a signal is sent to a microcontroller, processed and then internal tree rot results are reported to the user as well as to the USDA's International Tree Failure Database. This solution presents a minimally invasive means for analyzing the structural integrity of trees.

The CircuiTree System utilizes user-generated impulses to determine time of flight (ToF) measurements and frequency analysis that identify whether a standing tree is decayed. An indexed database allows licensed users to search, sort, and record information. The technology associated with CircuiTree is custom designed, operable by a sole person and minimizes human measurement and input error. Figure 4 shows a high level overview of the system process.

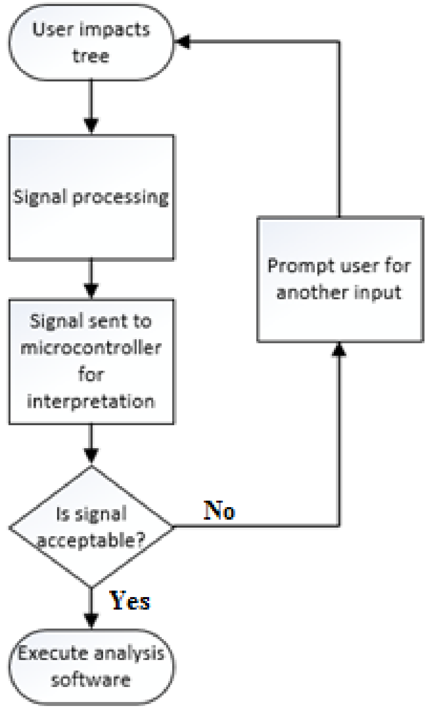


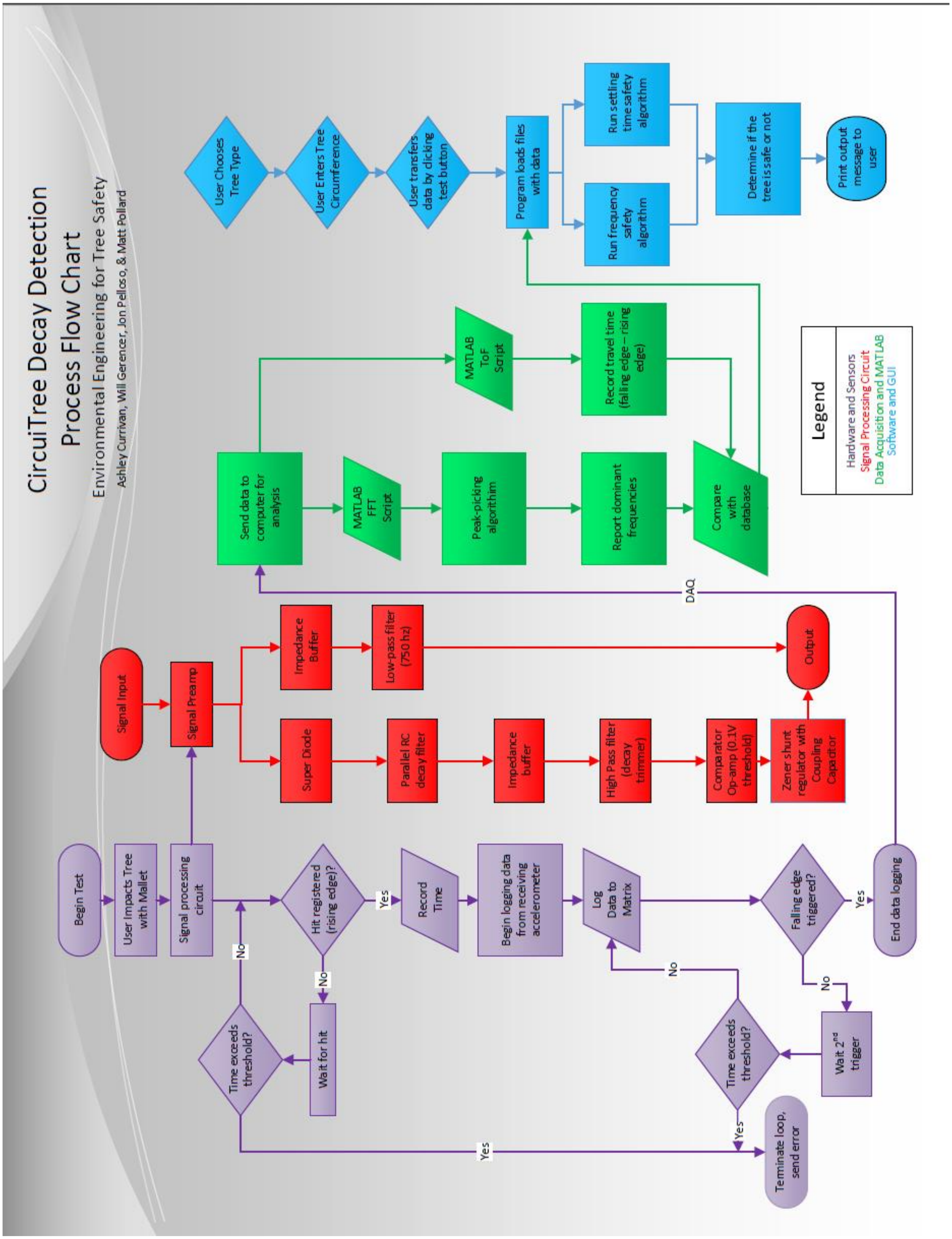
Figure 4 Overview of System Process

3 SYSTEM PROCESS FLOW DIAGRAM

The process begins with user impacting the tree with a CircuiTree mallet. The signal is then sent through a circuit for processing where a frequency and settling time of the signal is produced.

Simultaneously, the sensors are running to assure that the hit was actually registered. If it was not, the user is prompted to impact the tree again, but if the time exceeds the threshold before the next hit, an error is sent and the loop is terminated. If the hit was registered, the time it takes for the signal to reach the accelerometer is recorded and data logging begins from the accelerometer. The system then listens to determine if a falling edge on the signal was triggered, ending the data logging. If no falling edge is triggered, the system waits for the trigger unless the time threshold is exceeded, in which the loop is terminated and an error message is sent.

Once data logging has ended, data acquisition begins. For the bench scale demonstration, the data is sent to a computer where it will be analyzed by a number of MATLAB and LabVIEW scripts. MATLAB performs a Fast Fourier Transform (FFT), to normalize the wave and output a frequency, as well as a peak-picking algorithm that determines how many times the signal peaked at maximum amplitude to report the dominant frequencies of the signal. While the FFT is


CircuiTree Decay Detection
Process Flow Chart
Environmental Engineering for Tree Safety
Ashley Currivan, Will Gerencer, Jon Pelloso, & Matt Pollard
Begin Test
User Impacts Tree with Mallet
Signal processing circuit
Hit registered (rising edge)?
Yes
No
Wait for hit
Time exceeds threshold?
No
Yes
Record Time
Begin logging data from receiving accelerometer
Log Data to Matrix
Falling edge triggered?
Yes
No
Wait 2nd trigger
Time exceeds threshold?
No
Yes
Terminate loop, send error
End data logging
DAQ
Signal Input
Signal Preamp
Super Diode
Parallel RC decay filter
Impedance buffer
High Pass filter (decay trimmer)
Comparator Op-amp (0.1V threshold)
Zener shunt regulator with Coupling Capacitor
Impedance Buffer
Low-pass filter (750 hz)
Output
Send data to computer for analysis
MATLAB FFT Script
Peak-picking algorithm
Report dominant frequencies
Compare with database
MATLAB ToF Script
Record travel time (falling edge – rising edge)
User Chooses Tree Type
User Enters Tree Circumference
User transfers data by clicking test button
Program loads files with data
Run frequency safety algorithm
Run settling time safety algorithm
Determine if the tree is safe or not
Print output message to user
Legend
Hardware and Sensors
Signal Processing Circuit
Data Acquisition and MATLAB
Software and GUI

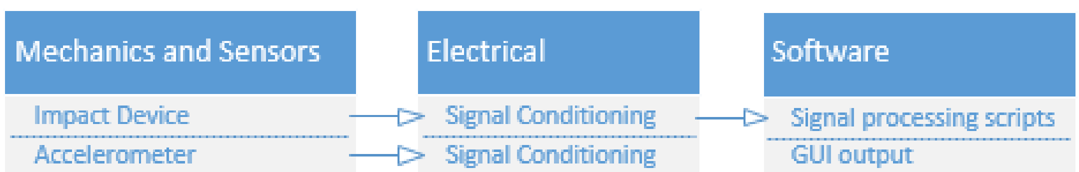
running, a time of flight algorithm is also running to record the travel time (falling edge to rising edge) of the signal. The values are compared with the database and sent to a program that determines the safety of the tree.

While the computer is analyzing the signal of the impact, the user is selecting their tree type and entering the trees circumference on a graphical user interface. Once the user clicks the "Run Test" button, the program loads both the file that contains the frequency of the signal and the file with the settling time of the signal. Once the program has determined if the tree is safe or not, the result is sent to the user.

For full scale implementation, the system will be marketed as a mobile device application. The diagram displayed on the following page depicts an overview of the CircuiTree Decay Detector components and processes, including those of the CircuiTree control system.

4 CIRCUITREE DETAILED SYSTEM DESIGN

The CircuiTree Decay Detector is composed of three main sub-systems: mechanics and sensors, electrical, and software. The system as a whole was designed using a waterfall system approach, and can be seen below.



Using this waterfall design methodology allows for optimum interaction between sub-systems, making the experience seamless for the user, while also dividing the system in to distinct subsystems.

4.1 Mechanics and Sensors

The mechanics and sensors sub-system has been designed for ease of use, both in setup and execution. Two groups of components make up this sub-system: the impact device, and the sensors which will transmit analog signals to the electrical sub-system. For the impact device, a simple passive (requiring no power supply) piezoelectric disc transducer is integrated in to a hammer-style impact device. Upon impact, this piezoelectric disc will deflect, generating a measureable voltage which will be used in the electric sub-system. The second component of this sub-system is the accelerometer, which is used to measure how long the impact takes to travel through the tree, as well as the vibrations present in the wood. The system currently uses an ACH-01-04, manufactured by Measurement Specialties, Inc. This accelerometer is affixed to the tree via bark penetrating screws, which will make light contact with the cambium of the tree. While the sensor is not penetrating the wood, accurate measurements can still be made without driving nails or screws deep in to the wood. Only penetrating the bark fully allows for minimal invasiveness on the part of the tree.

4.2 Electrical

Following the mechanics and sensors sub-system, the electrical sub-system manipulates the raw signals gathered in the first sub-system. In order to maximize accuracy in the electrical measurements, a parallel approach to design was taken. Rather than creating two separate circuits to realize these functions required for ToF and frequency analysis, a single circuit was designed and constructed that was robust enough to process both of types of inputs. This circuit is shown in the Figure 5 below:

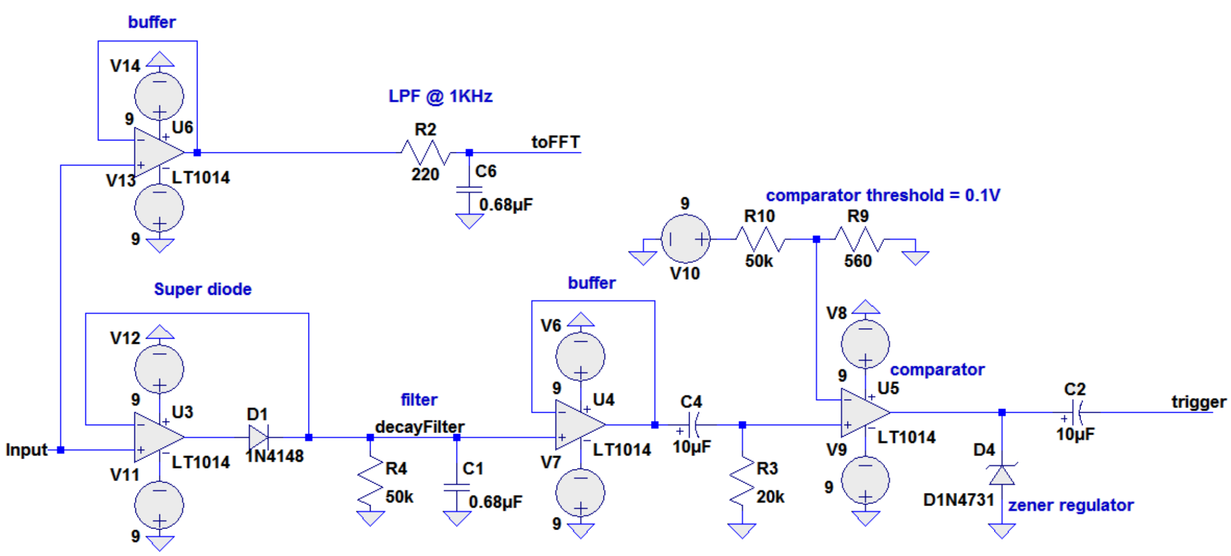


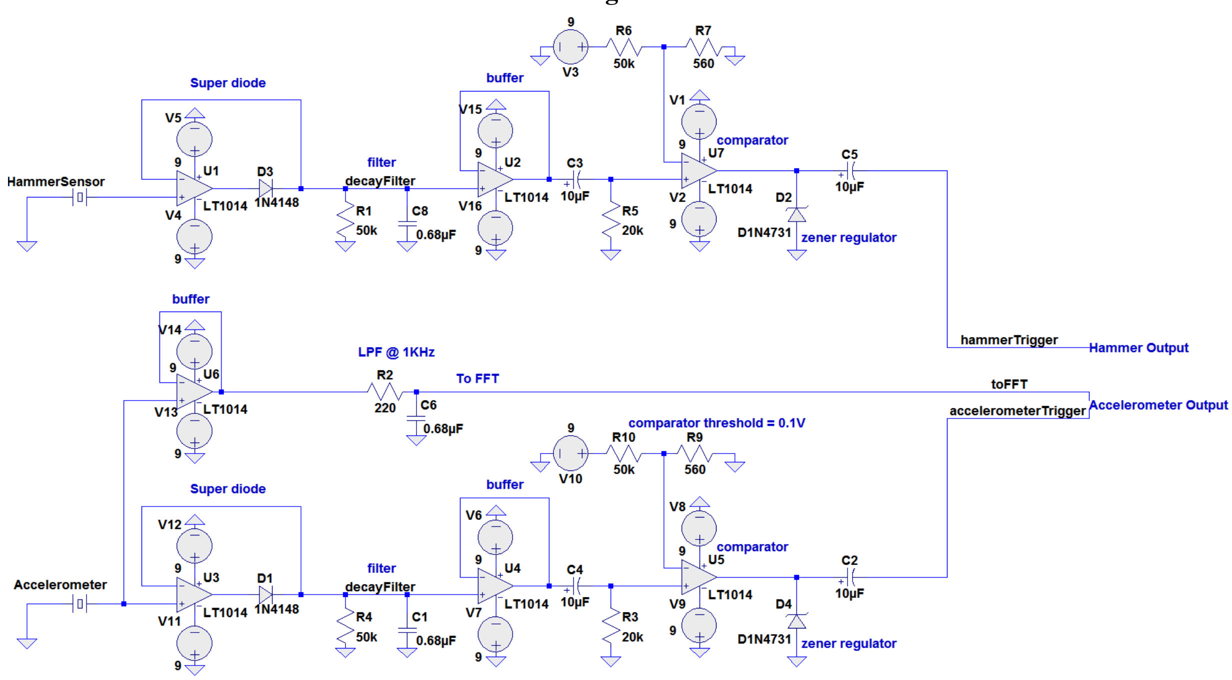
Figure 5

The goal of this circuit is to process any incoming signal from any vibration transducer, and give two outputs: one analog-generated digital trigger which displays signal length/input impulse conformation, and a second output which will be used to perform a frequency analysis. This analysis is based off of the widely used Fast Fourier Transform (FFT) algorithm, which measures the frequency content of any given signal.[13,14] By extracting relevant data from its output, the system can report the dominant vibrational frequency measured.

The circuit works by taking an input signal, and passing it through a subnet of operational amplifier (op-amp) circuits to produce the desired outcome. The pre-conditioned signal is split in to the following sections: a low-pass filter (LPF) sub-circuit (upper), and a trigger sub-circuit (lower). For the LPF sub-circuit, the signal is buffered and is then sent through a passive LPF set at 1 KHz, which removes any high frequency noise present in the signal; the output from this sub-circuit is now ready for FFT analysis. For the trigger sub-circuit, the signal is sent through an additional four circuit subnet. These subnets have been implemented in order to manipulate the input signal to have the form of a square wave. This square wave carries the properties of the input signal, such as start time and duration, which will be used in the software sub-system for both ToF and frequency analysis. For more details and further elaboration on the specifications and functions of the circuit, bench scale model booklet will be available at the competition. Since the mechanics and sensors sub-system has two outputs, the electrical sub-system then requires two signal conditioning circuits in order to complete the electrical sub-system.

Figure 6 is a complete schematic of the electrical sub-system used in the CircuiTree system. Both the hammer and accelerometer have their respective circuit and respective outputs, as illustrated in the schematic. The outputs from this sub-system are able to be directly wired to a computer, or ultimately transmitted to a mobile device, ready for the signal processing scripts.

Figure 6



Last, the software sub-system will handle outputs. The software consists of two main components, the signal processing scripts, and user interface (UI) interactions. The signal processing scripts simultaneously perform the two types of analysis mentioned previously: ToF and frequency analysis. The script for the ToF analysis reads in both the timings signals from the impact device and the accelerometer, which are both square waves. By analyzing when a rising edge occurs in the waveform, the script is able to tell the travel time of the imparted stress wave through the wood, and report this result. For the frequency analysis, outputs from the Low-pass filter subnet of the signal conditioning circuit are read in, and FFT analysis is performed on the sampled signal, which creates a graphical display of the frequency content of the input signal. Using peak-picking algorithms, the script then pulls the peak frequencies from the FFT, and reports the results to the UI.

4.3 Software and Control System

One of the central features of CircuiTree is the control system (CS).

Figure 7

CircuiTree CS implements a graphical user interface (GUI) that displays tree specific information and was developed using Eclipse. Designed to be user-friendly, the CircuiTree system makes it as easy as possible to test a tree's safety against tree rot. The user selects a tree type, enters the circumference of the tree, and clicks a button to run the test. When a tree type is selected a graphic of the tree, its respective leaf, and a description appears on the GUI so that the user is assured that the correct type of tree is tested. All of the analysis and calculations are run in the background of the program and an easy to understand message is displayed to the user regarding the safety of the tested tree.

Depending on the tree chosen and the size of the tree trunk, the algorithm will determine if the outputted frequencies and settling time of the signal are safe. Tree type and size have their own characteristics that alter the frequency and settling time of the signal. Once the button is pressed, with a tree type selected and circumference entered, two files are scanned into the program containing the frequency and settling time of the signal. Depending on the size of the tree trunk, the program compares the frequency and settling time signals that were produced by the impact of the tested tree and compare them to the values that were found during experimentation. If the values of the signals for the tested tree fall within a certain threshold for each categorized decay, the extent of the decay will be recognized for that tree and a corresponding output message to the user is generated. Only if both the frequency and time signals are considered to be within a safe range of decay, will the output message display the tree is safe. If either of the tests reports the tree safety as false, then program outputs a message that the tree is potentially unsafe and further investigation by professionals is warranted. Also, in case of any complications that may arise during testing or setup, a hyperlink to a user's manual is included on the GUI.

5 DEMONSTRATION OF VIABILITY

5.1 Experimental Methodology

The foundation of the experimental setup for proof of concept testing consisted of 24 different trunk sections secured to a workbench via a set of clamps. The twenty-four test sections corresponded to varying trunk diameters and levels of decay. In the testing case, decay was simulated by precisely hollowing a certain percentage of the trunk. The trunks were firmly clamped such that vibrations through the tree would be simulated well enough to match that of a real tree. The trunk sections used were freshly cut white pine, and were hewed less than 24 hours before testing. By having fresh logs, moisture and sap content of the samples were kept as close to realistic as possible, making the testing a viable approximation of real tree samples, while maintaining control in a laboratory setting.

For the impact device, a simple piezoelectric transducer was affixed to the back of a rubber impact hammer. This inexpensive sensor was very effective for this task, since only an impulse is needed for a time measurement. The sensor was wired directly to an HP5252xA's first channel, and the oscilloscope was set up to record a waveform upon a trigger response on this channel. An ACH-01-04 accelerometer was affixed to a 6"x1" piece of aluminum. This aluminum was then attached to the log samples via short wood screws, such that the screws penetrated the bark fully, but only mildly penetrated the cambium. By doing this, the sensor is easily affixed to multiple samples without the need for a new sensor. In addition, this method is defined as minimally invasive, as it is causing no actual harm to a living tree. The accelerometer was given a supply voltage of 10V, as required by the specifications sheet supplied by the manufacturer. The sensor was then directly wired to the oscilloscopes second channel. When the first channel was triggered, the oscilloscope recorded both the first channel's response, as well as the second's.

Using an IEEE-488 standard interfacing bus cable, the oscilloscope was connected to a data acquisition computer for data collection. Via LabVIEW 2013, a programming script was written using the HP 5252xA instrument driver to collect data from the IEEE-488 bus input. While the script was running, triggering the oscilloscope transmitted the waveforms from both channels to LabVIEW for analysis. LabVIEW saves these waveforms in Microsoft Excel ".xls" format, and prompts the user for a file name. The Excel file extension was used for future statistical analysis. As a feature of LabVIEW, it is possible to run the script continuously, such that rapid measurements can be taken. Upon completion of data recording, LabVIEW requests a filename and file-path to save the data.

5.2 Experimental Results

Protocol for experimentation included a full-factorial design of experiments approach controlling both tree diameter as well as level of simulated tree decay. Table 1 illustrates that for each of the test specimens, i.e. 9 inch circumference healthy trunk, 9 inch diameter 15% decayed trunk, etc. that 100 test runs were undertaken for each case. A total of 2,200 experiments were run. Upon completion of the experiments, box plots were generated using MATLAB 2013a, for use in comparative analysis. See Figure 8.

Table 1 Experimental Set-up

Diameter (in)	Decay % (of diameter hollowed out)					
	No Decay	15%	30%	45%	60%	75%
9	100	100	100	100	100	100
12	100	100	100	100	100	100
15	100	100	100	100	100	100
18	100	100	100	0	100	0

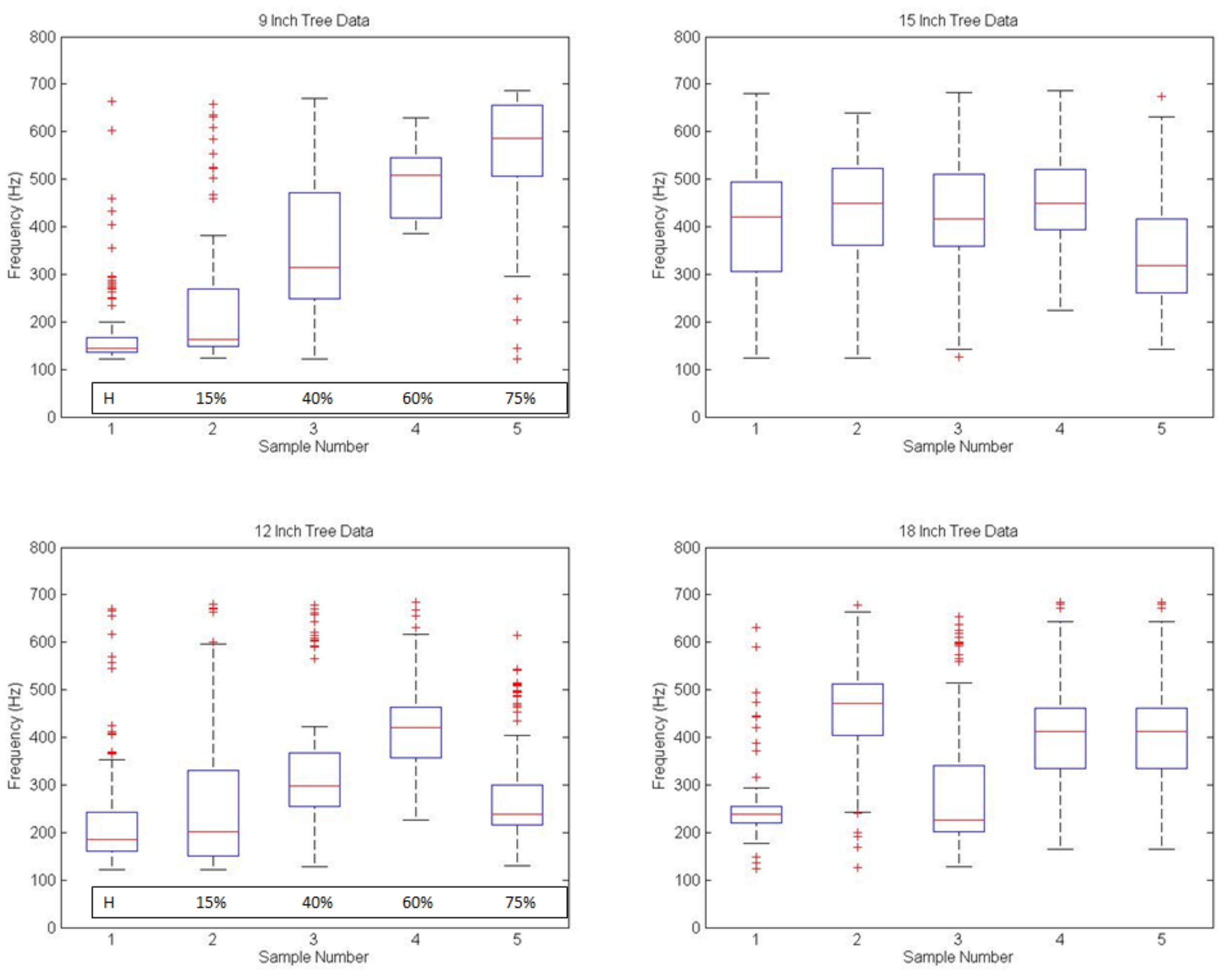


Figure 8

From these plots, one can see that the 9 inch and 12 inch log samples produced an obvious correlation, whereas the 15 and 18 inch samples were inconclusive. This discrepancy could have been be caused by altering the clamping mechanism in experimental setup because the larger logs were affixed to the ground instead of the table because the diameter exceeded clamping mechanism limits.

Therefore, taking the 15 and 18 inch samples to be outliers, both the 9 and 12 inch samples were considered instead.

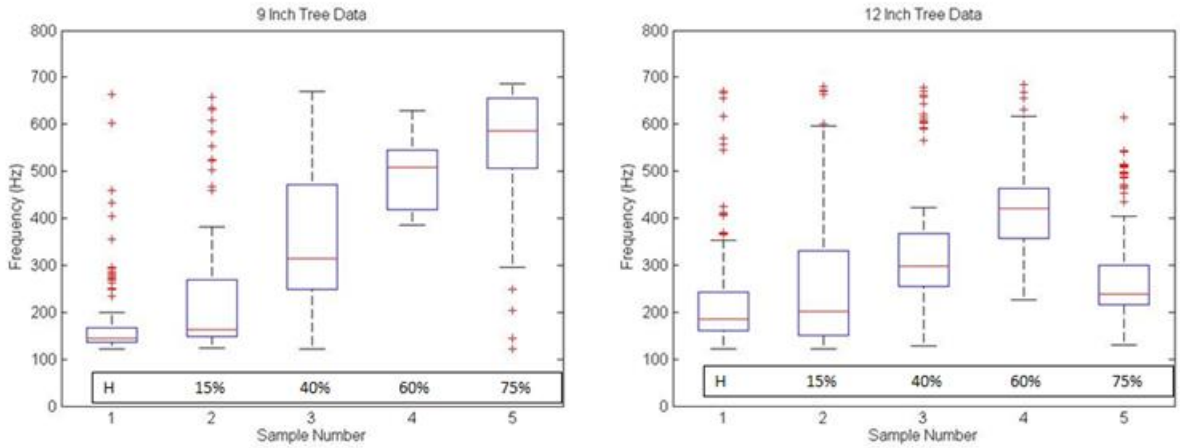


Figure 9

When looking at the 9 inch sample box plot in Figure 9, a trend in the data collected can be seen: as the decay increases, so too does the frequency of the vibrations measured. The 9 inch tree was the most secure to the table, and as such produced excellent results with minimal outliers. Outliers can be seen on the healthy tree samples, with a count of 23 outliers out of 100 samples. The 12 inch tree samples also follow a similar correlation to that of the 9 inch samples, but with some more data outliers. The 75% decayed samples have a clear concentration of frequencies that would correspond to the linear trend found in the first graph; however, a large concentration of frequencies around 250 Hz were taken as dominant in the sample set, since this group contained 6 more samples than the former. Again, by comparing the two samples, it can be seen that there is indeed a correlation between tree rot and vibrational frequency of stress waves. This satisfies the desired outcome for proof of concept testing, and allows us to confidently go forward to full scale testing for frequency analysis of live tree samples.

5.3 Bench scale versus Full Scale Implementation

For full commercialization of the CircuiTree system, the DAQ computer will be replaced with an Apple iOS app. The bench scale data acquisition method will be replaced with a digital microcontroller with an appropriate sampling rate. Data from the embedded microcontrollers will be sent over Bluetooth to a mobile application, where the collected data will be processed. The mobile application is in early stages of beta prototyping. The goal is to have an application retrieve the files wirelessly and run the same computation that the current GUI runs. A similar message will display, but the availability and ease-of-use of an app would make for a much better product. In the future, a CircuiTree database will be created, where all data will be sent to improve the efficiency of the technology. The user will also be able to sign in with a unique username and password to access their own personal database to keep track of the tested trees without having to hold onto SMS text messages.

Another feature of the fully commercialized system is a partnership with the USDA Tree Failure Database. The CircuiTree system will send all data from users to this database to expand on the knowledge of tree failure in specific areas.

6 BUSINESS PLAN

6.1 Overall Business Strategy

The Environmental Engineers for Tree Safety Consulting Group will pursue a licensing strategy for commercialization of the CircuiTree Decay Detector. There are several prospect companies to approach for licensing partnerships that meet our anticipated needs with respect to the marketing, operational and financial plans. The licensing agreement will define royalty, performance guarantees and length of partnership. This strategy was selected to minimize capital investment and risk on the part of the consulting group.

As a requirement for obtaining a patent and licensing the CircuiTree Decay Detector, a complete patent search was undertaken to assure there were no existing patents for identical devices. Using classification code and keyword search methods through the ustpo.gov website, the search indicated no U.S. existing patents for systems using the same concept or similar approach. This is most likely due to the fact that only academic articles primarily from Europe and Cornell University suggest the methodology but no implementation of the methodology into a fully functioning product has been commercialized.[15,16,17,18] There are devices that accomplish the same goal but not in the same way or at the affordable cost.

6.2 Competitive Analysis

There are several competitive systems on the market that assess a tree's structural integrity, however none with the same features as the CircuiTree Decay Detector and targeted to the homeowner or small nursery businesses. Four primary competitor products are presently on the market however the cost far exceeds that of CircuiTree, the testing methodology is different and all are targeted to large arborist or forest service companies. The four products are: Metriguard Model 239A, Incremental Borer, Arborsonic Decay Detector and the Shigometer.

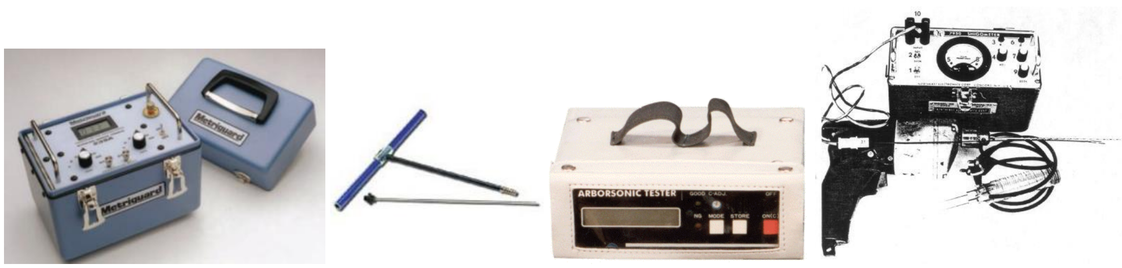


Figure 10 From left to right, Metriguard Model 239A[19], Incremental Borer[20], Arborsonic Decay Detector[21], Shigometer[22]

The Metriguard Model 239A is a stress wave timer. This method is a portable instrument that measures sonic propagation time in wood. The product uses two accelerometers along the propagation path to detect the signal. The first accelerometer is built in the impact device and the second is secured to the testing area. This device is powered by battery and displays only time of flight measurements. This device costs approximately $5,000.

The second competitor is the Incremental Borer. This device is a classic system for determining the integrity of the tree cavity. Borers are invasive to the tree but do produce fast and reliable results to measure decay. The device requires knowledge of the biological material of the tree in order to determine whether the tree integrity has been compromised.

The Arborsonic Decay Detector uses ultrasound and is complex, making it inappropriate for a homeowner market. For this method, two round bark plugs are removed from the tree to allow the inside of the tree to be exposed 180 degrees apart. Then transducers are pressed simultaneously to generate the ultrasound reading. This device costs $3,000 and only allows for one reading at a time. It also doesn't allow the measurement of signal amplitude and evaluation of waveform patterns.

Last, the Shigometer uses electrical resistance to test tree integrity. This device generates a pulse of direct current and reads the resistance to the current as it is passed through the tree. One problem with this method is that once there is moisture in the tree the ions effect the resistance to the current. Another drawback with this system is that it requires a hole to be drilled into the stem section of the trunk to insert a twisted-wire probe. Again here, this device requires advanced knowledge of tree biological matter and interpretation of the results. The price of this device is $1,700.

6.3 Competitive Methodologies Analysis

The radar chart, Figure 11, below illustrates how well the different techniques researched meet the major design goals of the project. The major point to notice is that the hybrid system does not possess any weak areas while every other approach does. It may not be the strongest in every individual area but overall it best meets the design goals.

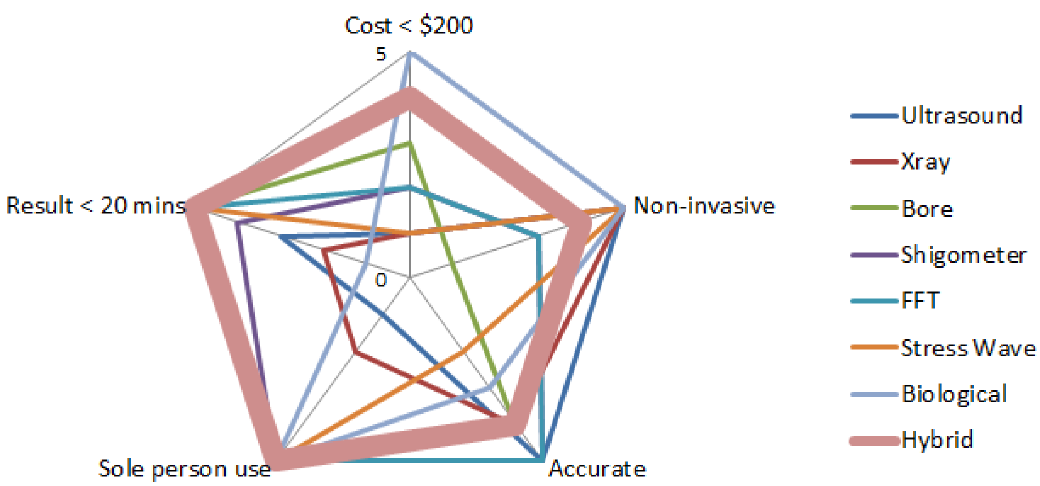


Figure 11

6.4 House of Quality

A quality function deployment approach was also used to analyze competitors with the CircuiTree Decay Detector on the basis of customer requirements and technical evaluation. This evaluation shows that the CircuiTree system separates itself from other competitive products by its low cost and user friendly approach. None of the other products on the market are using the hybrid FFT approach and are therefore unable to achieve accuracy without a high cost due to expensive sensors. Figure 12 shows the House of Quality comparing the CircuiTree Decay Detector with other more expensive entries on the market.

House of Quality

● Strong +
○ Positive
X Negative
Strong -

= 9 High
= 3
= 1 Low

Customer Requirements \ Design Requirements	Importance (1-5)	Accelerometer	Peizo Electric Sensor	Nailed to Tree	Computer Moniter Display	Signal Processing Circuit	○ Company	□ Arborsonic Decay Detector	◁ Metriguard	● Shigometers	Planned Satisfaction Rating	Improvement Rating	Overall Weighting	Percentage of Total
Quick Result	3	9	3	1	1	9	3	4	5	5	4	1.2	3.6	15.3
Accuracy	5	9	3	1	1	3	4	5	5	4	5	1.2	6	25.4
Cost	4	1	9	9	1	9	5	1	1	2	5	1	4	16.9
Ease of Use	4	1	9	3	9	9	5	2	4	3	5	1	4	16.9
Non-invasive	5	9	9	1	3	1	4	5	5	3	5	1.2	6	25.4
Targets: Technical Priority		148	155	64	68	128	1	2	3	4	5			
Technical Evaluation: Percentage of Total		0.26	0.27	0.11	0.12	0.23	5	1(low) - 5(high)						
Our Product ○		Y	Y	Y	Y	Y	4							
Arborsonic Decay Detector □		Y	N	N	Y	Y	3							
Metriguard △		N		Y	Y	Y	2							
Shigometers ●		N	N	N	Y	Y	1							
Absolute Importance		125	141	61	63	119								

Direction of Improvement

Customer Rating

Figure 12

6.5 Marketing Plan

6.5.1 Product

The CircuiTree Decay Detector consists of piezoelectric sensors, an integrated circuit on a PCB board, a patented impact device, and a microcontroller. The piezoelectric sensors are attached to the impact device with the accelerometer on the opposite side of the tree, consequently no manufacturing for that part is required. The microcontroller requires programming with the CircuiTree software to read sensor and report sensor. The impact device consists of a mallet that uses gravity as its force for striking the tree so that all impacts are consistent and produce accurate results. The heart of the system, the circuit, is implemented on a PCB using surface mount components to keep cost down. The circuit is used to reduce noise from the waves, measure the settling time of the waves and register high and low peaks through the data.

6.5.2 Price

Table 2 details the cost of the CircuiTree bench scale identified by individual subsystems:

Table 2 Bench Scale Cost

Component	Mouser Electronics Part #	Unit Cost	Quantity	Line Total
Electrical:				
100μF capacitor, polarized	647-UKL1C100KDD1TD	$0.42	4	$1.68
300Ω resistor, 1%	660-MF1/4DC3000F	$0.06	4	$0.24
560Ω resistor, 1%	660-MF1/4DC5600F	$0.07	4	$0.28
1N4148 diode, fast	512-1N4148T50R	$0.61	2	$1.22
50kΩ resistor, 0.1%	71-PTF5650K000BYEB	$0.23	4	$0.92
1N4721A 4.3V Zener, 5%	512-1N4731A	$0.28	2	$0.56
0.68 μF capacitor	810-FK28X5R1E684K	$0.09	4	$0.36
20kΩ resistor, 1%	660-MFS1/4DCT52R2002	$0.52	2	$1.04
LT1014 Quad Op-Amp	595-LT1014CN	$5.85	2	$11.70
Mechanics and Sensors:				
ACH-01 Accelerometer	824-ACH-01-04/10	$25.00	1	$25.00
Rubber Mallet	N/A	$2.50	1	$2.50
30 min. Epoxy	N/A	$4.00	1	$4.00
Piezoelectric Sensor	254-PB125-ROX	$0.52	1	$0.52
Software:				
Developers License	N/A	$99.00	1	$99.00
Total:				**$149.02**

When considering these costs in relationship to the fully commercialized product, it is important to note that the cost of the developer's license can be subtracted as it is a one-time purchase. If components were bought in bulk, the prices would scale down accordingly making the electrical components significantly less expensive. The printing method used for our bench scale circuits is appropriate for small scale production, such as alpha and beta prototyping. For a full scale commercialized model, switching the components from through-hole to surface mount devices (SMD) would ultimately decrease cost, make the final product smaller and reduce the cost of the circuit board. When taking into account manufacturing costs and buying components in bulk, the cost of the CircuiTree system is expected to decrease by 60% bringing the final cost to manufacture one fully commercialized product to $20.01.

6.5.3 Promotion and Distribution

Since Environmental Engineers for Tree Safety Consulting Group is pursuing a licensing strategy, the promotional and distribution strategies of the selected licensed company will be used. Our strategy is to approach companies with complementary product lines such as Husqvarna, John Deere and Toro. All of these companies have established sales and distribution channels and have already navigated the high barriers to entry into the retail market. In addition to the marketing activities of the licensed company, we will depend on tree services providers to recommend our product to potential buyers. We anticipate that a homeowner will find the CircuiTree Decay Detector at local depot stores such as Home Depot, Lowe's or Ace Hardware.

6.6 Economic Impact

The CircuiTree Decay Detector has the potential to save lives as well as millions of dollars per year. Impact is realized in reduced insurance claims and increased safety. The Environmental Engineering for Tree Safety Consulting Group estimates selling 61,000 products in the first year. This number is calculated on the basis of capturing .005% of 12 million, or 1 in 200 potential coastline northeast homeowners and 1,000 northeast nurseries. At a negotiated royalty agreement of $5.00 per unit sold, this translates into $305,000 dollars of income for the group. At a contribution margin of $25 per unit for the licensed company and 61,000 in sales, the licensee earns $1,525,000 in the first year under this scenario.

However from a cost benefit perspective, if the system can save just one life by identifying a priori a diseased tree that may fall, the economic, legal and safety ramifications are priceless.

6.7 Public Involvement Plan

Essential partners for our product are the USDA Forestry Services - Hazard Tree Management Program, The International Society of Arboriculture (ISA) and The Tree Care Industry Association (TCIA), state Agriculture Extension Offices. These partners have already established informational programs that educate homeowners on tree safety. We will also partner with the USDA Tree Failure Database Program. This database is home of thousands of samples of failed trees across the United States and world. By adding our samples to this database, users can identify where and how certain species of trees have failed across the country.

7 CONCLUSION

The CircuiTree Decay Detector is a successfully demonstrated solution to the WERC Task 1 problem statement. This affordable, easy-to-use system allows homeowners and small nurseries to test for potential decay in trees on their property thus avoiding potential catastrophic events during storms or hurricanes. Through experimentation, proof of concept was supported and prototypes built for under $50 dollars. CircuiTree Decay Detector fills a present market and technology gap and addresses an issue of national importance to the government, homeowners and insurance organizations.

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Roger Williams University

Legal Audit

Date: March 20, 2014

To: WERC Reviewers – Task 1

Subject: Legal Audit for WERC Task 1 – CIRCUITREE DECAY DETECTOR – DESIGN OF A HYBRID AND INEXPENSIVE SYSTEM TO MEASURE STRUCTURAL INTEGRITY OF TREES

The legal implications of the report prepared by the WERC Task 1 team from Roger Williams University involve three areas. The first involves the novelty of the concept and its patentability, the second encompasses liability for improper use and the resulting destruction of a healthy tree and the third deals with the legal ramifications a product. Having worked the team as advisor on this project, each of the three cases was central to their thinking as they progressed from conceptualization through realization and finally testing of the product.

In the first case, they have conceptualized and manufactured an innovative product that from their background research is appropriate for a patent application. They have undertaken an extensive literature search, spoken with manufacturers and completed a patent search to assure no similar product or approach is patented here in the U.S. I have explained to them the ramifications of displaying their product without a provisional patent application in process. They understand the potential consequences. Yet they also recognize that for licensing to be a viable business option that they must have a patented product.

To assure that the homeowner properly uses the product, the students have created a User's Manual to train the user in the proper approach to take readings from trees. In addition, the students recognize that partnerships with organizations having the same goals of tree safety are critical to their success in educating the public. This is the case in not only using their product but also with respect to canvasing homeowner property for signs of tree rot and disease.

In the third case, I am confident that all of the national electrical codes and standards, OSHA requirements, as well as safe handling practices have been addressed in constructing the CircuiTree Decay Detector. They are depending on outsourcing their custom designed circuit board and have already worked with vendors in ordering the boards. They recognize the challenges from a quality assurance perspective with outsourcing critical components that ultimately will make or break the product.

I am satisfied that the students have taken my suggestions throughout the two semester project and addressed them in the final report submission.

Linda Ann Riley Ph.D.
Engineering Program Coordinator and Professor of Engineering
Roger Williams University

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Health and Safety Audit

Date: March 20, 2014

To: WERC Reviewers – Task 1

Subject: Legal Audit for WERC Task 1 – CIRCUITREE DECAY DETECTOR – DESIGN OF A HYBRID AND INEXPENSIVE SYSTEM TO MEASURE STRUCTURAL INTEGRITY OF TREES

I have had the opportunity to read the WERC Task 1 Team report from Roger Williams University as an outside objective reviewer. From a health and safety perspective, the procedures used in constructing the prototype as well as the experimental testing in the lab appear to have been undertaken with caution and adhering to standard safety protocol.

One area where I had concern involved the clamping device the students used in their lab testing that held their tree trunk securely in place. This was especially so with the larger diameter trunk pieces. It appears that because of the weight and size of the larger trunk sections, the ability to safely carry out certain experiments became compromised. This explained why they moved their testing to the floor for the very heavy large trunk sections. Although I applaud their attention to safety, I also recognize that certain samples had to be eliminated from their tests because of the change in protocol.

From the perspective of the user there are several safety implications associated with the product. The impact mallet, similar to a hammer has the potential to be improperly used by children if not stored safely. In addition, when undertaking a test, if a tree is in fact internally rotted, there is the potential that through the act of testing, the tree may fall. The students appear to have considered this by recognizing the need for external partnerships with organizations where the primary objective is communication with the public on tree hazard identification.

Overall from what is presented in the paper, the students have addressed issues of health and safety. The product the students are proposing meets a definite need for homeowners in New England given the general condition of the pine population and frequent storms.

Bahram Nassersharif, Ph.D.
Distinguished University Professor & Nuclear Engineering Program Coordinator

Economic Audit

To: Evaluators

Subject: Economic Audit for WERC Task 1: Open Task– CircuiTree Decay : Design of a Hybrid and Cost-Effective System to Measure Structural Integrity of Trees

Date: March 19, 2014

1. In accordance with the instructions issued as part of the WERC Competition, I performed a review of the Roger Williams University team report submitted for the WERC Task 1. My review included an audit of their economic analysis of an initial marketing / licensing plan for the CircuiTree Decay system.

2. This is a special-purpose device for a broad market ranging from home-owner to professional arborist. CircuiTree marks the first time such a device has been targeted to home-owners so that is a new market. However, at the professional arborist level it is entering an established market. While there are economic comparisons made to equipment currently in use by professional arborists, the intent of marketing seems oriented towards home-owners, small businesses, and those directly impacted by damaged trees.

3. I determined that the team's assumptions used in the analysis were well founded for a mixed purchase/licensing approach for the intended market. I also concluded that the parameters selected for analysis and results attained were reasonable.

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