

# A Tree Tour with Radio Frequency Identification (RFID) and a Personal Digital Assistant (PDA)

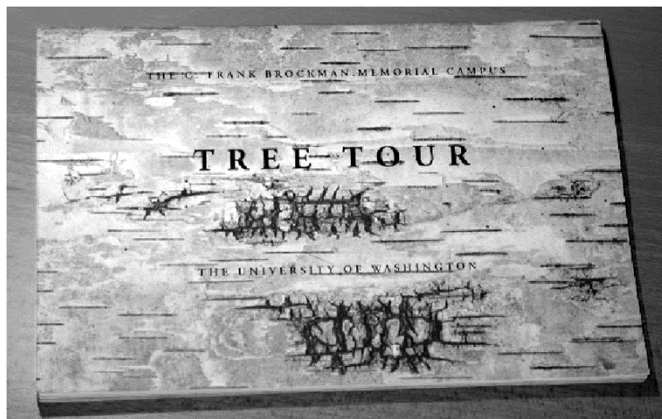
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**Abstract**—A popular tree tour at the University of Washington campus has been automated via RFID and a PDA. The previous 81-tree hardcopy tour has also been updated to include more information on each tree, including digital photos. A survey conducted demonstrates the updated, electronic tree tour is easier to navigate, full of better visuals, and results in less false identifications.

**Index Terms**—RFID Technology, PDA

## I. INTRODUCTION

The University of Washington's Brockman Memorial Tree Tour [1] published in 1980, has been updated and improved using radio frequency identification (RFID) and personal digital assistant (PDA) technologies. These new technologies combined increase the ease of locating and positively identifying each tree along the lengthy, spacious tour around the campus.



**Fig.1** The original C. Frank Brockman Memorial University of Washington campus tree tour booklet, published in 1980.

The University of Washington campus is lavish with history and beauty. The most obvious are the gothic-style buildings, but a closer look indicates that the trees around them have just as much history. At the beginning of the 1900's, forestry professors, gardeners, botanists, and landscape architects planted trees on campus for beauty and education. Across the

hundreds of acres are 480 different types of trees of which only a few dozen are native to the Pacific Northwest [1].

In 1980, a professor emeritus of forestry, the late C. Frank Brockman (1902-1985), along with Louise Hastie, edited a campus publication called *The University Report* [1]. They worked together to create an eight-page tour of 81 campus trees, which consumed one issue of *The Report*. This issue soon after became the Brockman Tree Tour, which contained a campus map and many tree photos. The Brockman Tree Tour instantly became popular and people demanded many reprints of the paper booklet (Fig. 1).

The mechanics of the booklet tree tour are simple and straightforward. Each tree is individually profiled including details such as origin, data planted, type of flowers and other pertinent information. A map, located at the rear, visually locates each tree by its unique number. Additional guidance from tree to tree is embedded within the tree details to aide navigation. Approximately half of the trees are accompanied by black and white photography to supplement the text.

The work described in this paper improves the tree tour with available electronic technology. There was great opportunity to make improvements in the tour by increasing the detail of the map, providing positive tree identification via RFID, and vocalizing tree information.

The original goals, information and usability of the paper pamphlet tree tour are completely transferred to the new electronic version. In addition, the transfer enables corrections and updates, such as misidentified trees, removed trees, new buildings and landmarks. The new version adds robustness to the tree identification process by embedding the ID numbers within the tree. In addition, it serves as an accessible demonstration of RFID to industries and the public.

## Increasing the detail of the map

The original pamphlet includes a gray-scale map of the University of Washington campus with the tree locations in the back pages. Each tree is numbered and some pathways and streets are shown. Most buildings are named and colored solid black.

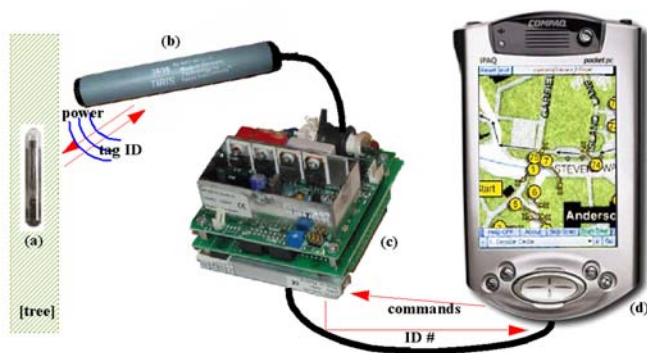
In the electronic version of the tree tour, a map with significantly higher detail is displayed on a PDA device with a crisp, color-screen at a magnification roughly four times that of the paper version. Instead of viewing the whole campus at once, as in the paper version, a "sliding window" is employed, much like the way microfiche is viewed. Comparably, a paper

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version of the electronic map with this level of detail would be bulky and cumbersome.

### Providing positive tree identification via RFID

Originally, a nameplate was attached to each tree along the tree tour for quick identification from a distance. Over time, however, many nameplates have been removed, damaged or destroyed due to weather, growth or vandalism. For those trees presently missing their nameplates, the tour participant must rely solely on the tree information within the booklet to make an accurate identification, which may be a frustrating task depending on the season.



**Fig. 2.** The electronic tree tour system. The ID tag (a) is embedded within the tree, scanned by the wand antenna (b), decoded by the reader (c), and finally sent to the PDA (d) for information retrieval.

To solve this problem, the ideal solution would be to hide the identification marker in a place where time and environment will have minimal effect on system robustness. A standard bar coding system would require a clear, unobstructed optical link lending the system to the same issues surrounding the nameplates. The optimum solution proposed by the authors was to embed RFID tags within the trees and retrieve the identification numbers via a tree-penetrating RF signal (Fig. 2). These tags are an electronic circuit composed of a microchip, an antenna and other small components encapsulated in glass to protect them from rainy weather. A battery is not present within the capsule; instead, energy is received wirelessly from a handheld antenna connected to the PDA. Remote, on demand power transfer allows the tags to remain hidden within the tree indefinitely, a major advantage toward maintaining longevity and reliability for this type of identification marker.

### Vocalizing tree information

The updated tour information is professionally read and recorded into PC formatted sound files. The files are then embedded within the electronic tree tour version. At the click of a button, the text for each tree is played back through the onboard speaker on the PDA device. The advantage is that the user can simultaneously observe the tree and receive audio information. Also, the high-volume capability of the chosen portable information device enables groups to share a single system with one person designated as a chief navigator and tree scanner.

This paper is organized as follows. In the next section, RFID is described. In Section III, the RFID parameters are explained in detail. In Section IV, the electronic tree tour design is described. In Section V, the design and results of a survey are presented. In Section VI, conclusions and other application areas are discussed.

## II. RADIO FREQUENCY IDENTIFICATION TECHNOLOGY

### A. An RFID Overview

RFID is a system in which radio frequency communication is used to exchange data between a mobile device equipped with memory and a host computer. A wide variety of electronic devices such as television, radio, and wireless telephone use radio frequency technology to transmit or receive information. RFID operates much the same as current laser-scanning barcodes: information is stored within the label and retrieved from a reader through a scanning process. From there, a computer makes sense of the information, such as linking it to a product.

RFID systems can be classified according to the excitation frequency used, the type of carrier wave modulation and the method of data encoding. The parameter of paramount importance is the system excitation frequency generated by the reader. Many characteristics of a RFID system are determined by the excitation frequency including read/write range between the reader and tag, noise immunity, and penetration through various non-metallic objects. The excitation frequency also largely influences antenna type, size and shape.

Commercially available RFID systems can be broken down into three main frequency bands: the low frequency (LF) band operating between 100 and 500 kHz, medium frequency (MF) between 10 to 15 MHz and high frequency (HF) systems in the 850-950 MHz to 2.4-5.8 GHz range [3].

### B. RFID Components

The mobile portion of RFID is called a transponder or tag. It contains an antenna, a microcontroller to monitor the state of the tag, and limited amount data storage, either permanent or rewritable. The reader circuit provides power to the tag (in a passive tag setup) and controls the data transmissions. A host computer interfaces with the reader and directs the interrogation via parallel, serial or bus communications.

### Reader circuit

The first function of an RFID reader circuit is activating the tag circuit. The reader-tag system is based on a transfer of energy between two resonant circuits. The microcontroller onboard the reader generates a digital signal at the required frequency, which is routed to a current amplifier. The amplified current passes into the reader antenna, which resonates at the system frequency and creates the RF wave. If a tag is present within the RF field area, the tag will energize and transmit data back to the reader. It is the responsibility of the reader circuit to decode the incoming signal and finally send the decoded identification number to a host computer.

## Tags/Transponders

An RFID tag unit is comprised of a coil or etched antenna and an application specific integrated circuit (ASIC). A tag is issued with or without an internal power supply. Those tags without power are labeled *passive tags* and are powered by charging an internal capacitor using the onboard antenna in conjunction with an externally-provided RF field. These tags do not have any maintenance requirements and have a virtually limitless life. *Active tags* are manufactured with onboard batteries to power the electronics and typically allow longer ranges between the host computer and tag via signal amplification.

Generally, the operational frequency of the RFID system determines optimal shape, size, and geometry for the antenna and tag. To resist environmental affects, tags are typically housed in glass or plastic. The encapsulation protects the electronics from moisture, shock, corrosion, wear, and electrical shorts.

## Antennas

An antenna enables a device to convert current and voltage to an electromagnetic wave. Both the reader and tag are required to have an antenna of some form to enable communication. The operational frequency of the RFID system will determine the type of antenna, whether it be a magnetic coil antenna or an electric dipole. Typically, the transmission frequency determines the type of antenna.

## Host computer

The final stop for data in the RFID system is the host computer. The host computer can also determine what mode the reader operates in. For example, in an environment where tags are passing near the antenna, the reader can be instructed to continuously look for tags. If the reader antenna were to become portable, the host computer may instruct the reader to energize only at the users command.

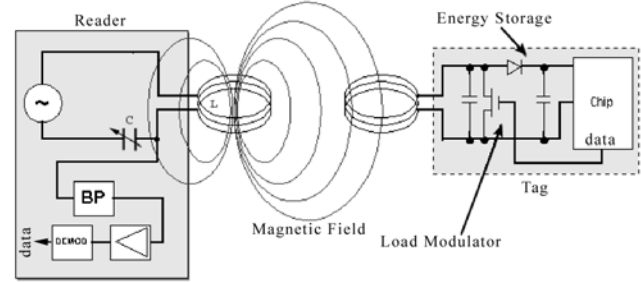
### C. RFID Market

RFID can generally be applied to any area where optical scanning is employed. In addition, it can be used where optics would not operate, such as harsh environments, high-speed tracking, identifying hidden items, or long-range package scanning.

Several companies are involved in RFID component production. Motorola, Microchip, Phillips Semiconductors and Texas Instruments are large manufacturers of industry-proven RFID tags, readers, and antennas [4]. There are hundreds of third party consultants that specialize in mating RFID technology from the larger manufactures with many categories of applications [5]. The numbers of applications using RFID are increasing as the costs of the systems (mainly tag prices) are reduced through mass production. Example applications are, and not limited to retail stores [6], security systems [7][8], tracking [9][10], manufacturing [11], and payment systems [12][13].

## III. RFID SYSTEM PARAMETERS

An RF signal can be effectively generated if the linear dimension of the antenna is comparable with the wavelength of the excitation frequency. In the low to medium frequency bands, predicted to be the optimal operation frequency in the tree four environment, the wavelength of the excitation frequency is close to two kilometers. This large length prohibits construction of a true dipole antenna, but a small resonating loop antenna solenoid is effective.



**Fig. 3.** At low to mid RFID frequencies, the reader and tag are linked through coil antennas. Energy is transferred to the tag where it is stored in a capacitor. The tag modulates the antenna circuit to transmit data back to the reader over the reader's carrier wave.

The reader and tag antenna coils are linked using near-field magnetic induction coupling between the reader and tag coil antennas show in Fig. 3. A time-varying current passing through the reader antenna coil creates a time-varying magnetic field in the direction perpendicular to the coil plane. The field is not a propagating wave, but rather an attenuating carrier wave with its strength given as [14]:

$$B_z = \frac{\mu_0 I N a^2}{2r^3}$$

where:

- $I$  = current through the coil
- $N$  = number of windings in the coil
- $a$  = radius of the coil
- $\mu_0$  = permeability of free space ( $4\pi \times 10^{-7}$  H/m)
- $r$  = perpendicular distance from antenna.

To maximize the magnetic field, given fixed antenna dimensions, the equation above dictates that the current delivered to the antenna must be maximized. Additionally, to maximize current, the antenna must resonate at the excitation frequency provided by the reader circuit. Resonance frequency ( $f_0$ ) is determined by the inductance ( $L$ ) of the antenna (determined by the radius of the coil, the number of windings, the thickness of the windings, and the length of the coil) and a tuning capacitor ( $C$ ) and is calculated as [14]:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

An antenna and capacitor tuned to the desired excitation frequency,  $f_0$ , will have equal and opposite values of impedance. In a series LC resonant circuit, equal reactance values of the inductor ( $X_L$ ) and capacitor ( $X_C$ ) will cancel using:

$$Z(j\omega) = r + j(X_L - X_C)$$

where,

$$X_L = 2\pi f_0 L, \quad X_C = \frac{1}{2\pi f_0 C}$$

Total resistance is thereby minimized and current through the antenna is maximized, yielding a maximized magnetic field strength.

Passive tags utilize the energy provided by the carrier wave through an induced antenna coil voltage. The voltage is proportional to the product of the number of turns in the tag antenna and the total magnetic flux through the antenna. The ASIC within the tag must receive a minimum voltage to operate. The voltage across the tag antenna is given as [14]:

$$V_{tag} = 2\pi f NSQB \cos \alpha$$

where:

- $f$  = frequency of the carrier signal
- $S$  = area of the coil
- $Q$  = quality factor of the resonant circuit
- $B$  = strength of magnetic field at the tag
- $\alpha$  = angle of the field normal to the tag area

Voltage is built up in an onboard storage capacitor. When sufficient charge has accumulated to reach or surpass the circuit operating voltage, the electronics power up and begin transmitting data back to the reader. Two main methods of communication occur between the reader and tag: full-duplex and half-duplex. Both the reader and the tag must use the same transmission method in order to synchronize and successfully exchange data. In a full-duplex configuration, the tag communicates its data by modulating the reader's carrier wave by applying a resistive load. A transistor (load modulator) within the tag shorts the antenna circuit in sequence to the data, removing the antenna from resonance at the excitation frequency, thereby removing its power draw from the reader's carrier wave. At the reader side, the loading and unloading is detected and the data can be reconstructed. In a half-duplex RFID system, the carrier wave transmits power and then pauses. Within the pause, the tag transmits the data back to the reader.

#### IV. ELECTRONIC TREE TOUR SYSTEM

The initial planning and design for the electronic tree tour begins with assessing the restrictions imposed by the tree tour participants and the environmental conditions surrounding the tour. The up to three hour length of the tour restricts the weight and size of the overall device while the type of environment determines the RFID system operation frequency, size and shape of the reader antenna, type of tag, shape of tag antenna, data encoding and power of reader. In addition, the type of information display and the user input method are evaluated for optimal tree tour system structure.

Addressing these issues guides the design process and narrows the field of potential RFID systems and information

display devices. The system must be practical and non-intrusive to avoid detracting from the tree tour experience. Optimally, the devices used to navigate and access information should become comfortable to the user shortly after learning how to use them.

#### Size and weight of system

The paper tree tour requires the user to carry a small pamphlet. In comparison, the electronics and packaging of the new system will exceed the size and weight of the pamphlet due to power requirements and the number of electronic components needed to execute a RFID acquisition.

Power is largely consumed by the RFID device during the interrogation process. The larger the current consumption in the antenna circuit, the larger the read range. If the reader power usage is limited to times of interrogation only, battery usage can further be minimized while maintaining a maximized read range.

The battery weight and size of electronic packaging could be disabling when trying to navigate and view information. This can be countered by enabling the participant to "wear" the devices around their waist or on their back with only the information display device in hand. One hand holds the device and the other interacts with it. Placement of the RFID antenna on or near the information display device is desirable to enable the reader to narrow the distance from the antenna to the tag position for ID acquisition.

#### Type of information display and method of user input

Minimizing size and weight means acquiring the smallest and lightest possible information display device that satisfies the requirements of the tree tour. These requirements are displaying text large enough to easily read, a detailed color map for navigation, tree information text, and photography. The screen must be bright and visible in the target environment.

The device of choice should be able to interface and control the RFID system. While walking, the participant must be able to carry the device in one hand and interact with it with the other hand. User input via a small keyboard or stylus input to an LCD touch screen would be optimal.

#### Evaluating the tree tour environmental factors

As mentioned above, the type of environment determines the system parameters. Other primary design issues are where and how to place the tree tags and the practical minimum read range between the reader and tag. Analysis of the environment will help to choose optimal electronic system components for the Brockman Tree Tour.

The Brockman Memorial Tree Tour takes place outdoor on the University of Washington's campus. Rain and snow, time, tampering and other environmental factors were considered when selecting the correct RFID system and handheld device.

To resolve tag theft or loss, the RFID tags for the electronic tree tour can be hidden from view, embedded inside each tree. To remain in the tree and not be forced out by tree growth, the tag should be placed below the periderm (bark) and epidermis

layer. These layers are the “active” part of any tree. Soon after the tag is inserted, the bark would grow around the entry hole and conceal the tag from view.

A very limiting environmental factor influencing RFID read range is the material in the area surrounding the tag and reader. In any system, ferrous material will detune a tag by shifting its excitation frequency. In addition, water in the environment will absorb or reflect the carrier wave, to what degree is determined by the operating frequency band used. Interference, absorption and reflection will decrease the effective read range of the system.

Wood is a *hygroscopic* material, which means it naturally takes on and gives off water to balance with its surrounding environment. In the living tree, the walls of the wood fiber are saturated with moisture and will have free water partially or fully filling the cavity (lumen) inside the fiber, which runs the length of the tree. This means that the RFID carrier wave must penetrate both the wood from the tree and the large volume of water within the wood.

Water responds to the carrier wave due to polarization characteristics and the size of the molecule relative to the RF wavelength. The time-varying electromagnetic field will cause the water molecules to oscillate from one orientation to another at the frequency of the carrier. The oscillation causes friction among the molecules whereby the energy is converted to heat.

Peak carrier wave absorption in water and resulting generation of heat occurs at microwave frequencies around 2 GHz [4]. The effect of energy absorbed by water denies an RFID tag within the water from its source of power and an information transmission path. At lower carrier wave frequencies, the water absorption effect is less pronounced. Therefore, it is obvious that a medium to low frequency RFID system will outperform a high frequency system in the Brockman Memorial Tree Tour environment where a tag is embedded within the tree.

The major factor concerning the information display device is screen clarity. A bright sun can have adverse affects on an LCD color screen. Some screens may wash out when exposed to direct sun. This is an issue if the screen is used to navigate the campus. Therefore, a screen suitable for outdoor, sunny weather is necessary.

### Optimal system components

Texas Instruments (TIRIS) produces a glass capsule tag measuring 4mm diameter by 23mm length that operates in half-duplex transition mode at 134.2 kHz. This tag is optimal for embedding *within* a tree. The tree is drilled and a tag is inserted below the bark. Combined with a Texas Instruments handheld wand antenna, typical read range is specified as around 60 cm (about two feet). The TIRIS system is also easy to control through simple serial port commands and the read range is acceptable.

The class of graphical user interface devices that meet the environmental and user requirements discussed above is a personal digital assistant (PDA). Although a laptop is portable

and meets most of the requirements, the size and weight is prohibitive. A PDA device can be easily accessed via an integrated touch screen and stylus pen. The size and weight permits the device to be held in hand for extended periods of time without fatigue. The internal rechargeable batteries can store enough power for over 4 hours of usage. The built-in serial port, typically used to transfer files to and from a desktop PC, can be programmed to communicate with the RFID system.



Fig. 4. Integrated PDA and RFID hand-held device for the UW Electronic Tree Tour. The screen shows part of the campus map with trees identified with numbered circles. The RFID wand extends to the right of the PDA. The user carries the reader and batteries in a hip pack.

PDA devices with new, transreflective LCD screens are the best choice for the outdoors tree tour environment. Transreflective screens do not wash out in bright light; rather, they use the ambient/direct light to increase the contrast and brightness of the graphics on the screen. Of the available PDA devices, only a few offers a transreflective LCD screen.

The optimal user interface PDA is the iPaq 3855 Pocket PC PDA. It boasts a transreflective touch screen, small palm-size form, a free software development package (available for all Pocket PC devices) and a fast 400 MHz processor. Tree information is stored within an ODBC database and software is written in eMbedded Visual Basic. The integrated PDA and RFID wand system can be seen in Fig. 4.

## V. SURVEY: DESIGN AND RESULTS

An appropriate survey was developed to test assumptions regarding increased usability, satisfaction and knowledge gained from introducing the new electronic tree tour. Given two versions of the tree tour to test, there were two independent samples; therefore, the survey method is a “between-subjects” design [15]. Participants were not matched up between the different conditions. Likewise, the participants were not tested in different conditions. In this survey design, instead, one random sample of participants took the paper tour, and another, separate sample took the electronic tour. Each participant was asked to take a subset of the actual tour. At the conclusion of this mini-tour, each

participant was given a survey form to record personal attitudes toward the respective tour version. Finally, the surveys were analyzed and used to compare the tree tour paper version to the electronic version.

The questions chosen for the survey are closed-ended and fit a Likert-type response scale. The Likert response scale is useful when it is desirable to find the degree of a subject's agreement or disagreement (attitude) towards a particular statement. Each degree of agreement is given a numerical value on an interval scale typically from 1 to 5. Thus a total numerical value can be calculated from all responses [15].

A useful statistical method for demonstrating significant differences between two independent data sample sets is the parametric 'Student's' t-test. The direction of the score's mean is known so a one-tailed t-test is used. Values of  $P$  less than 0.05 are considered to be statistically significant differences between means. A total of 20 surveys were conducted, although more participants were desired but not feasible due to time constraints. Participants were randomly selected from engineering-related fields. For the section concerning tree tour usability, the  $P$  values are 0.018, 0.0002, and 0.0006. Testing for visuals, the resulting  $P$  values are 0.023, 0.048, 0.00005, and 0.006. Finally, one question concerning tree knowledge gained is a  $P$  value of 0.006. From these results, we conclude that the electronic tree tour was better received than the paper version with statistical significance.

## VI. CONCLUSIONS

The Brockman Memorial Tree Tour has been improved through the combination of wireless, tree-locating technology and a portable, handheld information display device. Radio frequency identification (RFID) provides the tree tour participant a method of positively identifying each tree through wireless scanning for an identification marker, or tag, embedded beneath the bark of the tree. Once the unique identification number is retrieved, the information is used to locate specific information linked to that number and finally displayed on a portable digital assistant (PDA) device. From tree to tree, the PDA assists the participant through a digitized University of Washington campus map. The participant simply navigates using the stylus on the integrated touch-screen.

This new electronic tree tour system has made significant improvements upon the previous paper version, generating survey results that indicate significant increases in ease of finding the trees, navigating around campus. Also, satisfaction of accompanied visuals and information has been increased.

Identifying individual trees is becoming more important for environmental, regulatory, and wood production reasons. Trees are now being included in conservation easements and a method to identify these trees, both now and in the future, is needed. Regulations are becoming increasingly complex and protection of individual trees or classes of trees is often

required. Improved wood production can be possible with greater information about individual trees. Information can also be passed down the manufacturing process stream once the tree is harvested; this would provide a method for tracking certified products.

Some possible extensions of this work could be museums in which the pieces are approachable, nature hikes with points of interest, electronic city guides, aquariums, or zoos. There are preliminary ideas concerning expanding the campus tree tour to include a local arboretum at the south side of campus. Geographic Information System (GIS) specialists with the University of Washington's College of Forest Resources are beginning work utilizing our RFID and PDA system in conjunction with global positioning system (GPS) technology in an effort to tag all trees on campus for maintenance tracking. The addition of GPS within the tree tour is hoped to automate campus navigation while RFID is still necessary to acquire a positive identification.

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