REVEAL Intermediate Report

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Abstract

REVEAL, (Reconstruction and Exploratory Visualization: Engineering meets Art / ArchaeoLogy) is a four year NSF-funded project promoting paradigm shifts in archaeology, currently at the 1.5 year point This is a project to create an environment for acquiring and presenting archaeological data in a way that streamlines the excavation process and supports and enhances the expert's understanding of the data. REVEAL leverages three aspects of technology: using vision algorithms to speed up or replace measurement and documentation tasks, using computer automation to speed up data entry tasks, using integrated 2D and 3D media to enhance data comprehension. This paper is an update on what the project has accomplished, what has been learned, and what is planned for the rest of the project.

1. Introduction

REVEAL is structured around the three key questions: Where are things located; How are the data organized; and Who executed the work?

One of the key issues is how to locate finds accurately. Traditionally, archaeologists take manual measurements and use hand-drawn sketches, and occasional photographs to record the location of artifacts, layers, and architectural elements. This methodology suffers from inaccuracy, inconsistent terms, transcription errors, and is time consuming. Also, data are sometimes not recorded because their significance is not recognized until too late.

REVEAL combines multiple modes of input, a back end database, and a sophisticated user interface to address these issues. Low frame-rate continuous video recording captures the entire excavation process, [1] allowing the excavation record to be "rolled back" to determine exactly where an entity was at the time it was discovered. In order to address issues of occlusion, multiple cameras are used to record from many viewpoints.

On-demand high resolution photographs from multiple cameras surrounding the area of interest are used to capture detailed images of finds as they are uncovered and to provide data for 3D reconstruction of the area for detailed analysis and measurements from any angle [2]. This is combined with more traditional form-based object data entry.

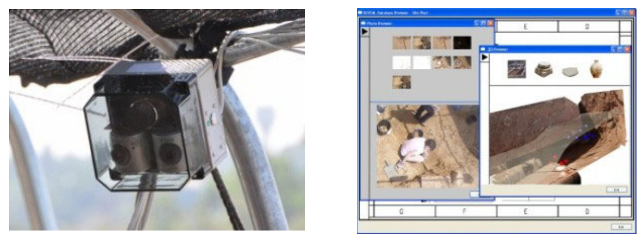

Figure 1: Features of REVEAL: Continuous recording camera node; Multi-modal Analysis Interface

An additional spatial concern is to present data to the archaeologist in 2D and 3D context. The standard 2D format for displaying archaeological data is the plan view, used for site plans, trench plans, and building drawings. REVEAL presents data as an active plan or set of layered plans, where data is displayed as icons. The user can select icons and drill down for detail or bring up related data, photographs, images, and 3D models. REVEAL provides the same level of interactivity for 3D data, so an excavation model can be combined with artifact models and be spatially located relative to each other. Volumes of interest (loci with defined boundaries) can be displayed as bounded polygonal objects. Other data can be represented as spatially located icons, which can be selected and drilled down into for related data.

Another key issue is how the data are being organized. Understanding the meaning, context, and function of an object evolves over time as it is examined and categorized. The following object attributes are based on the Getty Trust "Art and Architecture Thesaurus".

- The excavation context – relationship to other objects, loci, architectural elements.
- Find genre and function – a sherd, an architectural

detail, a coin, a structure, an assemblage such as a coin hoard

- Physical attributes – color, size, shape, material
- Conceptual and iconographic attributes, what it represents, related religious or cultural concepts
- Activity Attributes – processes or techniques that created it.
- The attributes are supported by the REVEAL database and the user can use the attributes to select and display objects in the REVEAL user interface.

Central to the excavation and recording process is the staffing. Participants of an excavation range from highly professional to lay people.

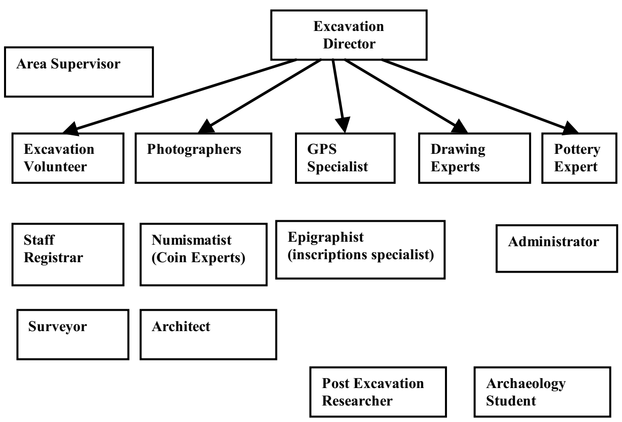

Figure 2: Example user role hierarchy

REVEAL uses role-based authorization to provide appropriate access to the individuals building the database, those who are analyzing the data, and the individuals managing the data. For instance, the area supervisor can create new artifact records, while the volunteer who is washing pottery can only update existing records.

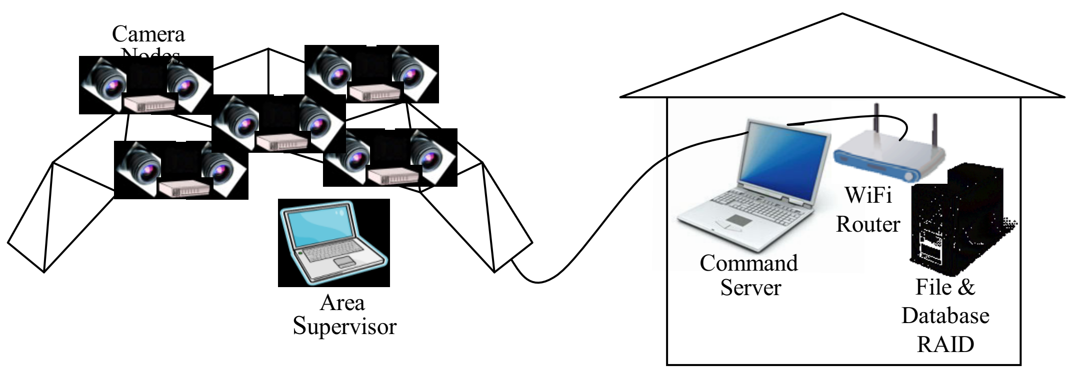

Figure 3: Physical System

2. First Year Alpha Field Test

REVEAL requires data in order to function. The first year of the project focused on an alpha field-test of automated collection of video and high resolution photos, coupled with web-based entry of form data such as artifacts, walls, and excavation squares. [2]

As a test bed, we decided to instrument one 5x5 meter excavation square at the Apollonia-Arsuf excavation, a joint project of Brown University and the Institute of Archaeology at Tel Aviv University. We designed a data acquisition system that consisted of three main parts, the automated camera system, the web-based form-entry interface, and the archaeological database.

The camera system consisted of five camera nodes. Each camera node had a pair of D-Link DCS 900 Ethernet video cameras and a USB-controllable Olympus SP-500UZ 6M-pixel camera. Each node contained control software running on a fit-PC Slim Diskless computer.

The camera nodes communicated with the command server and the file server over a hard-wired ethernet connection.

The Area Supervisor laptop ran a camera control application for calibration and parameter setting. The laptop also provided data entry through the form input web site hosted on the Command Server.

The laptop was connected to the command server and storage RAID by a WiFi link. Video, Photographs, and data were stored on the RAID.

The biggest challenge with a fixed-camera installation was budgetary. Covering the typical 4-5 active excavation areas of a site requires a large investment in equipment that is beyond the budget of the typical expedition.

The second largest challenge was the time and number of people required to set up the cameras every day and take them down at night.

Furthermore, getting a working structure to hold the cameras turned out to be more difficult than expected. In order to have full image coverage there were five camera nodes, one on each corner of the 5x5 meter excavation square, and one over the center. To avoid impeding the archaeologists, the cameras were mounted on a framework over the excavation square.

Several different framework solutions were explored. Setting up a commercially available framework over the excavation turned out to impede the archaeologists too much and had the disadvantage of sinking into the sand baulks at the edge of the pit.

Attaching the cameras directly to the frame of the sun-protection tent got the cameras out of the way of the workers, but the cameras were too far from the bottom of the square to record sufficient detail and it was very difficult to get the cameras attached and oriented each day.

The final solution was to build a suspended frame that hung above the workers but could be adjusted to be the right distance from the excavation and could be lowered for easy mounting and dismounting of the cameras at the beginning and end of the day. This framework was at the right height, but moved when the wind blew, compromising the quality of the images.

Camera calibration also turned out to be more difficult in the field than expected. Each camera node had to be oriented so that the excavation filled the field of view. The

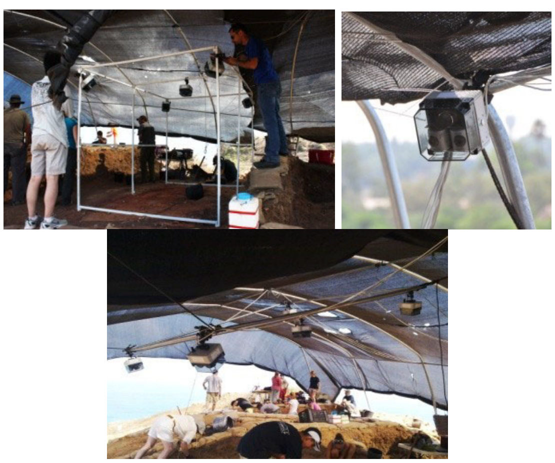

Figure 4: From top left: standalone frame, camera connected to sun-protection tent, suspended camera framework

DCS 900 video camera has a fixed focus lens, so after each node was mounted, the two video cameras had to be manually focused. With the camera node mounted on the frame, the only way to tell if it was correctly oriented and focused was to look at programmatically "grabbed" images with the computer. The software interface for grabbing and displaying images was not streamlined for this task, which slowed the process. In addition, the bright sunlight and the dust made it very hard to see the computer screen.

As excavation progressed through the day, the depth of the bottom of the excavation could change sufficiently that the fixed focus cameras were no longer in focus. This required the users to check periodically to see if the cameras were still in focus, and if not, either recalibrate them or lower the camera framework to compensate.

Another problem was that the workers blocked the active work area in the camera's field of view. The intent of having continuous video was to be able to roll-back

Figure 5: Occluded view of the active excavation area

time. This would make it possible to answer questions like what was immediately above an artifact, even if that had not been manually recorded at the time. However, practically, all that was visible on the video were the backs of the people doing the excavation. The uninteresting parts of the excavation are clearly visible, but the critical area is obscured by the people doing the work.

The computer hardware consisted of the area supervisor's laptop, the base station with the router, Command Server, and storage RAID, and the wiring that connected the base station to the camera nodes.

Initially, all this equipment had to be set up every day. A major difficulty was setting up and maintaining the connections between the cameras and the computers. First, there were so many connections that it was time consuming and delayed the start of excavation. Second, some of the connections did not have industrial connectors and had issues with getting disconnected. In particular, the network connections were unreliable, and they were critical to communicating with the cameras.

Permanently mounting the computers and network router in a single case allowed their interconnections to be permanent so that only the camera connections needed to be redone each day.

Figure 6: Permanently mounting the computers in a case simplified setup and made the connections more reliable

The strong Mediterranean sunlight washed out the laptop displays. They could only be used in shaded areas and even then could be hard to read.

The dust at the site was a continual problem. Dust on the laptop screen made it hard to read even out of direct sunlight. Dust was also a problem for all the computer hardware, getting into the fans and connectors.

Aggravating the situation, the humidity (and resulting sweat) turned the dust to mud, smearing the screen and clogging the connectors.

Figure 7: Sunlight and dust obscured the laptops screens

Heat was an issue for the computers. Ideally they should have been placed in a fan-cooled environment.

The user interface was designed for a 1024x768 resolution or larger. But field laptops are typically small, and the difficult viewing conditions due to sun and dust made 600x800 a common display resolution to keep the text large. The result was a lot of time lost to scrolling around trying to find fields that were off the screen.

The user screens assumed that all the data for an artifact or other entity would be entered at one time. However, the initial record has a limited amount of data. Later, after cleaning and further examination, the data was updated. As the excavation progresses, earlier finds may be better understood and the data updated again. The user interface presented all the fields in one large form and did not order them appropriately for the steps in the process. This caused the users irritation and lost time from scrolling around the display. There are also fields that could have been filled in based on the context, which would have helped speed the data entry.

The tools for examining the data once it was entered into the database were quite limited, which made it hard for the users to check and correct data once it was entered.

The decision to use a high-level UI form tool worked well. The users wanted different fields in the forms. Using a Ruby on Rails with Active Scaffolding made that possible in the field.

3. Lessons Learned

A fixed framework is difficult to construct, tends to be too flimsy to hold the cameras steady in wind, and is either too far from the active area for the cameras to be effective, or is in the way of the workers.

The fixed cameras were too difficult to physically install and remove each day. They needed quick-connect mounts that could be left in the correct position and orientation. The wiring needed to be reduced to just power and all other communication should be by WiFi.

The cameras were difficult to orient and get focused. The cameras should operate in an auto-focus and auto exposure mode. The software for checking the image should be very quick to use. The computer display should be visible in bright sunlight.

The recorded video did not provide a significant return to the archaeologists, so did not justify the cost and complexity of setting it up and running it.

Ideally, data entry and camera calibration should be possible from a hand-held device that is readable in direct sunlight.

Dust got into everything. The laptop would need to be protected somehow, or a ruggedized version used. The base station hardware should be in a sealed, filtered, cooled box. All external connectors should be industrial-grade dust-proof connectors.

In spite of all the issues, data was recorded for this year, and was also augmented with manually entered data from the records for 2006. This data is being used to develop the REVEAL data analysis tools.

4. Second Generation

The next revision of REVEAL builds on the lessons learned from the first revision and extends the functionality into the analysis stage of the archaeological process.

We will reduce the cost and introduce flexibility by replacing the fixed camera system with a hand held camera and a photographing process for the users to follow. We will be stepping back from the continuous recording. The users already take photos at significant points, such as an artifact being found or a level being exposed. We trade off simplified hardware for more complex software challenges.

We will have the archaeologists extend their current limited number of hand-held camera photographs into a larger overlapping series of photographs that have sufficient information for a Scale Invariant Feature Transform (SIFT) algorithm and camera calibration software [3][4][5] to locate the photos relative to each other. We are investigating 3D curve sketch-based calibration[6]. By including markers at geo-located points, and using a marker location and tracking algorithm we will locate the photos in real world coordinates.

The photographs will then be fed to a 3D model generation algorithm which will generate a representation of the 3D scene, then create a surface model for import into the REVEAL 3D display [7].

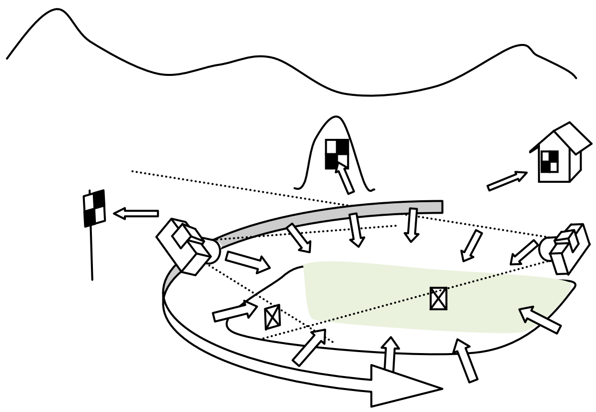

Figure 8: Geo-locating Photographs. Take overlapping photographs of sides and bottom of active excavation area. Make sure some photographs include geo-located markers

The 3D models can then be used to show the in-situ positions of artifacts for a better understanding of their spatial relationships. Also, taking measurements from the 3D models can be used to augment or replace traditional measurement tools.

Figure 9: Example of overlapping photographs for use in geolocating excavation photographs and automatic generation of 3D excavation site models

5. New Features

New in this generation of REVEAL are analysis tools that allow the archaeologists to immediately benefit from the data they have entered and the photos they have taken.

The analysis environment integrates a wide variety of data representations, from 3D reconstructions, to "live" site plans, charts, graphs, down to traditional spread sheets. This allows instant rendering of data in site context, providing faster and more comprehensive understanding of the subject matter embodied in the data. Figures 10 and 11 show snapshots of the REVEAL analysis interface while an archaeologist is answering the question "What pottery fragments were found in Area M, excavation square E2, how were they distributed spatially, and what excavation photographs do we have showing those fragments in-situ?"

Note that this question is important for understanding the use of the site over time, but it would be a very time consuming question to answer with existing tools. REVEAL is able to show the archaeologists their data in full 2D and 3D context as soon as it is acquired in the field. The 3D model interface also allows importing externally created 3D models, such as a reconstruction of the Apollonia-Arsuf castle through procedural modeling and laser scans of the castle walls [8][9]. These can then be geo-located and used in conjunction with the rest of the REVEAL data to examine the archaeological data in context.

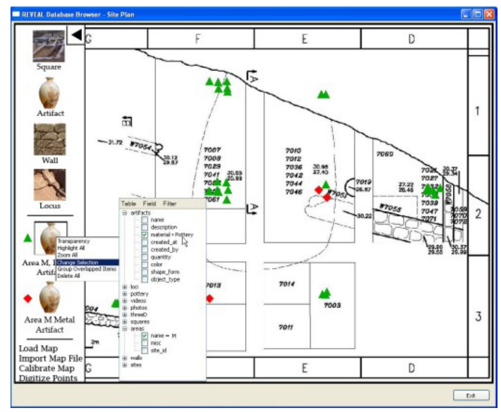

Figure 10: Interactive 2D site plan window

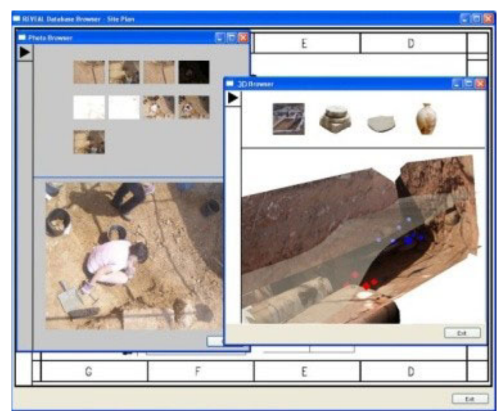

Figure 11: Photo window and interactive 3D Model window

The REVEAL interface also allows the data to be formatted and exported for use by external applications, such as GIS systems and for importing into publications. The new version of REVEAL will provide a distributed processing environment which will allow photographs and data to be fed to a server farm running distributed algorithms.

Currently under development for use in the REVEAL distributed environment is a fragment assembly application for reconstructing pots from pot sherds [10][11][12].

Potentially this will be extended to handle reassembling wall fragments.

6. Anticipated Benefits

Compared to traditional written form records, the web-based form entry solves the readability issue common to hand-written entries and helps to provide consistent categorization through the use of dropdown menus that display previous entries. In addition, the form entry associates the artifact / locus / other form data with relevant photographs, video, 3D models, and site positions.

Traditional position recording relies on time consuming hand sketches and a limited number of manual measurements. The detailed photographic records in REVEAL, combined with automatic 3D in-situ model generation, provide geo-located in-situ 3D models accurate to a centimeter without requiring a laser scanner. The system will also accept models from other sources, such as a structured light or laser scanner.

REVEAL enables rapid access to relevant photos, models, and other data. It provides the ability to visualize relationships between related artifacts found at different times and to take additional measurements, both on-site and post-excavation, from the in-situ models.

The user interface also enables integrating data, such as artifact placement on site plans and in in-situ 3D models. Doing this manually would be a significant effort and would only be undertaken when a conclusion was already suspected.

This makes possible highly integrated contextual examination and review of data in the field, providing unprecedented field analysis detail and support for daily excavation decisions. This also provides powerful support for post-excavation analysis tasks.

These features are combined with strong search and filtering capabilities, flexible data export to external applications, and an architecture designed to allow extension for new functionality.

A planned extension to REVEAL is to provide semi-automatic 3D reassembly of fragments, such as pottery sherds or sections of castle wall [13].

REVEAL will provide a new level of rapid and comprehensive exploration of excavation data.

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