MetaTree: Augmented Reality Narrative Explorations of Urban Forests

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ABSTRACT

As cities world-wide adopt and implement reforestation initiatives to plant millions of trees in urban areas, they are engaging in what is essentially a massive ecological and social experiment. Existing air-borne, space-borne, and field-based imaging and inventory mechanisms fail to provide key information on urban tree ecology that is crucial to informing management, policy, and supporting citizen initiatives for the planting and stewardship of trees. The shortcomings of the current approaches include: spatial and temporal resolution, poor vantage point, cost constraints and biological metric limitations. Collectively, this limits their effectiveness as real-time inventory and monitoring tools. Novel methods for imaging and monitoring the status of these emerging urban forests and encouraging their ongoing stewardship by the public are required to ensure their success. This art-science collaboration proposes to re-envision citizens' relationship with urban spaces by foregrounding urban trees in relation to local architectural features and simultaneously creating new methods for urban forest monitoring. We explore creating a shift from overhead imaging or field-based tree survey data acquisition methods to continuous, ongoing monitoring by citizen scientists as part of a mobile augmented reality experience. We consider the possibilities of this experience as a medium for interacting with and visualizing urban forestry data and for creating cultural engagement with urban ecology.

Keywords: mobile augmented reality, citizen science, urban forestry

1. INTRODUCTION

As major cities world-wide adopt and implement reforestation initiatives to plant millions of trees in urban areas, they are engaging in what is essentially a massive ecological experiment. For example, the City of New York is planting one million trees from 2008 to 2017[1]; Albuquerque, New Mexico has completed its first planting of one million trees and is in the process of planting its second million[2]; The City of Los Angeles is also engaged in a one million tree planting initiative[3]. Non-profit and government organizations in Washington DC are planting trees on public and private land in order to reach their 40% tree canopy goal. Monitoring programs and urban forestry research is struggling to keep up with the rapid pace of these tree-planting initiatives, leaving urban forestry managers lacking the comprehensive understanding they require to better inform their activities.

The comprehensive, timely, and actionable understanding that urban forest stewardship requires provides challenges and opportunities in designing new methods for data collection and public participation[1] . Existing overhead remote sensing and field inventories have been used to provide key information for informing management, policy, and supporting citizen initiatives for planting and stewardship of trees[2,3,4,5], but these data collection approaches suffer from limitations. These limitations range from the lack of spatial resolution and vantage point, to the cost of acquiring multi-temporal imagery over a growing season, to the inability to obtain cost-effective measurements of tree structure and health for an entire city. For example, while overhead remote sensing approaches using high-resolution data from air- or space-borne platforms have been able to accurately map tree canopy[6], the complexity of the urban forest makes it impossible to apply techniques that have been successfully used in rural forests to estimate such factors as basal area and stem

[1] http://www.milliontreesnyc.org
[2] http://www.treenm.com
[3] http://www.milliontreesla.org

The Engineering Reality of Virtual Reality 2012, edited by Ian E. McDowall, Margaret Dolinsky,
Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 8289, 82890G · © 2012 SPIE-IS&T
CCC code: 0277-786X/12/$18 · doi: 10.1117/12.912051

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volume[7] to urban forests. While field-based inventory mechanisms can overcome the limits of overhead observation, they are costly, require trained crews with specialized equipment (e.g. the UFORE methods outlined by Nowak and Crane[8]), and do not provide persistent ongoing and ubiquitous monitoring of urban trees.

Our art-science collaboration asks the following questions in response to these collective challenges: Can we shift people's perceptions of urban spaces so that trees and urban ecology become the foreground experience in the context of urbanity? Given the heterogeneous nature of this data, is mobile AR a viable medium for interacting with and visualizing it? Can mobile AR-enabled urban forest monitoring allow us to realize our artistic intent of creating a shift in perception of urban spaces while simultaneously enabling public participation to generate calibrated and validated data for monitoring the status of urban forests?

2. MOBILE AUGMENTED REALITY AS A MEDIUM FOR URBAN FOREST MONITORING

A wide variety of inventory and monitoring methods are utilized to quantify the ecosystem services and cultural benefits of urban forests. Two examples at differing levels of scale and resolution are the geospatial analysis of overhead (space-borne or air-borne) imagery to determine percentages of urban tree canopy coverage within cities[4] or field-based inventories of tree plots for estimating tree counts. Software tools such as i-Tree[5] created by the USDA Forest Service, are utilized to analyze data and quantify ecosystem benefits (e.g. removal of air pollutants, carbon sequestration and storage or reduction in storm water runoff) or to provide indicators of community livability. The volunteer stewardship of urban forests has also created methods for data collection and analysis. Examples of these include the work of groups such as Urban Forest Map[6] and TreeKit[7].

As part of an interdisciplinary collaboration researching approaches for public engagement in bio-imaging science comprised of researchers from the fields of new media arts, geospatial analysis, forestry, and computer science, we established partnerships with two organizations in New York City, NYC Parks and Recreation and TreeKit. NYC Parks and Recreation has conducted detailed surveys of tree health every decade starting in 2005 from which it has been able to draw conclusions on the causes of street tree mortality[9]. One of the shortcomings of NYC's street tree inventory are the positional inaccuracies resulting from tying the location of the trees to a street address as opposed to geographic coordinates. To overcome this TreeKit has embarked on a five year quest to accurately map the location of every single street tree using a simple, yet effective, set of protocols that enable volunteers to obtain precise locations during weekend "tree mapping parties" that are lead by an instructor. TreeKit's efforts have provided the most accurate maps of the locations of street trees ever produced for NYC. What is needed is an approach that can combine elements of detailed health and structural characteristics gathered by NYC Parks and Recreation with the positional accuracy of the TreeKit approach, but at much more frequent time intervals so as to better support adaptive management. Such an approach must also insure consistency and alignment with the existing "best available" data, such as the tree locational information from TreeKit.

Regardless of scale, resolution or source these methods share a common dimension, they produce data for a specific time frame and geographic region. In addition, they require complete data for individual trees for effective analysis. As cities engage in large-scale tree planting efforts the understanding of urban forests would benefit from methods to easily collect repeat measurements on an ongoing basis, including multiple measurements over a growing season, and the ability to work with partial data.

Our selection of mobile augmented reality (AR) as a medium is motivated by several factors in addition to these emerging needs. It enables us to address the criteria of immediacy and locative interaction that emerged as central to continuous monitoring from discussions with our urban forestry collaborators in NYC. Fulfilling these criteria allows our work to complement methods in use by Treekit, NYC Parks and Recreation and similar organizations while providing new opportunities for cost-effective near-real-time inventory and monitoring of newly planted and existing trees in ways that increase public participation. Additionally, mobile AR supports our collaborative interdisciplinary aims of shifting perceptions of urbanity and its ecology, and of exploring the design of approaches for public participation in calibrated

[4] http://nrs.fs.fed.us/urban/utc
[5] http://www.itreetools.org
[6] http://www.urbanforestmap.org
[7] http://www.treekit.org

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and validated data collection and analysis in bio-imaging based research. Its capabilities empower the first, and current phase of our work detailed in the sections below, which entails the design of an imaging-centric workflow that integrates heterogeneous data in support of calibrated data collection. This integration positions the citizen science workflow itself as a foundation for the second and future phase of our work aimed at the design of narrative and collaborative explorations of urban forests facilitated by social media integration, increased immersion, data validation, visualization and analysis. Below we describe our ongoing explorations and research in the design of a mobile augmented reality urban forest monitoring citizen science workflow.

3. DESIGN OVERVIEW

The MetaTree set of mobile AR measurement tools (mAR) are designed to engage both data and its metadata. Our workflow, diagrammed below (Figure 1) explores the possibilities for mobile AR to integrate the immediacy of real-world experience with citizen science calibrated location and bio-imaging data capture, validation and analysis. Its design is grounded in the concepts of mobile participatory sensing[10,11]. The user experience is centered on five primary tasks: calibrate, capture, validate, analyze and share. It incorporates a basic set of tree status metrics identified in consultation with our urban forestry partners. These are: diameter at breast height, crown width, tree height, biometrics, socio-environmental factors and tree location. Additionally, it contains tools for data validation, image acquisition, re-photography, and a data completeness dashboard.



Figure 1 : Flow diagram of our prototype workflow within Layar.

Diameter at breast height (DBH) provides an indication of tree growth and health. DBH is traditionally measured by using wrapping a specially designed tape measure around the trunk at four-and-a-half feet from the ground. Our mAR DBH tool utilizes a combination of virtual measurement tool and image processing, as described below. Crown width measures the width of the tree canopy with leaves. Tree height is simply the height of the tree from the ground to its uppermost branch. Both are traditionally measured through direct observation of the tree with specialized measurement tools. Within our workflow, they utilize the same design principles as the mAR DBH tool. We capture biometrics observations such as overall leaf color and leaf condition, soil compaction or erosion, broken or missing limbs, and overall status of the tree (live, dead, or fallen) through recording of direct observations on mobile-web forms. Additional contextual socio-environmental metadata such as observations of watering/gator bag presence and status, mulch at base, features nearby or around the tree (seating, weeds, nearby residential lawn/yard, vandalism, graffiti, trash, and type of nearby building) are also captured by recording direct observations in mobile web forms. Lu et al, (2011) have shown that these conditions affect the survival of street trees. The mAR data validation tool enables users to validate positions for existing tree location. In mAR terms, this is referred to as a Point of Interest (POI). The image capture feature allows users to take and upload photographs, or re-photograph trees. The data completeness dashboard allows us to explore

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ways of working with partial/incomplete data and socially-mediated data validation. Tree location, currently part of an initial calibration task, is the foundation for future work in mapping of new tree locations or validating existing tree locations and is integral to calibrated data capture.

Launching the Layar MetaTree app auto-loads the location calibration 3D POI canopy mesh. The calibration of user location initiates the workflow. Once this task is complete, users access tools for tree monitoring in the form of actions that are presented in a main view along with a completeness/status dashboard. Within the prototype, each of the tree actions (tools or web forms) incorporates basic social network functionality via options to post/share to a users Facebook or Twitter account.

4. PHASE ONE: INITIAL DEVELOPMENT EFFORTS

During this first phase, our work focused on tree canopy data from NYC and San Diego as a test case and proceeded through three stages: pre-visualization, proof of concept (POC) and mobile AR workflow rapid prototyping.

We conducted early pre-visualization work with tree canopy data from NYC to identify a workable geospatial coordinate system that we could translate to 3D computer graphics Cartesian systems. Initial tests resulted in placing several 3D tree canopy models (meshes) from NYC into Google Earth for pre-visualization.



Figure 2: The top left and bottom left panels are views of a street in NYC with two trees identified (markers A and B) for which we created tree canopy mesh models. The top right panel shows the two tree meshes located at their geographic positions within Google Street View. The bottom right panel shows the tree meshes located at their geographic positions within Google Earth.

Based on the success of these early pre-visualization efforts, we proceeded to develop a proof of concept and rapid prototype using canopy data from San Diego in a general purpose augmented reality browser. To accelerate the process we elected to used Layar[8], a proprietary AR platform and browser. The Layar browser is free to use, has robust user base and development documentation, provides basic functionality for location-based and near-field vision AR, supports 3D models and 2D images as billboards with the ability to position this content in either a fixed or relative orientation to the user, and allow for download via the Layar stream directly or via a custom branded Layar launcher application from Android Market or iTunes app store. Additionally, Layar provides support for Android, iOS and Symbian platforms, providing the widest range of commonly utilized handheld device operating systems. At the time of initial development, the second most popular mobile AR application was Junaio which had just added the ability to track POIs near users. The focus of Junaio seemed to be mainly on near-field AR using QR codes or image features and thus their API for location based tracking was not as robust as Layar which already supported specific features like event auto-triggering, relative POI positioning and Layar sharing. These features have made Layar a suitable choice for our rapid prototyping and design iterations.

[8] http://www.layar.com

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In Layar location-based POIs are presented as layered media over live camera views on smart phones or tablets. The Layar API provides a set of basic functions for interacting with this content. These can be configured, and somewhat customized, but creating new and fully custom controls are not available within Layar. Even with these limitations the ability to create a proof of concept in Layar to demonstrate our approach and rapidly iterate and prototype workflow design is of significant value when compared to the time and resources required to develop custom augmented reality applications. Our implementation is diagramed below, in figure 3.

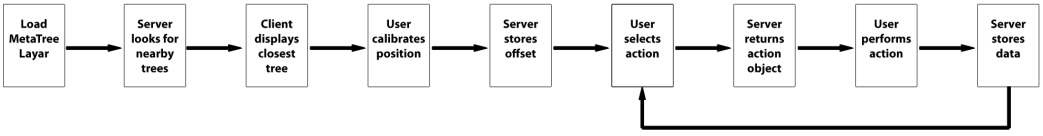


Figure 3: Implementation within Layar.

Layar development requires establishing a MySQL database to hold the POIs, Objects, Transforms, Actions, and Dialogs that comprise the augment layer/application. Server-side scripts are created to respond to Layar mobile client requests, and media assets are placed on our server. Once the Layar layer is created, development mode is used for mobile testing prior to making it publicly available via the Android Market or iTunes Store for download.

5. LOCATION

5.1 Tree Position Challenge

Tree location data is often difficult to obtain yet essential to monitoring tree status. In urban areas features such as tall buildings degrade the accuracy of GPS measurements making precise tree location using the GPS capabilities of handheld devices virtually impossible in cities like New York. Using known locations of trees from the TreeKit database we compared the accuracy of determining the location of 33 trees using a DroidX smartphone, Xoom tablet, and Garmin GPSMap76S (Figure 4, below). These tests were conducted during a field inventory session in which the user was given minimal time at each tree location. The average accuracy for these devices ranged from 4.2m to 8.8m, with the maximum error being 18m, 28.1m, and 36.4m respectively. In certain situations sub-meter accuracy was achieved.



Figure 4: Example of the positional limitations of consumer grade devices in an urban setting. The target tree is the tree for which the location was recorded using the three devices. The circles represent the minimum, mean, and maximum distance difference for all points.

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5.2 LiDAR

In response to these challenges we are prototyping methods for increasing accuracy of tree location data from handheld devices. We are exploring the indexing of user GPS location data from the handheld device into existing data with known GPS coordinates for individual trees. To integrate existing tree canopy data as a geospatial reference model within the workflow we are utilizing air-borne, overhead LiDAR (Light Detection and Ranging) data. LiDAR is becoming increasing common for urbanized areas in the developed world. In comparison to overhead imaging cameras that rely upon reflected light, LiDAR systems emit and receive their own electromagnetic energy in the near infrared portion of the electromagnetic spectrum. Because LiDAR is an active sensor the resulting data does not contain shadows, which are one of the chief drawbacks to using passive imaging systems (e.g. aerial and satellite imagery) in urban areas. LiDAR data consists of a "point cloud." Each point has x, y, and z coordinates, representing the location of where the laser pulse made contact with a feature such as a branch of a tree or the tile of a roof. For a given tree, LiDAR imaging returns many points from the top of the tree such as the leaves and branches that form its crown. High-quality LiDAR data over urbanized areas is typically acquired in the fall or spring during "leaf-off" conditions, and while LiDAR point cloud data provides an excellent representation of an individual tree's branching, it's vantage point prevents it from acquiring sufficient amount of information about the tree trunk from which to accurately measure factors such as DBH.

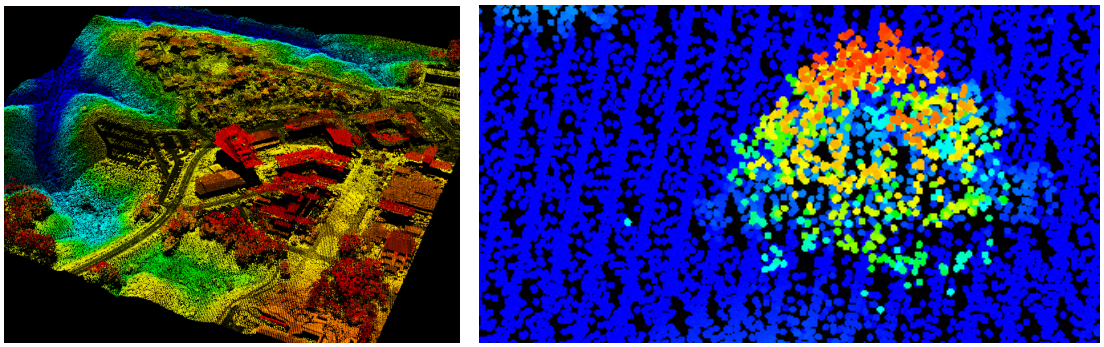


Figure 5: Overhead LiDAR of portion of UC San Diego campus (left) and LiDAR scan of individual tree (right) with warm-cool color ramp applied to indicate height.

LiDAR data for NYC collected in 2010 has a 9.24 cm vertical accuracy and a 27.75 cm horizontal accuracy. To incorporate LiDAR canopy data in our mobile AR workflow, we created a preliminary data processing pipeline to generate 3D meshes for individual trees with their associated GPS coordinate data. Tree crowns were extracted using a rule-based expert system within the eCognition software package[9], which offers robust object-based image analysis tools.

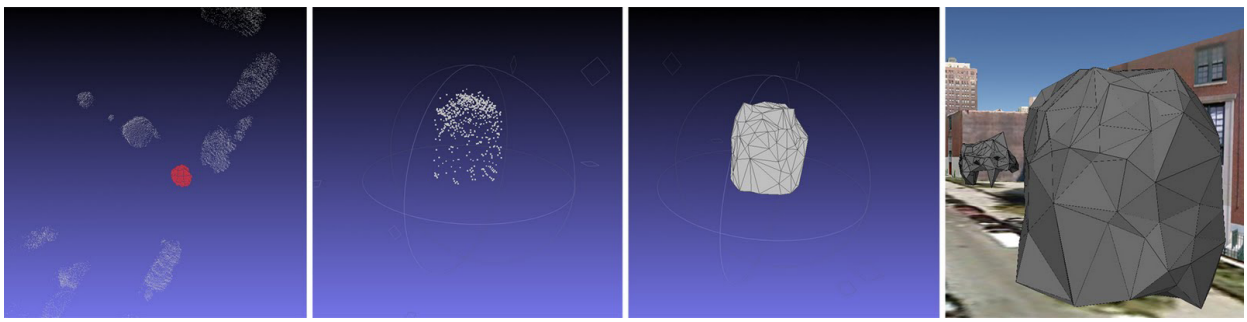


Figure 6: From point clouds to meshes

In the first panel, point cloud data for an individual tree is isolated from a larger LiDAR data set. The individual tree point cloud (second panel) is then used to create a low-resolution polygonal mesh representing the tree canopy (third

[9] http://www.ecognition.com

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panel). The fourth panel shows the resulting tree canopy positioned at its GPS coordinates within Google Earth. Tree canopy meshes are utilized as POIs within the Layar application.

5.3 Location Calibration

As location is fundamental to tree monitoring, we utilize location calibration as the entry to our mobile AR workflow. Upon launching the Layar application, the 3D tree canopy mesh nearest the user/device location is automatically loaded as a POI in the live camera view. The user is presented with 6 directional buttons for aligning the 3D canopy mesh with the corresponding tree in the live camera view. They can move the 3D tree mesh North, South, East, West, Up or Down. To complete the calibration step they tap on the "finish calibration" button in the live view. This sends position information back to the Layar application server.

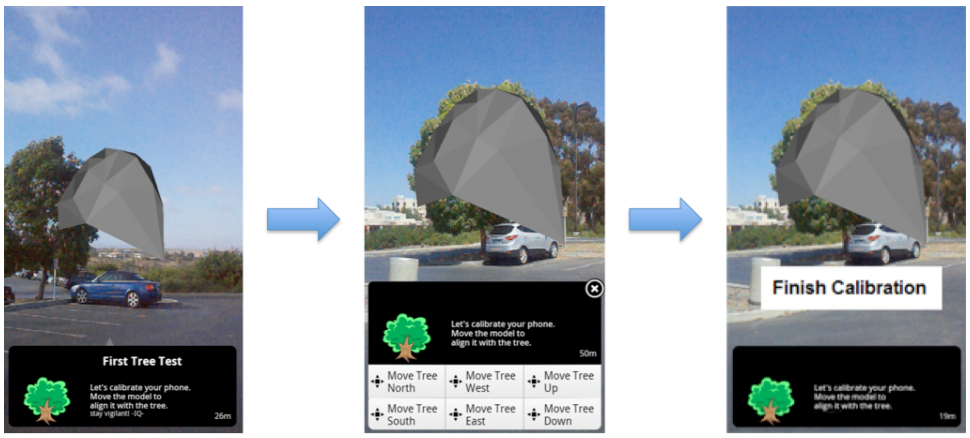


Figure 7: Location calibration process utilizing 3D tree canopy mesh and Layar interface for repositioning the POI. The POI mesh auto-loads (left), directional buttons allow the user to reposition the mesh (middle), then a finish calibration button displays once the user has modified the position of the POI (right).

We are developing an approach for calibrating user location in which we calculate a series of offsets based on the known tree location from the LiDAR canopy GPS information. For testing our methodology, we are measuring the phone GPS error along with the accuracy of user calibrations. Using a Differential GPS (DGPS), accurate to within 1-4 cm, we determined the precise location of a reference test tree. We then measured the distance between the user position as reported by the phone GPS and the actual user position derived from DGPS. We also measured the distance between the actual tree position as reported by DGPS and the position of where the user placed the virtual tree using mAR Layer application.

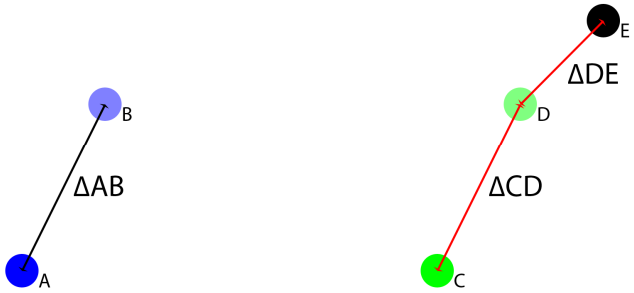


Figure 8: Calibration Accuracy Measurement. A represents the DGPS lat/lon of the user; B represents the lat/lon of the user derived from mobile GPS; C represents the DGPS lat/lon of the tree; D represents the *ideal* location of where a user would calibrate the 3D AR tree to; E represents *actual* location of where the user positioned the 3D AR tree during location calibration. ΔAB is equal to ΔCD and ΔDE tells us the error in the users' calibration. *Ideal* represents a perfect calibration by the user that is offset only by the phone GPS error.

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The objective of this DGPS test was to identify all potential sources of location error within our system and develop a methodology for correcting them. The desired end state was an approach that would enable us to evaluate the potential for repeat calibration measurements collected for an individual POI mesh by multiple users to result in increased user location accuracy by triangulation of data points.

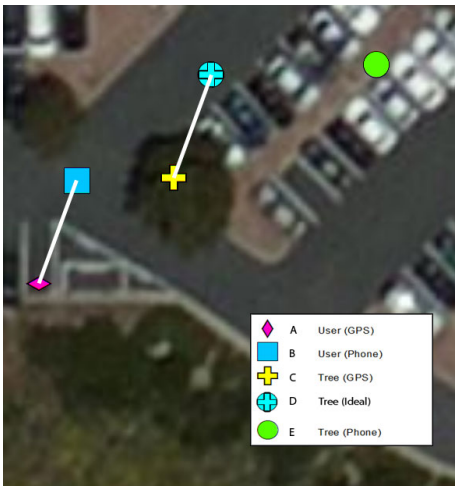


Figure 9: Example test with DGPS, mobile phone GPS and user calibration within Layar.

Table 1: Three validation tests from specific positions with DGPS and Mobile Phone GPS. This shows the offsets from the mobile phone GPS as well as the user calibration error.

Test Location ID	User lat/lon (DGPS) (A)	User lat/lon (Phone) (B)	POI lat/lon (Phone) (E)	Tree lat/lon (DGPS) (C)	User Offset (m) (ΔAB)	Tree Offset (m) (ΔCE)	Calibration Offset (m) (ΔDE)
West Spot	32.8835456, -117.234913	32.883525866, -117.23494283	32.883985, -117.23456	32.8836276, -117.234672	3.48990	40.85138	37.36147
North Spot	32.8836347, -117.234828	32.883623766, -117.23484720	32.883785, -117.23446	32.8836276, -117.234672	2.11812	26.02903	23.91091
East Spot	32.8837218, -117.234585	32.883695383, -117.23467011	32.883485, -117.23476	32.8836276, -117.234672	8.48298	18.06857	9.585596

The results of our calibration tests indicated that a chief challenge to calibration is that there are two sources of error: 1) the GPS location determined by the phone and 2) the location of the tree as determined by the user through the mAR workflow. To eliminate contributions to error not related to the phone GPS we plan to review our workflow for constructing polygonal meshes from the LiDAR data and evaluate the Layar projection matrix in relation to our setup. Our first task will be to confirm that the 3D model is accurately representing the shape, position and scale of the tree as depicted by the LiDAR point cloud. Next we will perform tests within Layar to confirm the projection matrix is accurately representing models at the appropriate size and location. (Sources of error relating to the user experience are discussed in the section 7, below.) In actual use, the system would collect the mobile GPS (B) location, the location where the user placed the POI mesh (E) and the tree canopy GPS from LiDAR (C). The ultimate objective is to improve the accuracy of mesh POI and phone GPS locations around the tree canopy position from LiDAR using data from multiple users. The updated user position information can be used to improve the accuracy of the image to real-world scale factor that is used for image processing to derive measurements from photographs taken using the mAR tools.

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6. mAR MEASUREMENT TOOLS

We are developing mobile AR measurement (mAR) tools that share a common design principle: the user manipulates virtual objects (POI augments with real-world physical dimensions) in relation to real-world coordinates within live smartphone camera views to produce images and metrics as the outcome of these interactions.

6.1 DBH as a Test Case

While significant work remains to validate and develop robust implementations of each tool within our workflow, we prototyped a tool for measuring DBH as a test case. DBH is a key metric in urban forest monitoring and insights from developing a DBH tool can be applied directly to both the canopy width and tree height mAR tools.

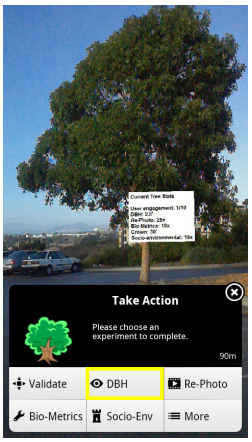


Figure 10: Accessing the DBH tool through the Completeness/Status augment

Users access the DBH tool from one of seven tree actions available within the mAR workflow after location calibration is completed. The five part task flow includes: selecting the DBH tree action, aligning the measurement augment with the tree trunk, taking a photo, uploading the photo, and optionally sharing it via Facebook or Twitter. Server-side image processing (described below) analyzes the images for DBH measurements. Selecting the DBH tool sends a request to our server to load the measurement augment at the centroid of the tree location provided from the location calibration step. The user then visually aligns the augment's center mark with the tree trunk, takes a photo and uploads it to the server for processing.

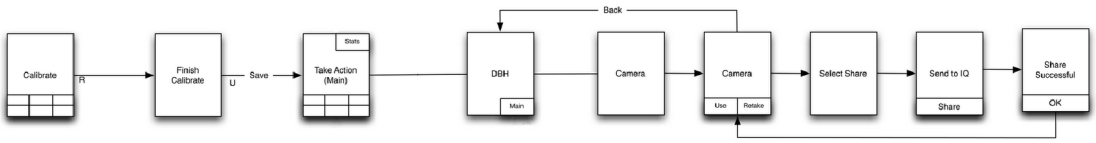


Figure 11: DBH Workflow in Layar.

Once the user has calibrated their location, they select the DBH action, take a photo and share it. For future work, once the image is sent to our server it will be automatically queued into the image analysis pipeline to measure DBH. Once the DBH value is derived from the image, it will be stored in the database and the new averaged DBH will be updated in the completeness/status dashboard.

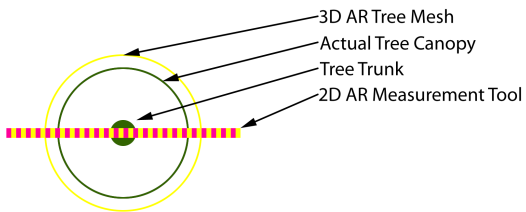


Figure 12: Alignment of 2D augment POI to determine DBH and crown width.

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6.2 Image analysis for DBH

Once uploaded to the server, the image of the tree with its augment, is analyzed to provide an estimate of the tree trunk's diameter. The image analysis is a two step process. First, the augment is located and used to identify the center of the tree and to establish scale. Then the outer edges the tree trunks are located in the image and used to establish the DBH.

By design, the augment is easy to identify in the image. It's alternating regions of saturated colors are easily segmented in HSV color-space. Additional morphological constrains such as alignment and size are used to eliminate spurious matches. Once detected, the size of the augment in the image is measured and used in conjunction with its known size in real-world coordinates to establish a conversion ratio from pixels to inches (in the region of the tree).

Next, the image is converted to gray scale. Horizontal and vertical edges are identified through convolution with horizontal and vertical Prewitt kernels[12]. The extent of the trunk is identified though a heuristic algorithm. A *candidate trunk* is a pair of lines, centered vertically on the augment, that extend above and below the augment in the tree image. A candidate trunk's *score* is a heuristic value that favors pairs of lines that coincide with vertical lines and avoids horizontal lines as calculated by the Prewitt filters. The score also favors pairs of lines that are near-parallel and equidistant from the center of the tree (as identified by the user when taking the photograph through the positioning of the augment).



Figure 13: Algorithmic identification of tree trunk edges using mAR augment.

The highest scoring candidate trunk is assumed to correspond to the edges of the trunk. A brute force search algorithm finds the highest scoring candidate. This is possible because most low scoring lines can be eliminated through use of a threshold before searching. The horizontal distance between the lines representing the trunk are measured at breast-height (as determined by the location of the augment). The trunk diameter in pixels is converted to inches using the conversion ratio established by the augment.

The trunk identification algorithm works well in our sample data but needs a larger data set to be well validated. Like most computer vision algorithms using low quality images in unconstrained environments, we assume it may fail. Because the vision algorithm is server based, it can be improved upon and validated while it is being used "in the wild." With use, trunk images can be gathered and used as training data to train a recognizer to further refine our trunk detection algorithm. This bootstrapping process will allow the accuracy of our algorithm to improve overtime.

Beyond computer vision failures, another possible source of error is GPS inaccuracies causing the augment to be rendered incorrectly. This would result in an incorrect image to real-world scaling factor. It is our hope that GPS error is not biased and that measurement estimates will converge on the real world trunk diameter.

7. USER EXPERIENCE PROTOTYPING CHALLENGES

Prototyping in Layar has allowed us to rapidly articulate the design concepts for our mAR tools, yet it has in some cases added steps to task flows, or necessitated work-arounds that might not be required in a custom application. These elements offered us insight in to ways to enhance our user experience, tool design and location calibration as we both iterate and expand upon the workflow and as we develop our future work for phase two.

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Since our work-flow is imaging centric, how users access and use the camera and upload photos impacts its usability. Utilizing the Layar proprietary AR browser's camera and social media/share feature set means that image capture and upload from within a mAR tool in Layar requires an additional 4 or 5 steps.

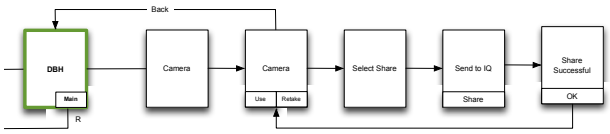


Figure 14: additional steps for image capture and upload

Within Layar, users follow a set sequence for image capture that includes; accessing the camera, taking the photo, selecting to either use or retake the photo (review), selecting to share the photo, and with what service (our server, Facebook, Twitter). Must importantly, they must select our server from a list of services to share with, or the image goes directly to Facebook or Twitter. This setting cannot be set by us as a custom default, and must be selected each time. After receiving a "share successful" message and selecting "ok" to return to the review screen, users must select the back button to go to DBH and then again to get to the main tree actions screen. While not exceedingly complex, the additional steps are a drawback to using Layar outside of rapid prototyping for an imaging-based workflow. Within a custom AR application the workflow could be streamlined to only include camera access, image capture, and a screen that integrates review with options to "send" (upload) to our servers as a default. Additional options could be provided to annotate a photo with a brief post or default input and share to Facebook or Twitter. Sharing settings could also be customized in a global manner to allow users to auto-post to their social media accounts or in an anonymous manner to a larger Facebook group on monitoring trees in a geographic region, or as part of a community stewardship group.

Another example that points to the benefits of developing a custom AR application is the requirement in Layar to use buttons to manipulate the position of a 3D POI. Each button press within Layar results in the POI making a move of a default step distance in the specified direction. Rather than offer a fluid, continuous manipulation via the touch interface with swipe gestures or other more direct forms of interaction that position the POI in variable increments, this results in a step-wise adjustment in the position of the POI, in the fashion of "snap-to-grid" style interactions. While helpful in some circumstances, in others this lack of more variable positioning can reduce the accuracy of location calibration.

One of the major user experience challenges we faced during prototyping includes the way in which Layar responds to GPS jitter. Each time Layar registers a change in the user/device GPS location, it initiates a refresh of the Layar app and the user is forced to undergo the calibration procedure. While this assures that a user's location calibration is current in the event they have actually changed position, there are currently no options for developers to change the GPS sampling rate to reduce the frequency of position updates passed to Layar from the device sensor. Ideally, in a custom AR application, the location client would decrease GPS sampling rate to reduce the effects of jitter on the user experience.

To enhance the location calibration user experience, ideally we would present users with two coordinated views: an overhead map inset that shows them the changes they are making in POI position in real time in relation to their position, and the live camera view with the 3D POI they are interacting with. Currently, users can toggle between map view and camera view within Layar, yet there are no options for coordinated viewing of map and live view within Layar's feature set. Additionally, the limited screen size and resolution of mobile phones makes these kinds of interactions with coordinated views difficult to achieve in ways that are truly useful. The larger screens and resolutions of tablets offer greater opportunities for these kinds of features to be useful in the context of our mAR tools and workflow.

Alternate rendering of the POI mesh object or mAR augments could also enhance the overall user experience. For example, Fischer, et al[13] have demonstrated the ability for stylization to increase the sense of immersion within AR. These and other novel rendering strategies, such as shadows responsive to real-world lighting conditions could provide additional depth cues for users in positioning the tree canopy POI mesh augment, thus increasing the accuracy of their location calibration.

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8. REFLECTIONS AND FUTURE WORK

We have presented our initial design iterations and rapid prototyping for developing mobile augmented reality tools for urban forest monitoring by citizen scientists. While limited, the prototype mAR DBH tool points to opportunities for utilizing augmented content (POIs) as virtual-physical tools for data collection, analysis and interpretation. This extension of augments from overlays to a means of inquiry about the physical world offers new potentials for citizen science. It invokes possibilities for a new genre of epistemic actions blending the physical with the virtual and their application to science learning [14,15]. In general, mobile AR provides new approaches for the creation of citizen science campaigns. Developing citizen science projects is both time and resource intensive, involving design of research questions as well as data collection and training protocols[16]. Along with training, recruiting and motivating participants to contribute data frequently and over the long-term is a major element in the success of citizen science campaigns[17]. Similar to approaches for augmenting manufacturing or complex assembly tasks or for medical or surgical training, mobile AR can enhance citizen science protocols with step-by-step instructions or real-time data. If training times for citizen science tasks can be minimized or concurrent with the act of data collection, this creates the possibility for decentralized recruitment in which a citizen science participant can recruit and potentially train others, thus expanding the reach and data collection capacity of a given project.

Significant work remains to achieve our long-term objectives of generating an experience compelling enough to engage a broad public audience in ongoing monitoring of urban forests. Within the near future, we will continue our work in user location accuracy and calibration, exploring alternative approaches in addition to the initial approach described above, developing prototypes of the remaining tools, creating an automated canopy mesh generation pipeline, and evolving the overall workflow in order to accomplish field testing with our partners in NYC during 2012. Our prototype workflow includes a dashboard envisioned to contain data for tree status alongside information salient to motivating participants to contribute on an ongoing basis, such as reputation-based metrics, points systems, self-programmed reminders to revisit a tree they have previously captured data for or prompts for events from local stewardship groups in which they are active. Along with this we will prototype methods for social media integration that lead to collaborative/social weighting of data collected by multiple users. Results from field-testing will enable us to iterate the mAR tools and workflow and identify touch-points for integration of social, gaming and cultural engagement.

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