Visualising Environmental Corrosion in Outdoor Augmented Reality

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Abstract

This paper provides a description of outdoor visualisation of environmental corrosion data. This system was developed to aid in the visual understanding of data from wireless sensors used to monitor large structures. Due to the laborious manual inspections required for large structures (such as bridges), wireless environmental sensors have been designed to automate this process. Our system visualizes this information in its real-world context using the Tinmith mobile outdoor augmented reality system. We provide an overview of the visualizations, outlining a user study that was conducted to determine the effectiveness of the visualizations in providing the user with context-sensitive information, along with the preliminary results of this study. The paper concludes with an overview of future work on the system and final thoughts.

Keywords: Visualisation, Augmented Reality, Corrosion, Wireless Sensor, Environment Visualisation.

1 Introduction

This paper presents a system for visualizing environmental corrosion with mobile, outdoor augmented reality (AR). Current methods for regular maintenance inspections of large structures involve a time consuming, manual examination by a site inspector to evaluate the structure's condition and integrity. By placing wireless corrosion sensors at key points around the structure, we can automate the inspection at certain points on the structure. The issue then becomes how we can manage the immense volume of data generated by these sensors and put it into an effective and intuitive format. This paper describes and elegant and intuitive tool for assisting the inspection of structures by visualizing this data in its real world context.

AR is the supplementing of virtual information and functionality into the real world (Azuma, 1997, Azuma et al., 2001). Given the nature of mobile AR's ability to allow a user's movement over large geographical areas, one application is the use of AR in large scale, outdoor environments (Feiner et al., 1997, Gerhard et al., 2004, Thomas et al., 1998).

We extend the definition of visualization (the use of computer support in interactive, visual representations to increase understanding and cognition (Card et al., 1999) to situated (in-situ) visualization, where visualizations are relevant to the context in which they are displayed (White et al., 2007). The use of context sensitive visualization aids in the understanding of the surrounding environment by the user. Following previous efforts examining the use of situated scientific visualization in AR (White et al., 2007, Rauhala et al., 2006, Belhumeur et al., 2008), the possibility of increased cognitive perception is present (Rauhala et al., 2006)

In this paper we describe the visualisation project, which aims to use mobile outdoor augmented reality to visualize the information from the sensors in an intuitive and easy to understand manner. An overview of the system is provided, along with an outline of the aids provided by visualizations, followed by a user study evaluating the effectiveness of the visualizations. A set of proposed changes, defined by the results of the user study, are then presented.

2 Background

Large structures (such as bridges) require regular maintenance inspections to ensure their physical integrity and safety. These inspections currently involve the inspector physically walking around the structure and examining each component and section as they move around, making notes regarding the structure's condition at that position. These structures currently contain an increasing number of visible and invisible components, which may remain hidden from inspectors without aids to increase observation (White et al., 2007).

Previous work has sought to improve upon these manual inspections by automating the collection of environmental conditions which may impact on the structure (Fan and Biagioni, 2004, Yuxi et al., 2009). The University of South Australia has worked with Australia's Defence Science and Technology Organisation (DSTO), under a grant from the Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM), to develop a wireless environmental sensor system to enable the installation of numerous wireless sensors over a structure (Kong, 2009). The sensors enable the monitoring, at regular intervals, of the environmental conditions at that position. Each sensor consists of a corrosion sensor, humidity sensor and internal and external thermometers. Currently, this data is only available in numerical form, creating two issues. The first is the inspector must have the ability to translate this information from the spreadsheet, into meaningful inferences regarding which areas of the structure have been affected, whilst deducing possible relationships between numerous sensors and attributes over temporal intervals. The second is the fact that by presenting the data separately to the structure to which it represents, the data loses important contextual information that is associated with the sensors' real world position.

An example is the SiteLens system (White et al., 2007, White, 2009, White and Feiner, 2009), which provides the ability to take carbon dioxide logs, taken during earlier visits to a construction site, and view them through a hand-held PC using the magic-lens technique. Carbon dioxide (CO_2) levels are represented in a number of different forms (floating spheres, cylinders and 'smog' clouds) (Figure 1) allowing the user to observe not only what the level is at a given point (as could be traditionally be done in the office), but also the possible causes for such a reading. For example, there may be a bus stop nearby which is used for scheduled breaks for the drivers, leading to increases in CO_2 at that position.

Figure 1: SiteLens showing CO_2 levels as floating spheres (left) and smog clouds (right)

Similarly, a proof of concept handheld mobile AR system (Gunnarsson et al., 2006) demonstrates the feasibility and effectiveness of real time AR sensor visualization. By using ARToolkit markers (Abawi et al., 2004), sensor values could be positioned on top of the user's viewport. The interpolation of sensor data was used to indicate the approximate values for surrounding areas (Figure 2), a point of differentiation with the previous systems which displayed only individual values. The SensAR handheld augmented reality system (Goldsmith et al., 2008) also used ARToolkit markers to overlay sensor information in real-time, using visual metaphors to aid in the representation of the data.

Figure 2: Showing humidity overlay and interpolation based on marker tracking

The ARVino system (King et al., 2005) enabled the visualisation of viticulture information on top of visible terrain. ARVino supported the visualization of geographical information system (GIS) data in mobile AR, enabling users to view geographic areas through a handheld system, with additional information inferred from an overlaid colour scheme on top of the terrain (Figure 3).

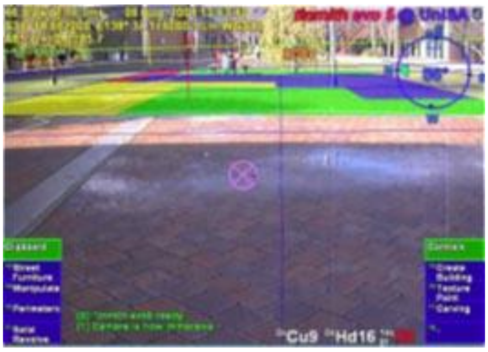

Figure 3: The ARVino viewport with visualisation utilising colour codes to identify geographic areas

A number of previous systems have used visualizations in conjunction with a virtual representation of an associated building/structure. This inclusion of a virtual structure provides increased contextual meaning to the visualization. Malkawi and Choudhary (1999) demonstrated a virtual reality (VR) system that visualised the heat transfer within a structure, given a set of parameters for the structure itself. Similarly, Rad and Khosrowshahi (1997) demonstrated a system that visually deteriorated (via discoloration, lighting and texture effects) a virtual building according to a set of formulae that defined the decay of the building over time. By adjusting the formulae's parameters, the visualizaiton would deteriorate the building's representation to refelect its estimated condition, given an amount of time.

Following on from the in-situ visualization of environmental factors demonstrated by the SiteLens and handheld interpolated visualisation system, our investigations aim to provide large scale, outdoor in-situ visualizations focusing on associating the sensor data with the surrounding structure. The use of in-situ visualisations ensures the integrity of important contextual data which may be impacting on the environmental conditions surrounding a sensor. The visualisations also enable the user to easily extrapolate relationships between sensors which may not be easily understood in numerical format.

3 Environmental Corrosion Sensors

Following the development of the previously discussed systems, our system utilises numerous wireless sensors distributed across a structure. The sensors are networked using RF in a master/slave architecture; with slaves (sensing nodes) recoding the values at requested intervals. A master node is connected via TCP/IP to a data logging application running on a PC. The purpose of the master node is to synchronise the start of sampling by the slave nodes and download their data, at regular intervals, over an RF channel. Each slave contains sensors for corrosion and humidity along with internal and external temperature sensors. The initial set-up for this project utilized four slave nodes, two each on the corners of two buildings located opposite one-another (Figure 10). All slaves reported to a single master node.

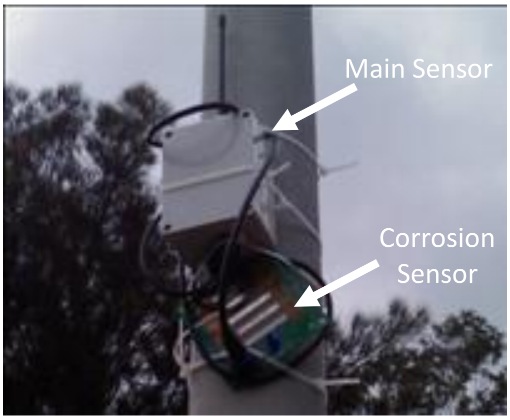

Figure 4: Sensing client node showing main sensor box with external corrosion sensor (metallic strips).

4 Tinmith Platform

The visualization system operates on the Tinmith AR platform (Piekarski and Thomas, 2003). Tinmith is an outdoor, mobile AR system that utilises a video see-through display to augment the user's viewport. Figure 5 depicts the Tinmith helmet that includes the HMD, orientation sensor, GPS antenna and camera. By utilising these devices, the system can track which direction the user is looking, and render viewable objects at their correct real world longitudinal and latitudinal coordinates.

Figure 5: Tinmith head-mounted display with sensors

The visualization system is loaded at runtime as a dynamic (shared object) library, essentially acting as a 'plug-in'. Previous mobile AR applications using the Tinmith platform, such as ARQuake (Thomas et al., 2000), were developed as part of the core system, which required modification of the source code. Our system is unique, in its modular approach to developing Tinmith applications. This modular approach provides two key functions; the system can be developed separately without continuous modification to the base Tinmith system (as has been done with previous applications), and the visualization plug-in can easily be utilised by any other OpenGL based augmented or virtual reality systems.

5 AR Corrosion Visualisation

This section provides an overview of the system requirements, issues with navigating large temporal data sets in mobile AR, along with an overview of the developed visualizations.

5.1 Functionality Requirements

During the early stages of development, a number of key features and requirements were outlined for the development of the AR visualisation system:

- Support the ability for an 'overview' mode, where the user can simply view the structure and observe any noticeable data anomalies.
- Provide 'drill down' functionality for providing detailed information about a sensor and its attributes.
- Be able to draw a user's attention to an area of concern.
- Be able to highlight similar areas of on the structure that match a certain criteria (e.g. all north-facing walls).

The first three points were identified to be implemented as part of the visualization, with the last as additional functionality in the system. The large, temporal nature of the sensor data requires an effective solution for navigating the data whilst in the field.

5.2 Hand Held Data Navigation

To provide intuitive navigation of large datasets over long intervals, we chose the use of a physical control board that provides a complimentary input method to navigate the data. An initial demonstration of the concept was achieved through the use of Phidgets[1]. Using a multi-line text display along with two hardware 'sliders' and a rotation sensor, we were able to create a hardware control panel for the system (Figure 6).

Figure 6: The Phidget control panel

By adjusting the top slider, users can navigate the date of the data set being displayed, with the second slider changing the time of day. As the sliders are adjusted, the LCD display is updated to reflect the currently selected date and time. In conjunction with the display, the immersive nature of AR led to two virtual representations of sliders which appear onscreen, mimicking the position of the real world sliders. These two inputs provide a quick, intuitive and easy-to-use method for navigating large data sets.

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[1] Phidgets Inc., www.phidgets.com

Due to the dual reality nature of AR, the user may need to adjust their focus to either the purely physical structures or virtual AR corrosion data or somewhere between. By using a rotation sensor, the user can adjust the level of transparency of the virtual overlay. This control panel enabled two modes of operation where the user could simply observe the structure as is, with the system highlighting areas of interest, or quickly adjust the sliders to view changes of structure over time.

5.3 Box Visualization

There are two representations used to represent corrosion – the Plasma and Crystal effects – with two other representations – the Box and Gauge – used to represent the values of the sensor's temperatures and humidity. The Crystal and Box representations were combined to form one representation that supported the visualization of all four sensor attributes, as the Gauge representation does. Due to rendering limitations of the backpack, the complexity of the Crystal had to be reduced to accommodate faster rendering times. This resulted in a less random, more symmetric crystal formation as can be observed in Figure 7.

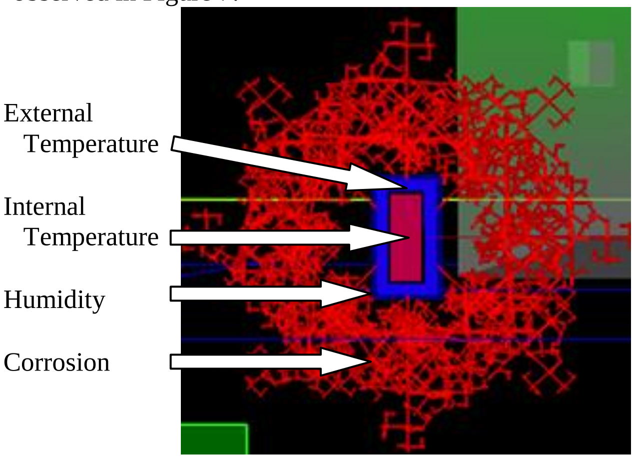

Figure 7: The 'Box/Crystal' representation

The Box/Crystal showed internal temperature as the inner-most box, external temperature as the middle box and humidity as the outside box/border. Temperatures use a blue (0^o) to red (40^o) colour range. Humidity changes from black (0%) to blue (100%). The corrosion crystal 'grows' on the outside, to indicate that surrounding areas may also be affected.

An encapsulated box metaphor was chosen for Box representation. Internal temperatures are represented as the inner-most colour for the Box representation. The same metaphor was applied to the external temperature, shown as the external (larger) box. For the humidity, the outer-most/border of the Box was designed to represent the humidity surrounding the sensor. Corrosion for was designed to be shown as an external entity, shown outside of the Box representation.

5.4 Gauge Visualization

The Gauge representation was developed due to concerns relating to the precision possible with the Box representation. We thought that by showing the user the value's position on attribute's range, they would be able to perform a more precise reading. The Gauge representation shows all four attributes (Figure 8) with external temperature, internal temperature, humidity and corrosion, respectively from top to bottom.

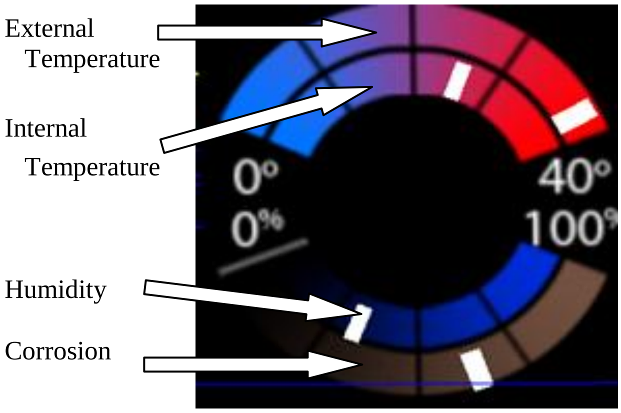

Figure 8: The 'Gauge' representation

Similar to the Box representation, a metaphor was present in the design of the Gauge. Internal temperatures are represented as the inner 'top' gauge. The same metaphor was applied to the external temperature, being shown as the 'external' gauge. For the humidity and corrosion, both are shown as the bottom gauge.

5.5 Plasma Visualization

One of the primary factors behind the development of the Plasma effect was to support the interpolation between recorded sensor points on the structure, allowing the user to view a basic estimate of how corrosion at a single point may be affecting surrounding areas. Despite the colour brown being associated with corrosion, the choice to use red for the plasma effect was done to highlight the severity of highly corroded areas, given its use as a cultural warning colour.

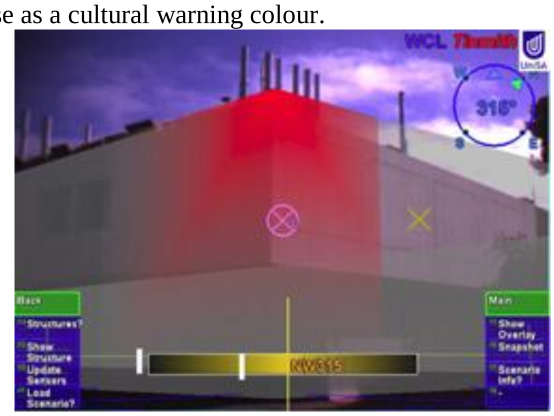

Figure 9: The 'plasma' representation

To enable 'drill down' functionality, the system was designed to use the Box representation as the standard visualization. However, upon a user focusing their view on a given sensor (with a dwell time of one second); the representation would rotate 180^o horizontally around its axis to show the Gauge sensor for more precise reading. This enabled the Crystal effect of the Box to be used to highlight areas of interest, which could then be examined in further detail. It was originally envisioned that by 'clicking' a focused sensor, a dialog box would allow the user to review the sensor's other information (such as exact position, orientation, battery level and graphs providing history and trend overviews). Despite the dialog box having been implemented for the sensor readings and graphs, the listing of additional attributes (e.g. battery level) remains as future work.

Semi-opaque building overlays are also rendered. These overlays provided three functions. The primary function was to act as a virtual anchor, linking the position of sensors in the virtual world with their real world positions (which may not be 100% accurate due to tracking errors). The overlays also provide a virtual canvas on which interpolation of the Plasma effect between sensor points could be shown. The overlays also allow the system to highlight areas of interest based on given criteria. As a demonstration of the concept, the two buildings' walls were divided into four groups, North, South, East and West facing walls. However, these groups could be modified to represent any other common attribute (such as the use of a common building material or non-regular orientation, etc.).

6 User Study

To evaluate the effectiveness of the visualizations, a user study was conducted. The intuitiveness of each representation was evaluated with participants seated indoors. Participants were asked to indicate what they believed each indicator of the Box and Gauge visualizations represented (prior to having the representations explained to them). Each sensor attribute was allocated a number 1-4. Users were able to indicate what they initially thought the sensor represented by placing each number next to the four attributes on the Box and Gauge representations. Following this, the participant was informed of the intended meaning of each sensor. Three samples, on paper, of the Box, Gauge and Plasma sensors at three levels (all attributes at 0%, 50% and 100% of their maximum) were shown to participants to confirm their understanding of the each set of values and how the values on each representation changed.

Following the initial overview, participants moved outside and wore the Tinmith backpack and helmet to view four simulated sensors located across two buildings facing each other (Figure 10). The sensors were entirely simulated for the purpose of the study; no real sensor data was used. The associated simulated data set was structured to evaluate the readability of information across the whole spectrum of the representation's range, with one value from each quarter of the sensor's range, e.g. values between 0% and 25%, 26% and 50%, etc. The data set consisted of four sets of readings for each sensor. The sensors were located at distances of 62m, 39m, 20m and 16m from the user, who was in a fixed location. All sensors were located 4m above ground level.

Using the simulated data set, participants were asked to look at each one of the sensors and read a given sensor attribute (e.g. humidity). If the participant could not read a value (e.g. too far away), a null value was accepted. A reading was repeated once for each sensor, before showing the next set of readings on the same four sensors. This was repeated four times for each of the Box (1x0.5m meters), Gauge (1x1 meter) and Plasma (4x4 meters) representations. The real world sizes of the representations were based on what was thought to be appropriate to facilitate reading without cluttering the users view. Each reading of a sensor was for an attribute not previously read from that sensor. By the end of the study, the participant had read the inside temperature, outside temperature, humidity and corrosion level of each sensor. The ordering of representations and the selection of sensors was randomised.

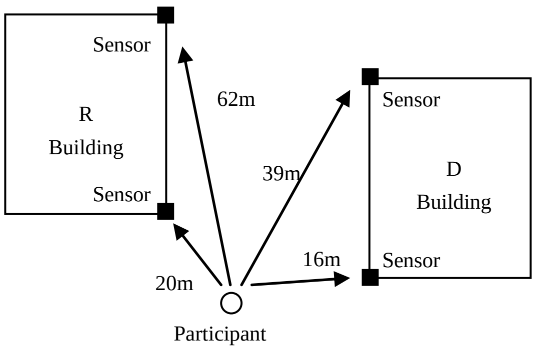

Figure 10: User study showing the user location relative to the simulated sensors

The participants were then taken inside and asked to complete a questionnaire. Following the initial questions covering their demographics and experience with AR and wearable computers, participants were asked how intuitive they felt each representation was how accurately they felt they could read values from each one and which one they felt drew their attention to areas requiring focus (high corrosion). The questionnaire concluded with a section for miscellaneous comments. This follows guidelines outlining the evaluation of visualizations using both quantitative and qualitative methods (North, 2006)

There were 14 participants, aged 20 to 31, with the majority (12) aged between 20 and 25. Of all participants, only three participants were female. Eight participants had no prior experience with augmented reality, three had some prior experience, and another three that had used it extensively. Only three participants had used a wearable computer before, one of which had used them extensively.

7 Results

We analysed the results using the error of participants' answers as a percentage of the valid range (v=absolute(solution-participantAnswer)/attributeRange). For example, a correct answer translates to a 0% error margin. It should be noted that where no answer could be given for a reading by the participant, this translated to 100% rate of error.

Due to the Plasma representation only representing corrosion, two sets of calculations were carried out. The first looked at humidity and internal and external temperatures across all distances for the Box (Mean=24%, SD=6%) and Gauge (Mean=16%, SD=5%) representations. The second data set compared corrosion across all distances for the Box (Mean=10%, SD=10%), Gauge (Mean=14%, SD=12%) and Plasma (Mean=16%, SD=3%) representations. ANOVAs were carried out for both data sets; there was a significant effect ($p<0.005$) for the humidity and temperature data sets.

By performing post-hoc t-tests against the Box and Gauge for external temperature for each distance, a significant effect ($p<0.005$) was found in favour of the

Gauge representation. Excluding the furthest (62m) reading, a significant effect ($p<0.005$) was also found for the internal temperature using the Gauge representation. Due to the small size of the internal temperature attribute on the Gauge, only two of 14 participants gave a reading at 62m. There was a similar result for humidity, with a significant effect ($p<0.005$) found in favour of the Gauge representation; however both representations suffered at 62m.

T-tests for corrosion across all three representations for all distances revealed a significant effect ($p<0.005$) in favour of the Box at distances of 20m and 39m when compared to the Plasma. However no effect was found when compared to the Gauge representation. This could be attributed to the fact that the Crystal is only capable of displaying seven levels of corrosion. The small range could have meant participants would be able to accurately read a value.

User feedback indicated a strong preference for the Gauge representation for reading data, with equal preference for the Box or Plasma effect in being used to draw attention to areas of interest. One participant summarised that the use of multiple colour scales next to one another (Box representation) led to the problem where nearby scales would influence others nearby (e.g. a purple tone will appear more blue if it is placed next to another blue scale, as is the case with the Box representation). Another comment received through feedback, was although not being affected personally; one participant raised the issue of colour blindness in both understanding and reading multiple representations.

It should be noted that the low 800x570 resolution of the head mounted display would have impacted on the reading of visualizations at a distance. This is especially true for the Gauge representation, which required fine detail.

8 Proposed Changes

Following the results of the study, the Gauge was shown to be an effective representation for reading three of the four attributes for distances up to 40m. Despite no significant result for representing corrosion, the ambiguous nature of the colour scales was demonstrated through both results and user feedback. This ambiguity and the requirement for visualizations to be read at distances beyond what the Box and Gauge supported, led to modifications of the Plasma representation.

The Plasma effect, despite having issues with an ambiguous colour scale (mean accuracy of 16%), has been adjusted to reflect threshold values. Instead of representing a continuous scale, the corrosion level can be classified as low, medium or high. This reduces the attribute's range that we must visualize. It is suggested that by applying a traffic-light (red, yellow, green) colour scheme to the Plasma effect, we can provide users with three distinct categories of classification for corrosion levels. This use of the plasma effect as opposed the Box or Gauge simplifies the visualization, as only one attribute is being displayed. As commented by one of the participants in the study, the use of only one attribute made the Plasma representation easier to understand.

To provide details for the other attributes, along with 'drill down' functionality, an opaque status bar is displayed on bottom of the user's view. Unlike dialog boxes, the status bar does not obstruct the user's current view, allowing them to maintain focus on the current task at hand. Given there is no direct indicator for the placement of sensors, a semi-transparent box (1x1x1m) is used to represent the presence of a sensor. Upon the user focusing on a sensor, that sensor's box is highlighted (as can be observed in Figure 11 as the red box) and the exact numeric values of its attributes are shown in the status box on the bottom of the screen.

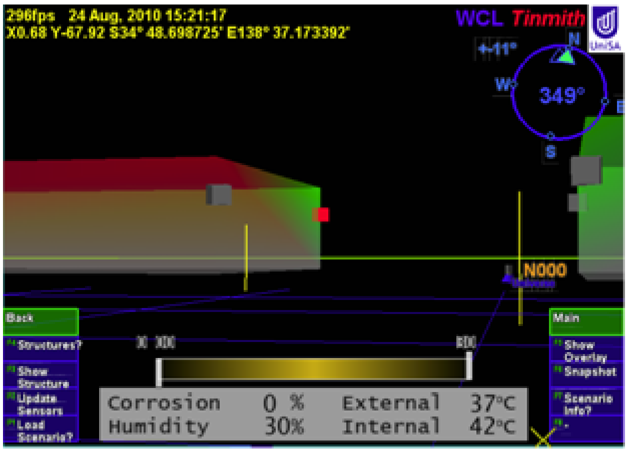

Figure 11 The updated 'traffic light' plasma effect shown on the two user study buildings

A dialog box can provide the 'drill down' information, along with a graph showing the change of the attributes over time. The graph is live, such that as the user changes the current date/time, the graph is 'scrolled' horizontally. The data for the currently visualized date/time is located in the middle of the graph, highlighted by a white bar (Figure 12), showing both future and historical trends.

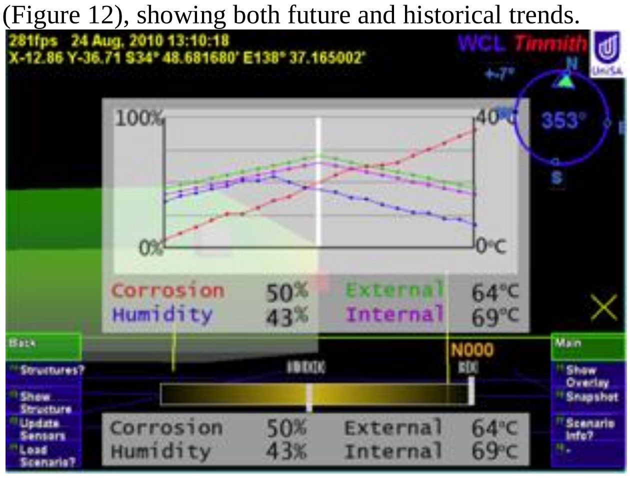

Figure 12: The dialog box providing trend data

9 Conclusion

In this paper we have presented an overview of the Augmented Reality Visualization of Outdoor Environmental Corrosion system using outdoor, mobile augmented reality. We have proposed a number of visualizations which have been shown to be effective (via means of a user study) for distances below 40m. The Gauge representation has been shown to be effective in visualising three of the four sensor attributes for distances up-to 40m. This was supported by participant feedback, with all participants preferring the Gauge for reading data. However, participant feedback indicated equal preference for the Box and Plasma visualisations for indicating areas of interest. We have also presented the use of a physical control board, via the use of Phidgets, to support the navigation of large data sets in mobile context.

Following the final pilot study, we hope to have a set of visualizations which have been shown to be effective across a wide range of distances.

10 Acknowledgements

We would like to thank Thuong Hoang for his help with the Tinmith backpack, software and proofreading, Dr. Robert Kong for his help with the environment sensors and proofreading and Dr. Stewart Von Itzstein for his help with the visualizations.

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