Geophysical and Laser Scan Surveys at the Longfellow House – Washington’s Headquarters National Historic Site

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Figure 1 Integrated laser scan and GPR survey results for the Longfellow House - Washington’s Headquarters NHS

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Figures
Figure 1 Integrated laser scan and GPR survey results for the Longfellow House - Washington's Headquarters NHS .................................................................1
Figure 2 Control survey points (A), with closed transect (B), and highlighted points 1, 3, and 5 used for static differential GPS session for link to State Plane.........................................................7
Figure 3 Geophysical survey grid points with control grid. .................................................................8
Figure 4 SIR3000 GPR unit with a 400 MHz antenna and survey cart used during the ASTDA Workshop...9
Figure 5 Instructor Ken Kvamme with the FM256 Fluxgate Gradiometer used in the ASTDA workshop. .11
Figure 6 The TR/CIA resistivity meter with twin probe array of 0.50m spacing used during the ASTDA workshop. (Instructors Ken Kvamme, left and Bryan Haely, right). ..................................................12
Figure 7 The EM38 conductivity meter used during the ASTDA workshop........................................13
Figure 8 Geophysical survey area for the Longfellow House - Washington's Headquarters geophysical surveys .................................................................14
Figure 10 GPR survey coverage...........................................................................................................16
Figure 11 Vertical profile of GPR data (A) with interpreted anomalies (B). The green anomaly is a back-filled sondage, the red outline defines the basement of a structure pre-dating the current Longfellow House, and the yellow points identify point reflectors, most likely pipes as part of the irrigation network on the property. ..........................................................................................................................17
Figure 12 Time slices, or horizontal plan maps, of GPR data can be rectified individually into GIS (A) or viewed actively in dedicated software B (in this case, GPR - Slice). .........................................................17
Figure 13 Survey area for Magnetic Gradient........................................................................................18
Figure 14 Resistivity survey area..........................................................................................................19
Figure 15 Survey areas for Conductivity and Magnetic Susceptibility surveys....................................21
Figure 16 GPR plan views at 0.07 - 0.19 m (A), 0.31 - 0.42 m (B), and 0.77 - 0.89 m (C) deep..............22
Figure 17 GPR interpretations for the Longfellow House - Washington's Headquarters NHS.............23
Figure 18 Magnetic gradient survey plan. Red arrows highlight anomalies caused by ferrous material. 25
Figure 19 Interpretations of the magnetic gradient survey. .................................................................26
Figure 20 Resistance survey plan.........................................................................................................27
Figure 21 Resistance survey interpretations. ........................................................................................28
Figure 22 Magnetic susceptibility survey plan.......................................................................................29
Figure 23 Interpreted anomalies in the magnetic susceptibility survey..............................................30
Figure 24 Compilation of interpreted possible archaeological anomalies from all geophysical survey methods. .................................................................................................................................31
Figure 25 Compilation of interpreted possible modern anomalies from all geophysical survey methods. ........................................................................................................................................32
Figure 26 Interpreted modern utilities overlain on irrigation plan. .......................................................33
Figure 27 Geophysical survey features for discussion include: A - the historic basement foundation, B - the circular landscape feature, and C - the historic garden feature..................................................34
Figure 28 Example of integration of GPR profile interpretation to refining the historic basement feature. A shows a plan map of GPR data with lines identifying the GPR profile positions that delineate the basement feature. B overlays the GPR profile positions on the GPR ‘basement anomaly’ polygon; C overlays the GPR profile positions on the magnetic gradient ‘basement anomaly’ polygon. D identifies a single GPR profile in the plan map that is displayed vertically adjacent to the plan. E shows the processed GPR data profile with the basement feature. F shows the interpretation of the archaeological and modern features in the GPR profile.

Figure 29 Geophysical survey interpretations for the circular landscape feature. A - combination of anomaly interpretations, B - resistance survey interpretation, C - magnetic susceptibility interpretation, D - GPR interpretation.

Figure 30 Geophysical survey interpreted anomalies for the south eastern historic garden feature. A is a compilation of interpreted anomalies from multiple geophysical survey methods. B shows resistance anomalies, C shows the magnetic susceptibility anomaly, D shows GPR anomalies, and E shows magnetic gradient anomalies.

Figure 31 Leica ScanStation C10 used for the ASTDA Workshop survey.

Figure 32 Pointools integrated visualization of the laser scan and GPR surveys.

Figure 33 A cross-section of the laser scan and GPR surveys demonstrating the above- and below surface nature of data integration.
Overview
Geophysical and laser scan surveys were conducted at the Longfellow House – Washington’s Headquarters National Historic Site (NHS), Cambridge, Massachusetts in August, 2011. This work was undertaken as part of the *Archaeological Survey Technology, Data Integration, and Applications (ASTDA) Workshop*. This workshop was funded by the National Center for Preservation Technology Training¹ and supported by the Joukowsky Institute for Archaeology and the Ancient World, Brown University², and Harry R. Feldman Survey, Inc³.

This work helped identify and map modern landscape features as well as previously unknown and significant landscape and archaeological features including structural foundations, potential garden beds, and colonial-period structures. Ground penetrating radar (GPR), magnetic gradient, conductivity, and electrical resistance survey methods were employed. The GPR and magnetic gradient most effectively identify architectural features in the form of rectilinear anomalies that most likely represent building foundations, or basements of structures pre-dating the Longfellow House – Washington’s Headquarters National Historic Site. The GPR and magnetic gradient methods were also most effective in identifying what appear to be colonial-period landscape features. These two geophysical methods greatly complimented each other in anomaly identification, providing insight to possible material composition of some of the potential archaeological features. The conductivity survey mostly identified modern features such as utilities and existing pathways, but also complimented the GPR and magnetic gradient surveys in mapping some of the colonial-period landscape features. Due to time restrictions, the resistance survey sampling rates were rather coarse (1 m x 1 m sample spacing with 0.5 m electrode spacing) and did not reveal any potential archaeological anomalies. In some instances the geophysical survey anomalies can be compared against features from previous excavations, which reveal that while the geophysical surveys (GPR & magnetic gradient) identified a basement feature pre-dating the existing structure) they also (with conductivity) identified a cultural feature that was not identified during excavations, thus revealing that geophysical surveys are necessary and complementary methods for site investigation.

3D laser scanning surveys were used to construct a high-resolution model of the Longfellow House - Washington’s Headquarters National Historic Site and its immediate environment. Geophysical survey results and 3D laser scanning models were integrated into 2D analytical (GIS) and 3D visual (Pointools) environments for enhanced site analysis and the development of new visual methods for data presentation and delivery.

ASTDA Workshop instructors included:

Dr. Meg Watters, Brown University
Dr. Kenneth Kvamme, University of Arkansas
Bryan Haley, Tulane University
Stephen Wilkes, 3DFeldman, Harry R. Feldman Surveyors, Inc.
Steven Pendery, University of Massachusetts, Amherst

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1 [http://ncptt.nps.gov/](http://ncptt.nps.gov/)
2 [http://brown.edu/Departments/Joukowsky_Institute/](http://brown.edu/Departments/Joukowsky_Institute/)
Jim Shea, Director of the Longfellow House – Washington’s Headquarters NHS.

**Introduction**

Geophysical survey methods of the sub-surface and 3D laser scanning of existing environments provide cost-effective means for capturing archaeological information for site recording, investigation, and management. Using non-invasive sub-surface and surface mapping methods can document the basic structure and layout of site. In instances where historic properties are active sites with maintenance and potential development impact demands, these methods can guide placement of expensive excavations and contribute to site impact strategies when dealing with upgrade of site infrastructure (such as utilities, and landscape management); thus providing large cost savings while reducing destructive impact upon important archaeological remains.

Geophysical survey methods can provide primary information on site settlement patterns. The continued application and development of broad area coverage for archaeological assessment has begun to introduce an alternative perspective into regional, or landscape archaeology (David and Payne 1997; Kvamme 2003). Because geophysical surveys are able to cover large areas in comparison to the limited extent of archaeological excavations, the information they provide introduces a new component to the concept of the archaeological landscape. Broad area geophysical surveys provide information on the structure and organization of a site enabling the study of spatial patterns and relationships relevant to research questions. In addition to the large-scale perspective of the site, geophysical survey results also provide a high-resolution focus on individual site features.

Geophysical surveys measure different subsurface properties at regular intervals across broad areas. Contrasting properties in a relatively homogeneous soil can identify buried objects or features such as foundations, compacted earthen surfaces, pits, stone walls, middens, hearths and any number of archaeological features. The different physical properties of the features, measured either in contrast to their surrounding matrix, or as recorded at the surface are referred to as ‘anomalies’ until they are able to be ground-truthed through excavation or other methods such as soil coring.

Different geophysical methods are sensitive to specific properties, such as magnetic fields, or the flow of an electrical current in the earth. Employing a combination of methods over a survey area can help provide information as to the nature, or material, of an anomaly, thus providing insight for site interpretation. Mapping the distribution of anomalies over a large area can help in the recognition of anomalies generated through cultural activities revealing the spatial distribution and association with site features (Kvamme 2003).

Geophysical surveys can provide important information for help in site planning and preservation. These non-invasive methods can help establish priorities and identify areas for further invasive investigations, or for preservation and management. They are a fast and cost-effective method for gaining insight to what is buried beneath the ground. Geophysical survey results can be spatially integrated with other data relevant to archaeological investigations to provide a comprehensive record of the site environment, both below, and above ground.
**Site Control Survey**

Key to all the remote sensing and data integration aspects of the ASTDA workshop a survey control network was established around the property. Survey control enables not only the spatial integration of results from the geophysical surveys to the 3D laser scanning but also to enables easy integration with GIS based data sets and previous and future activities on the site such as archaeological excavations and utility work.

In the planning phase of the workshop it was determined that State Plane coordinate system (zone 4151) would be adopted to allow for easy integration with the existing City of Cambridge GIS database. Although the data from this resource is on the NAD83 vertical datum it was decided that the workshop would utilize the local project datum established and used for all previous work. However, a direct vertical relation between this and NAD83 were established.

A five point closed traverse was run around the Longfellow house gardens to form the basic framework for the survey control (Figure 2, A and B). From this network all the geophysical grids were established (Figure 2, C) and laser scanning control targets located. Three of the principle points (Figure 2, B highlighted) within the network were also occupied for static Differential GPS sessions to accurately relate the local survey to State Plane. All traverse points, geophysical grid points, and laser scanning target locations were leveled to from the benchmark established on the front step of the Longfellow House during previous archaeological survey work.

*Figure 2 Control survey points (A), with closed transect (B), and highlighted points 1, 3, and 5 used for static differential GPS session for link to State Plane.*
Geophysical Methods, Principles, and Equipment

Ground Penetrating Radar

Method
GPR can provide high resolution records of boundaries between subsurface features with contrasting dielectric properties. A standard method for detecting buried archaeological features, GPR is able to collect large amounts of data, covering moderate areas, over a short period of time. GPR is a geophysical technique that can produce a three dimensional image of the subsurface and provide accurate depth estimates and information concerning the nature of buried features. The basic principles and theory of GPR operation have evolved through electrical engineering and seismic / geophysical exploration (Daniels 2000).

Principles
GPR maps the form of contrasting electrical properties (dielectric permittivity and conductivity) of the subsurface and records information on the amplitude, phase and time of electromagnetic energy reflected from subsurface features. The results are presented as 2D vertical profiles in the earth. The stronger the contrast between the electrical properties of two materials, the stronger the reflected signal in the GPR profile will be.

The GPR method measures the time elapsed between the transmission of an electromagnetic wave from a surface antenna into the earth and its reception back at the surface after reflection off a buried discontinuity; this is two-way travel time (twtt). The electromagnetic wave moves at a velocity determined by the electrical property of the material it is travelling through. The wave spreads and travels downward until it hits an object with different electrical properties where part of the energy is
reflected back to the surface while the rest of the energy continues to pass downward. Changes in mineral composition, water content and density are among the soil discontinuities that may cause reflections.

**Equipment**

There are a number of GPR manufacturers that produce instruments that use a variety of antennas. The SIR3000 GPR unit with a 400 MHz antenna (Figure 4) was used during the ASTDA workshop.

![Figure 4 SIR3000 GPR unit with a 400 MHz antenna and survey cart used during the ASTDA Workshop.](image)

**Magentometry**

**Method**

Magnetometry survey measures the variation of the magnetic field of the Earth and features contained within it. In archaeological applications magnetic survey aims to measure the magnetic fields associated with archaeological features. Through comprehensive mapping techniques, detailed plans can be acquired that delineate buried features. Not only can magnetic survey map buried features, many times these features produce characteristic shapes and strengths that can contribute information to the interpretation of archaeological features (Gaffney et al. 2003).
**Principles**

Magnetic survey measures the variation of the magnetic fields of the Earth and buried features across a site. Different soils and features can be mapped through their contrasting magnetic values. Examples of features that can be detected through this process include ferrous materials, soil affected by human occupation (rubbish pits and middens with organic materials), fired materials such as kilns and hearths, tiles, bricks, and concentrations of ceramics. Differences in soil type or soil perturbation are also detected through magnetic survey enabling identification of ditches, pits, foundations, graves and other excavated features (Clark 1996).

The magnetic gradient is used for archaeological applications of magnetic survey. Magnetometry collects two total fields from two separate magnetometer sensors. These sensors measure the total magnetic field at their respective distance above the earth. The gradient is calculated from the two total fields and effectively removes broader scale background noise. This background noise includes larger geological trends and diurnal effects and acts as an edge filter (Breiner 1973).

Magnetic survey in archaeological applications maps the contrasting values of the magnetic properties of buried or invisible anthropogenic impact on the Earth. The magnetic properties that are central to archaeological practice include magnetic susceptibility, thermoremanent magnetism, and ferrous objects.

Normally, the higher magnetic susceptibility of the topsoil in comparison to the subsoil helps define excavated features such as pits, ditches and post holes through the contrast between the lower background values to the higher susceptibility of the feature infill. The enhancement of magnetic susceptibility as the result of human occupation helps to define the limits of a site that may not have any visible or other distinctive features to identify it (Clark 1990).

Thermoremanent magnetic features tend to appear as strong anomalies in magnetic data. Features such as kilns, ovens, hearths and fire cracked rock many times can be identified in data based on their recorded field strength, anomaly shape and orientation (Gaffney et al. 2003).

Magnetic survey measures the anomalies in the Earth’s magnetic field based on the variation of the magnetic properties of the underlying rocks and minerals. As a result of geological formation and human impact, magnetic anomaly strength in geological and archaeological terms is dependent upon the two basic phenomena of induced magnetisation and thermoremanence (Breiner 1973; Clark 1990; Gaffney et al. 2003; Kearey et al. 2002; Mussett and Khan 2000).

Archaeological anomalies are present due to the contrast between cultural features and the surrounding environment. Both of these factors are mostly composed of materials with natural origins such as rocks, soils and minerals. Successful archaeological magnetic mapping depends upon the magnetic contrasts of materials based on the concentration of a material and the thermal and mechanical histories of magnetite present both the cultural feature and its surrounding matrix (Breiner 1973).
**Equipment**
There are three basic types of magnetometers that are commonly employed in archaeological surveys: the proton precession magnetometer, the fluxgate gradiometer, and the cesium (or alkali vapor) magnetometer (see Scollar et al. 1990 for details). The FM256 Fluxgate gradiometer was used during the ASTDA Workshop (Figure 5).

![Figure 5 Instructor Ken Kvamme with the FM256 Fluxgate Gradiometer used in the ASTDA workshop.](image)

**Resistance**

**Method**
Resistance survey maps the resistance of the earth to an electrical current injected into the earth. Earth resistance values are affected by the nature of buried archaeological features, the mineral content and compaction of soils in which they are buried and saturation levels of the subsurface. The saturation of the subsurface is dependent on rainfall, soil composition and compaction and subsequent percolation rates, evaporation rates and water take-up through the roots of vegetation. Weather and geological conditions impact on the effectiveness of resistivity surveys in archaeological applications and dictate careful consideration of resulting data (Clark 1996).
\textit{Principles}

Electrical resistivity introduces a current into the ground and measures how readily that current flows through the earth. The flow of an electrical current through rocks and other materials depends upon parameters such as water saturation, mineral content and porosity.

\textit{Resistance and Resistivity}

When first collected, data values are soil resistance which is then converted to apparent resistivity. The basic difference between resistance and resistivity values is that resistance is a bulk measurement of the material through which the electrical current is flowing and in part dependent upon how much of the material is present. Resistivity is a measure of the material itself which will not change in respect to the amount or shape of the material sampled (Gaffney and Gater 2003). The advantage of calculating apparent resistivity is that then resistivity values can be directly compared to values obtained in other surveys (Clark 1996:27).

\textit{Equipment}

A number of manufacturers produce resistivity meters that are used in archaeological applications. The ASTDA workshop used the TR/CIA resistivity meter with the twin probe array for site survey (Figure 6).
Conductivity / Magnetic Susceptibility

Method
Like resistivity instruments, conductivity measures how readily an electrical current flows through the earth. The conductivity instrumentation induces an electromagnetic signal into the earth and records the response of earth properties to that waveform.

Principles
Conductivity is measured using electromagnetic induction. A transmitter and receiver generate and read the response of an electromagnetic field which is induced into the soil when passed over it (Heimmer and De Vore 1995:34). The response in a material is proportional to the electrical conductivity. Unlike the ground probes used for resistivity, conductivity meters do not require contact with the ground. The prevalence of moisture, which can conduct electrical current in a material, is related to grain size for soil and porosity for rocks.

Equipment
The conductivity meter most commonly used in archaeology is the EM38 which has a 1 meter coil separation. The EM38B was used for the ASTDA Workshop and simultaneously measures the quadrature (conductivity) and in phase (magnetic susceptibility) components of the response to the induced field.

Figure 7 The EM38 conductivity meter used during the ASTDA workshop.
Geophysical Survey Logistics: Grid location, data collection, and data processing

Using the site control grid, the geophysical survey grids were established to cover as much of the grounds to the west, south, and east of the house structure. Because this survey was part of a training workshop, the survey grids were placed on level ground, thus not covering the area directly in front of the house front door, due to the steep slope to the south lawn.

Grid corners were surveyed in using a total station and wooden stakes were driven flush with the survey surface (Figure 11).

Each of the survey methods covered most of the established areas. Some areas within the survey grids were not covered due to ground cover (i.e. large bushes and trees).

Figure 8 Geophysical survey area for the Longfellow House - Washington’s Headquarters geophysical surveys.
Ground Penetrating Radar
The GPR survey was conducted using the GSSI SIR3000 system with a 400 MHz antenna in the survey cart (Figure 4).

GPR survey parameters were:
- 70 samples per meter
- 0.5 meter transect spacing
- Zig-zag data collection method (survey grid SW corner to grid NE corner)
- Distance based data collection using a survey wheel

The GPR data capture parameters were:
- Range Gain (dB) -4.0 29.0 44.0
- Position Correction 8.225 nS
- Vert Boxcar LP F =515 MHz
- Vert Boxcar HP F =295 MHz
- Range = 55 nS
- 512 samples / scan
- 16 bits per sample
- 120 scans per second

The GPR survey covered the majority of the established survey area as can be seen in Figure 11.
Post processing conducted in RADAN software, techniques include:

- Position Correction 4.51 nS
- Horz Boxcar Bkgr N=1023
- Variable Velocity Migration
- Range Gain (L) 4.0

Post processing conducted in GPR Slice software used the following parameters:

- Radar gram processing = regain, background filter, migration
- Number of slices = 20
- Slice thickness = 20 samples
- 0ns offset = 56 samples
- Grid algorithm = Inverse Distance (smooth factor = 2)
- Cell size = .25 meters
- Search radius = .75 (X & Y), blanking radius = .75
GPR data interpretation was conducted by examining individual vertical transects (Figure 11) and through viewing ‘time-slices’, or plan views (Figure 12 A), of the entire survey area after individual transects are combined into a 3D cube (Figure 12 B).

Figure 10 Vertical profile of GPR data (A) with interpreted anomalies (B). The green anomaly is a back-filled sondage, the red outline defines the basement of a structure pre-dating the current Longfellow House, and the yellow points identify point reflectors, most likely pipes as part of the irrigation network on the property.

Figure 11 Time slices, or horizontal plan maps, of GPR data can be rectified individually into GIS (A) or viewed actively in dedicated software B (in this case, GPR - Slice).

Magentometry
The FM256 fluxgate gradiometer was used during the ASTDA surveys (Figure 5). The survey area covered during this project is shown in Figure 13.

Magentometry survey parameters were:
- 0.125 m sample rate
- 0.5 meter transect spacing
- Zig-zag data collection method (survey grid SW corner to grid NE corner)

The magnetic survey data were processed using Geoplot 3.0. Processing techniques included de-spiking, grid/transect mean zeroing, 3 x 3 low pass and 10 x 10 high pass filtering. Once processed, data were interpolated along the x axis.
Resistance survey of the Longfellow House was performed using the TR/CIA Resistance Meter manufactured by the Council for Independent Archaeology (Figure 7). The TR/CIA instrument employs a Twin array type with a fixed mobile probe separation of 50 centimeters. As is required for the Twin away, the remote probes were placed at a minimum of 15 meters, corresponding to 30 times the mobile probe separation, from the mobile probes. This setup results in a maximum depth sensitivity of 50 centimeters.

Resistance survey parameters were different for the grids to the south and southwest of the Longfellow House and those to the southeast and east of the Longfellow house:

South and southwest:
- 2 samples per meter
- 0.5 meter transect spacing
- Zig-zag data collection method (survey grid SW corner to grid NE corner)

Southeast and east:
- 2 samples per meter
- 1 meter transect spacing
- Zig-zag data collection method (survey grid SW corner to grid NE corner)

* Note that the western side of the house was not surveyed using resistance due to time constraints and the abundance of obstacles there.

Figure 14 shows the resistance survey area.

The resistance data was processed using Geoplot 3.0. Data processing for the resistance data included de-spiking, 3 x 3 low and 10 x 10 high pass filters and were interpolated.
Conductivity / Magnetic Susceptibility

Electromagnetic induction (EMI) survey was performed using the Geonics EM38B instrument manufactured by Geonics Limited (Figure 8). This instrument uses a coil separation of 1 m in a vertical dipole mode. Figure 15 shows the conductivity and magnetic susceptibility survey areas.

Both quadrature phase and in phase readings were simultaneously collected for each station, relating to conductivity and magnetic susceptibility properties respectively. This specification results in a maximum depth sensitivity of about 1 m for the conductivity. For the magnetic susceptibility, the penetration is significantly shallower.

Conductivity survey data sampling:
- 2 samples per meter
- 0.5 meter transect spacing
- Zig-zag data collection method (survey grid SW corner to grid NE corner)

As with resistance data, the EMI data was processed using Geoplot 3.0. Null values were added in a text editor so that grid lengths and widths were in multiples of 10 meters and these were used to create a single composite data set.

A similar regiment was used to process the conductivity data as resistance data. This includes a despike operation and a 3X3 low pass, as well as the addition of a 10 X 10 high pass filter to a second version. The magnetic susceptibility data was processed in a similar fashion, without the creation of the second high pass filtered version.
Geophysical Data Interpretations
All of the geophysical survey results were imported to a project GIS using ArcMap 9.3. Data are rectified into the GIS project and polygon files are created to identify and map interpreted anomalies. Data results are presented below with and without interpretations. This is done so that the client may look at the data and consider what they may see based upon their viewpoint and expertise.

It is important to mention that these data and the final report were prepared as part of a workshop. The main focus of the workshop was to teach participants the essence of integration and application of non-invasive survey methods for historic property management and preservation. The data presented below were collected by workshop instructors in the evening after the workshop had concluded. Data interpretations are preliminary. If these results are being used to help plan any type of invasive activity, it is recommended that the client contact the report author for further consultation on data interpretation. Typically, the author prefers to meet with the client to review interpretations and include feedback into final conclusions.

Ground Penetrating Radar
GPR surveys record data along vertical profiles that are then interpolated to form a cube of data. During data interpretation individual vertical profiles (Figure 11 A) are examined individually. The cube of data can produce plan maps of the survey area at different depths. An interactive slide bar enables smooth transition from the ground surface down through the radar data. Once data are examined in this manner, plan maps are selected that best represent the interpreted anomalies and are imported to GIS.

In an attempt to best represent the data in a visual manner, some images may be repeated.

Figure 16 demonstrates the complexity of the deposits in the upper meter of the sub-surface. Figure 16 A represents mainly the surface characteristic of the soil which includes the gravel pathways (1), evidence of the 1990s sondage (2), and the contrasting moisture of the ground surface beneath the tree canopy (3). Figure 15 B, at approximately 0.35 m deep reveals circular features that are likely to be related to historic landscaping (1). Figure 13 C at approximately 0.8 m deep shows probable historic garden beds (1) that underlie the circular features in B.

A more thorough interpretation of the GPR data can be seen in Figure 17. The legend in this figure describes the possible identification of interpreted anomalies.
Figure 15  GPR plan views at 0.07 - 0.19 m (A), 0.31 - 0.42 m (B), and 0.77 - 0.89 m (C) deep.
Figure 16 GPR interpretations for the Longfellow House - Washington’s Headquarters NHS.
Magnetometry

Figure 18 shows the results of the magnetic gradient survey. Figure 19 has possible modern and archaeological interpretations annotated. It is important to note that iron (modern utilities, trash, cables, etc.) can overshadow more subtle archaeological features in magnetic gradient survey (also in conductivity and magnetic susceptibility). The iron utilities on this property are clearly delineated by the very strong contrasting high and low (black and white) magnetic field strength as visible in Figure 18 (red arrows).
Figure 17 Magnetic gradient survey plan. Red arrows highlight anomalies caused by ferrous material.
Resistance
Figure 20 displays the results of the resistance survey. Figure 21 presents the interpreted anomalies in the resistance data.
Figure 19 Resistance survey plan.
Conductivity / Magnetic Susceptibility

Results from the conductivity survey identified only modern and surface features thus the data are not included in this report. Magnetic susceptibility however, contributes to the understanding of the circular features and the underlying square (potential) garden beds. Figure 22 shows survey plan and Figure 23 interpreted anomalies).
Figure 21 Magnetic susceptibility survey plan.
### Integrated geophysical survey results

When combined, the interpretations from different geophysical survey methods contribute to discussion for potential identification of an archaeological feature (Figure 24). Consideration of the information that the different survey methods reveal may give insight to construction materials or even possible use of an area. Figure 25 shows a figure of the interpreted possible modern features on the
Longfellow House – Washington’s Headquarters property. These can be compared in part to the existing irrigation (Figure 26) plans, as well as in the future to additional plans of modern land use, utilities, and surface features.

Figure 23 Compilation of interpreted possible archaeological anomalies from all geophysical survey methods.
Figure 24 Compilation of interpreted possible modern anomalies from all geophysical survey methods.
The Anatomy of an Interpretation

GIS is an excellent tool for analyzing and presenting different types of spatial information. The graphics presented here are intended to guide the property manager in making decisions. There are a few excellent examples from this project that demonstrate how geophysical survey specialists can interpret data beyond a simple 2D polygon. Three features are discussed below that are identified through
multiple geophysical survey method, (Figure 27 A) the historic basement foundation, (Figure 27 B) the circular landscape feature, and (Figure 27 C) the historic garden feature.

The historic basement foundation
During excavations in 2000, a basement foundation was discovered that is believed to pre-date the current house on the property (which was built in 1759). This feature was mapped with magnetic and GPR survey methods as part of this project. The GPR did not readily reveal this feature in plan maps. Assessment of the GPR vertical profiles was essential in the success of identifying this feature in the data as well as provides important information on depth, character, and extent of the feature.

Figure 28 demonstrates how GPR provides detailed insight to the position, extent, and at times form of the basement anomaly. Figure 28 A-C shows the position of GPR transects that crossed over the basement foundation. Figure 28 D demonstrates how we are able to relate the vertical GPR profile (right) to the GPR plan maps (left). Figure 28 E shows a single GPR profile that crosses the basement foundation with interpreted anomalies (F). This single profile clearly positions the basement feature in space (x, y, and z). With accurate depth conversion, the GPR data can provide excellent information on depth to feature. In this case, the top of the basement foundation walls is approximately 0.75 m deep (+/- 0.10 m) with the floor of the basement extending to approximately 1.6 m. The floor seems a relatively intact horizontal surface for approximately 1.5 m (south to north along the survey grid) and then has an area that appears disrupted. The interpretation of the GPR data suggests the disruption may be a pit or hole that has been filled with rubble. The foundation walls both appear to be relatively
intact and upright. When comparing the GPR data results with the magnetometry results, the magnetometry survey appears to have picked up the immediate area around the foundations, delineating the extent of the basement.

The fact that this feature was not picked up in the resistance, conductivity, and magnetic susceptibility surveys is most likely a result of the depth of the feature. The effective depth sensitivity of this resistance survey was approximately 0.5 m, conductivity to approximately 1 m, and magnetic susceptibility approximately 0.5 m.
Figure 27 Example of integration of GPR profile interpretation to refining the historic basement feature. A shows a plan map of GPR data with lines identifying the GPR profile positions that delineate the basement feature. B overlays the GPR profile positions on the GPR ‘basement anomaly’ polygon; C overlays the GPR profile positions on the magnetic gradient ‘basement
One of the fascinating results from this project is the discovery of this circular landscape feature (Figure 29). The 2000 excavations that discovered the historic basement foundations dug straight through this feature, but did not recognize it. This demonstrates the importance of including geophysical surveys as a fundamental ‘tool’ in the archaeologist’s tool kit. Three of the geophysical survey techniques mapped this feature, resistance survey (Figure 29 B), magnetic susceptibility (Figure 29 C), and GPR (Figure 29 D). Each of the techniques picked upon some of the same parts of the feature, while highlighting other components individually. Figure 29 A shows the interpreted anomalies representing this circular feature from three survey methods.

Considering each survey technique and the physical properties of the earth that they map, and the fact that the archaeologists did not see this feature when they excavated through it, we can begin to build an idea of its character. GPR locates this feature at approximately 0.35 m deep. It is a thin feature, barely recognizable in the vertical GPR profiles. The clarity and strength of this anomaly in the GPR data suggests it is composed of a material that strongly contrasts with the surrounding site matrix.

Resistance survey data suggest a compacted surface on the eastern circular component of the feature, as well as a possible linear feature with a right angle. This linear feature though, may also be related to the historic garden feature (discussed below). The magnetic susceptibility may contribute to the actual type of material that was used to construct this feature. We can say for certain that this is not a brick feature, based upon the combined survey results; in particular that it did not appear in the magnetic survey data.
Figure 28 Geophysical survey interpretations for the circular landscape feature. A - combination of anomaly interpretations, B - resistance survey interpretation, C - magnetic susceptibility interpretation, D - GPR interpretation.

The south eastern historic garden feature
The geophysical surveys identified a historic (probable) garden feature that was previously unknown. This integrated approach to classifying this feature using geophysical methods reveals some insight to the character of the feature. GPR survey shows 4 separate rectilinear features (Figure 30 A). These can be interpreted as garden beds. These are not brick, or other stone type material as these features do not appear in any of the other survey methods, in particular not in magnetometry (brick would have a high magnetic field strength due to its thermoremanent nature).

An interesting challenge is to compare the resistance (Figure 30 B) and GPR data (Figure 30 E). Resistance data suggest there may be compacted surfaces between these ‘garden beds’, based upon the higher resistance value along what appears to be a central pathway in the GPR data. GPR data however, shows the garden ‘beds’ as a stronger anomaly than the ‘pathways’. If the ‘pathways’ were a compacted surface, in theory, they should show as a strong anomaly in the GPR data.

Magnetic susceptibility (Figure 30 C) may pick up on the ‘pathway’ feature, but this may represent something else potentially associated with the irrigation or utility component of the site. Magnetic gradient (Figure 30 E) survey identifies two small anomalies that may or may not be related to the ‘garden’ feature or also, to the circular features.

As can be seen by this example, different geophysical survey methods provide detailed information as to what is buried beneath the ground. We are able to integrate this information for a more insightful interpretation of the buried features, but to truly know what remains, archaeologists must ground truth these features through auguring or excavation.
Figure 29 Geophysical survey interpreted anomalies for the south eastern historic garden feature. A is a compilation of interpreted anomalies from multiple geophysical survey methods. B shows resistance anomalies, C shows the magnetic susceptibility anomaly, D shows GPR anomalies, and E shows magnetic gradient anomalies.
Laser Scan Surveys

Laser Scan Method
A Leica Scan Station C10 was utilized to perform a full 3D survey of the existing conditions of the Longfellow house and surrounding grounds. The intent of the survey was to underline the possibilities of what can be captured through 3D laser scanning, the decision making process underpinning any survey, and the potential deliverables obtained.

The goal of this and most laser scanning surveys is to capture as complete a 3D representation of the existing conditions of a location as can be achieved within the limits of a projects remit, time frame, and budget. The guiding principle behind such surveys is to be able to provide both immediate answers and products required for a project but also create a digital resource for further development, potentially without the need to return to any given location. Coupled with the potential to highlight areas of interest or concern not envisaged within the initial scope of a given project, a laser scanning survey can yield very good returns on invested time and resources.

The main goal for the ASTDA Workshop laser scan survey was to provide an above ground 3D context for integration of subsurface geophysical data whilst providing a data set for potential future drafting of elevation, section, and profile drawings to help inform and update the current park records.

Laser Scan Principles
The two main types of laser scanner are grouped as time-of-flight and phase based systems. The time-of-flight scanner may be the most familiar in terms of function as it operates similarly to more conventional equipment such as Total Stations. A laser if fired from the scanner at a rapid rate in a single burst and distance calculated by time of return. Unlike a conventional refectories total station this process can be performed over 50,000 times a second. Phase-based systems utilize a consistent laser beam modulated over its wave length to calculate the position of reflected surfaces. In general time-of-flight scanners have a far greater distance and field survey positional accuracy. Phase-based are generally slightly faster but with a shorter range. The Leica C10 used in this survey is one of the latest generation time-of-flight scanners and as such provides the best balance between speed, accuracy, and field survey capabilities.
Laser scanning produces a ‘point cloud’ comprised of many millions of individual X, Y and Z coordinate values. In addition to this each point has an associated Intensity value, a measure of the strength of reflection from any location. Bright dry objects reflect strongly while wet or damp dark organic surfaces reflect weakly. When onboard photographs are taken each point is also tagged with a red, green, and blue value taken from a matching location within the photograph. The same is achieved in post processing when using external images. It is the great abundance of captured data, sometime amounting to many hundreds of millions of points that make laser scanning so valuable and potentially more intensive to manipulate than conventional survey methods.

**Laser Scan Field Methodology & Data Capture**

The scanner was set up in twelve individual locations (or stations) around the exterior of the Longfellow House. Each station was positioned within the survey control network established around the property but which provided the best sight lines to any given façade or area of interest. At least four high reflectance targets were positioned on to either primary points of the survey control network or secondary spur points located from the primary control traverse. In this manner the scanner itself could be moved with the utmost flexibility to maximize coverage and sight lines.

For each station thought had to be given to the focus of the scanning, potential permanent or periodic obstacles (vegetation, groups of visitors), and site lines to survey control points. If the idea position for scanning had fewer than the idea number of survey control targets visible then additional ‘floating targets’ were utilized and tied into the overall survey from overlapping scans.

In general two levels of scans were performed from each station. Consideration was given to the smallest feature of interest required to be captured on the façade of the Longfellow House itself from that given location. A high resolution scan was set to cover the façade area often at a resolution of a point every ¼ inch. Resolution was determined by distance and set to the furthest point away from the scanner on the façade area being covered. This ensured that the scan data for the focus area was captured at the desired resolution or better. A second lower resolution scan was set as a full dome scan (360° x 270°) to cover the surrounds.

Photographs were also captured using the onboard color camera integrated in the C10. Exposure was set at each location to try and mitigate the rapidly changing light levels over the course of the scanning. High resolution external panoramic photographs were also taken using a custom camera kit allowing for direct matching of the external images to the scan data.

**Laser Scan Data Processing**

Initial data processing was undertaken within Leica’s proprietary software Cyclone. Data firstly was downloaded from the onboard drive of the C10 and then imported into the software with each station being treated as a separate entry containing hundreds of thousands of points. A control file was produced from the conventional survey network. This list the exact coordinates of the targets scanned from each location. By automatically matching the target locations contained within each station to the same identified survey point within the control network all the individual locations can be brought together or registered into a single point cloud model. In the case of the Longfellow House survey this
was done to an accuracy of ¼” across the survey area. Manual editing was then performed on overlapping station locations to crop out redundant data and produce the best possible match of color balance and point cloud detail.

For the purposes of the data integration a copy of this final registration was made and the data decimated to an average of ¼”. This process filtered out the incredibly dense data collected close to the scanner as a result of the resolution at range or where overlapping scan data created redundant points.

Two versions of the final registration were then exported from Cyclone. The first from the unified/decimated dataset in the PTS file format, ascii XYZ plus Intensity and RGB columns. The second in the Leica PTX format from the un-decimated dataset which includes far more information about the origin of the points and so has more potential in visualizations but is a far more proprietary format.

**Data Integration**

The focus for the integration theme of the workshop covered three areas:

- The underlying and critically important forward planning in terms of initial survey control for the site.
- The GIS based integration of results, digital mapping resources and survey control data.
- Cost effective, intuitive off the shelf approaches for integration 3D data visualization

For the third element of the workshop the Pointools Pro free viewer was selected as the software platform. Although there are now many potential options available for free laser scan data viewers it was felt Pointools had a good open interface, an active user community and, along with the free viewer, good non-profit/academic pricing for more fully fledged versions of its software.

All the techniques utilized in the workshop were related due to the survey control network established around the site. The 3D laser scanning data and GPR survey information also share common characteristics in that both can be broken down into a series of spot readings or sample rates, in other words it could be treated as points. This is most familiar as the basic form of laser scan data, the point cloud. However for GPR the archaeological deliverables mostly come in the form of 2D images. By producing the results of the GPR as a list of X and Y coordinates based on the relative grid positions and sample spacing, and treating the calibrated depth as a Z the data could also be interpreted like a point cloud. In this case the signal response then becomes the Intensity value just like the reflection of the laser from the scanner.

The GPR could then be imported directly into Pointools as an ascii XYZI files and positioned in direct relation to the laser scanning data. In this environment both data sets could be visualized utilizing the tools available with Pointools Pro free viewer for taking basic measurements and height/depth information (Figure 31). Profiles could also be taken through the Longfellow house and ground surface down to the GPR and captured anomalies all within a simple, easy to utilize environment (Figure 32).
The GPR data, as with the laser scanning information, could also be adjusted to highlight reflected features by utilizing alternative color ranges, contrast and brightness levels.

Potentially any geophysical data with sampled depth properties could be integrated in this manner and combined within one 3D environment. This cost effective and intuitive platform could and allow experts, interested members of the public, and media to interactivity visualize a site in 3D whilst being sure of the spatial integrity of the data as they might be used to with more widely utilized GIS and web-based packages.

Figure 31 Pointools integrated visualization of the laser scan and GPR surveys.

Figure 32 A cross-section of the laser scan and GPR surveys demonstrating the above- and below surface nature of data integration.
Conclusions and Recommendations

Leading academic programs, preservation organizations, and agencies including the NPS, must explore and embrace preservation technology that is responsive, accurate, and cost effective. This project at the Longfellow House – Washington’s Headquarters NHS in Cambridge, MA presents an ideal example of the integration of these methods for better site comprehension while providing vital information for site management and preservation.

The Longfellow House – Washington’s Headquarters NHS possesses a unique cultural landscape, architecture, and collections reflecting the use of its core area from pre-contact occupation through its use as Commander-in-Chief George Washington’s Headquarters and later as the residence of poet Henry W. Longfellow. Until recently, there has been no unified way to examine or to visualize the three-dimensional qualities of known sub-surface features distributed across the site.

This report is responsible for presenting the results from the geophysical surveys, only one part of the larger project. The report also includes a brief overview of the laser scanning and 3D data integration methods employed at the Longfellow House – Washington’s Headquarters NHS. Data integration and visualization led to the discovery of previously unknown and potentially significant landscape and archaeological features including probable garden beds and colonial-period structures.

Continued work at the Longfellow House – Washington’s Headquarters NHS with additional geophysical surveys, laser scanning, and data integration would help complete the picture from what has begun as part of this project. If more work were to be contracted, it is recommended to communicate with the report author in order to help produce similar final data and facilitate integration into the data processing, interpretation, and visualization methods conducted to this point.
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References
(Cited and recommended reading)


LYALL, J. & D. POWESLAND. 1996. The application of high resolution fluxgate gradiometry as an aid to excavation planning and strategy formulation. Internet Archaeology 1. (http://intarch.ac.uk/journal/issue1/lyall/himag.html)


