A Standardised Remote Monitoring Photographic Capture System (RMPCS) for *In-situ* Documentation of Corrosion Protection System Tests

James Crawford[1], Christian Degrigny[1], Quentin Glorieux[2], Pierre Bugeja[3] and Daniel Vella[1]
[1]Heritage Malta, Kalkara, Malta
[2]Institut d'Optique Graduate School, Palaiseau, France
[3]PrevARTI, Mosta, Malta

Heritage Malta,
Conservation Division,
Old Royal Naval Hospital, Bighi, Kalkara, CSP 12, MALTA
Phone: +356 21 80 76 75,
Fax: +356 21 67 44 57,
e-mail: jamesbcrawford76@gmail.com

An automated remote macrophotography system was designed and developed by Heritage Malta and PrevARTI to objectively monitor the protective efficiency of corrosion protection systems under in-situ exposure at the Palace Armoury, Valletta, Malta, within the European Union PROMET project. The system, a computer-connected high-resolution digital camera, is programmed to automatically acquire, at 24 hour intervals, reproducibly illuminated macroscopic images of an exposure rack holding "protected" low carbon steel coupons. The acquired images are to be automatically analysed (digitally) to monitor changes attributable to corrosion product evolution: thereby indicating protection system failure. By integrating and standardising the digital processes of data acquisition and analysis, objective monitoring of protection system efficiency, limited to visible spectrum surface imaging, is expected.

Keywords : Corrosion, in-situ, digital photography, cooccurrence matrix, autocorrelation

1. INTRODUCTION

Conservation of material cultural heritage, by its nature, is about limiting the destructive alteration of human-made material artefacts over *time*. In an *applied conservation* context the comparison of artefact documentation (e.g. drawings, photos, material analyses) over time or before, during and after conservation treatment provides a form of condition monitoring - mostly unreferenced. In a *conservation research* context, referenced monitoring, over multiple points in time, of the performance of new and/or untested materials designed to protect artefacts from alteration is of significance in determining their efficiency and future possible use in cultural heritage applied conservation intervention procedures.

Over a decade ago, Heritage [1] summarised the literature on documenting dynamic processes over time at macroscopic and microscopic levels via imaging (e.g. photography, film, video) with subject illumination techniques (e.g. visible, infrared, x-ray radiation) used in various scientific fields (e.g. biology, medicine, physiology, chemistry & heritage conservation). Heritage's particular research was in the conservation of cultural materials domain and emphasised associating environmental data directly on the viewed footage of time-lapse video microscopy of several materials (parchment, clays & salts on painted lime plaster) responding to humidity changes [1]. Winter et al [2] and Thornbush and Viles [3] described examples of integrated digital (photographic) image acquisition, processing and analyses for cultural heritage conservation research. Heritage [4] further emphasised the emergence of visual documentation media as an "analytical and investigative tool" by correlating environmental data and thermal imaging over time. More recently, in 2006 the research of Adriaens et al [5, 6] catered for the need to improve knowledge about the effects of common conservation treatments on artefact material surface composition and appearance. This work again demonstrated the possibilities and benefits of documenting dynamic experiments with visual imaging, while performing in parallel other analytical measurements. For example, imaging was performed by either pausing research treatments at intervals for photo-microscopy, or by continuously recording in-situ via macroscopic digital video. The "treatment" was the stabilisation of chloride containing copper coupons via immersion in sodium sesquicarbonate and was simultaneously subjected to chronoamperometry and synchrotron radiation X-Ray Diffraction (XRD) analyses [5, 6]. Some other recent in-situ studies that were imaged microscopically over time and are relevant to metal corrosion phenomena or metal conservation (via reduction) are listed [7, 8].

Similar to non-imaging analyses that represent spectral data with a graphical interpretation (e.g. XRD, XRF (X-Ray Fluorescence), etc.), the possible combinations of imaging techniques for monitoring conservation treatments or research experiments over time are only limited to the current technologies available. However, fundamental factors to consider for dynamic imaging include:

- Subject's characteristics (e.g. dimensions, quantity, light reflectivity, environmental sensitivity).

- Temporal scale (e.g. treatment/experimental timescale and recording intervals).
- Spatial scale (e.g. magnification).
- Recording medium format (e.g. analogue, digital) & resolution.
- Illumination/irradiation spectrum (e.g. x-ray, ultraviolet, visible, infrared).

Objective, precise and accurate monitoring of the efficiency of metal corrosion protection systems (i.e. barrier coatings and corrosion inhibitors) (PS) exposed in-situ in a museum environment over time requires standard means of data acquisition and processing. Digital photography (macro or micro) is now one of the simplest, affordable and most effective means of documenting visible surface phenomena – e.g. corrosion product (CP) activity and PS transformation. Establishing and maintaining standard photographic lighting and subject conditions, especially over long durations and in a museum gallery context, is less easily achievable.

The development of a Remote Monitoring Photo Capture System (RMPCS) - an automatically operated digital camera and lighting system installed to acquire images of corrosion PS tests over time is described. Focus is given to the practical strategies implemented to obtain environmental and photographic conditions that result in images that are comparable over time – i.e. standardised. The methodology of analysing the resulting digital images for determining PS efficiency is also outlined. This process, still under development, involves simultaneous comparative temporal analysis of local structure and pattern recognition and analysis. This is used to detect significant and consistent changes attributable to corrosion PS failure. Factors contributing to the *PS failure detection time* are also described in the paper.

The standardised RMPCS complements an overall characterisation strategy of documenting the protective efficiency and exposure environment of the corrosion PS tests and is summarised. Combined with previous analyses of the metal coupons [9] and their CPs [10] an outline of the material and environment system is obtainable; providing the possibility to better rationalise the phenomena observed during the tests.

2. BACKGROUND

2.1 The PROtection of METals (PROMET) project & the Remote Monitoring Photographic Capture System (RMPCS) subproject

The RMPCS is a subproject of the 3-year European Union 6th Framework Programme, priority INCO, PROMET project. One of PROMET's objectives is to develop innovative & safe corrosion PSs to advance the conservation strategies for metal cultural heritage in the Mediterranean basin. For the PS efficiency tests on ferrous metals, Heritage Malta (the National Agency for Museums, Conservation Practice & Cultural Heritage) and the University of Malta's Department of Metallurgy and Materials Engineering produced artefact analogues, referred to as coupons (50 x 75 x 3mm), to mimic the material properties of low-carbon steel cultural heritage artefacts. The composition and metallographic structure of the coupons were based on metallographic observations and Scanning Electron Microscopy with Energy Dispersive Spectrometry (SEM-EDS) of late 16th-early 17th century North Italian style infantry armour from the Knights of St John, Malta [11]. This collection is currently displayed in the uncontrolled indoor museum environment of the Palace Armoury (PA), Valletta, Malta. To conduct the PS tests in an environment representative of wall-displayed armour, and the most aggressive display conditions at the museum, the coupon test rack was installed on a PA wall (Figure 1).

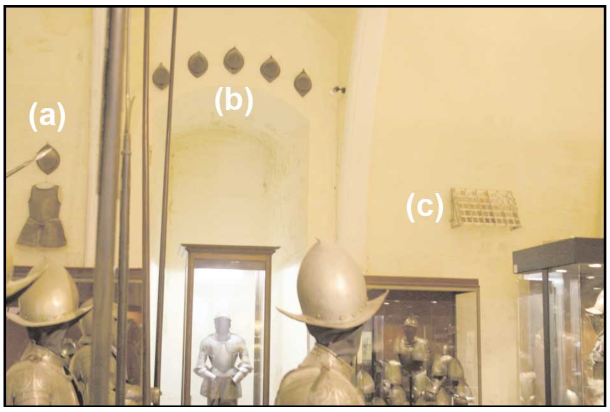

Figure 1a & b - (Wall displayed armour and c) the PS coupon test rack

The exact methods of coupon inspection varied between PROMET partners according to their resources, but at least required visual and photographic examination at macroscopic and microscopic levels before and after exposure.

With the advent of lowering costs of high resolution digital cameras and computer technologies Heritage Malta decided to launch the RMPCS, an innovative means of rigorously monitoring, via imaging, the in-situ corrosion PS tests over time.

3. PROBLEMATIC

3.1 Subjective, insensitive & infrequent data acquisition via human observation

Accurate *and* precise in-situ PS assessment efficiency during the test-exposure was predicted to be problematic. This was mainly due to the intentional fabrication of coupons with pre-existing CP layers prior to starting the PS tests. During restoration, CPs on the armour at the PA are only partially removed since their total removal can leave an irregular and pitted surface not representing the artefact's original surface shape [12]. The preliminary development of CP layers on the coupon surfaces was required to mimic the armour artefacts (or indeed similarly corroded artefacts) since the surface composition and morphology attributable to CPs is expected to affect corrosion PS performance. This difference in protection performance would potentially be especially noticeable when comparing the performance of the same PS applied to a polished, uncorroded and unpolluted surface – a material like a newly manufactured item, not an aged artefact. So it was anticipated that this initial CP layer prior to PS application would make the detection of any possible new CPs (thereby attributable to PS failure) difficult to achieve solely by human visual observation. The exact reason for this is that it would be less likely to differentiate new CPs developing on zones already covered with pre-existing CPs than when compared with CP development on areas of previously reflective metal. It is the rough red-brown ferrous CPs against the polished reflective ferrous metal that provides this discernible contrast. To exemplify this significant point, new CPs developing onto *totally corrosion product-free coupons* (Figure 2a) would be very easily observed (according to the CP size, observation magnification scale and illumination levels).

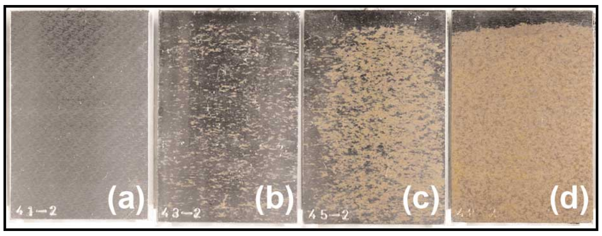

Figure 2 a - Reference coupon: neither precorroded nor exposed, 0% surface area coverage of corrosion products, b) precorroded 3 months (5-10% CP coverage), c) precorroded 6 months (45-55% CP coverage) and d) precorroded 11 months (90-95% CP coverage)

So applying this principle to the coupons under test that have *pre-existing corrosion products*, it can be seen from the coupon series with relatively less pre-existing CPs (Figures 2b & c) that the appearance of new CPs would be much easier to detect than when compared with a surface almost entirely covered with pre-existing CPs (Figure 2d).

Any new CPs would most probably eventually be noticed, if given sufficient time to become very obvious, and the authors define this as *PS failure detection time*. This *detection time* evidently cannot include imperceptible failure and is not only dependent on the coupon's pre-corroded surface area and duration under test, but also human error.

Simply summarised, *PS failure detection time* (via means utilising human optical examination under visible light) is decreased with the lesser amount of precorroded surface area. This detection time could be a significant amount of time after the PS initially failed, i.e. when corrosion started, and provides data that is potentially precise, but less accurate. A relative timescale of corrosion PS efficiency would therefore be produced, not an absolute timescale. In the unlikely case that CPs developing onto pre-existing CPs were immediately detectable to the human eye, human observation is subjective and memory is not infallible, hence the need to consider human error. As an example, during the coupon pre-testing preparation process of natural corrosion on site at the PA, corrosion evolution was monitored in a variety of ways detailed elsewhere [10]. However, one method, based on human visual examination over time is represented graphically in Figure 3 and shows several *reported* decreases in corrosion product presence. The Human Visual Grading Scale is based on a count of sites or coverage of corrosion products. Since a fall in CP presence is an impossibility on these thin layers, the subjective nature of human observation is illustrated.

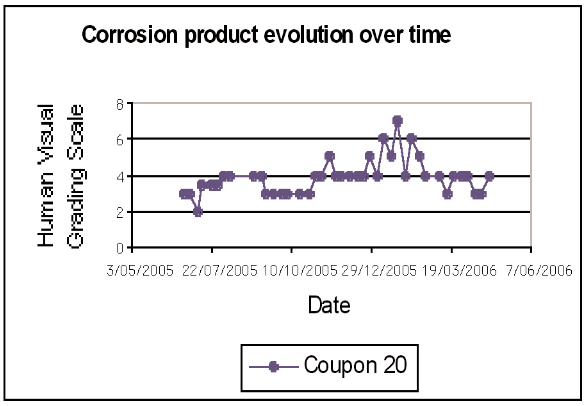

Figure 3 - Corrosion product evolution over time via human observation and grading according to a predefined scale (0 to 8)

Reference to coupon pre-exposure photographs would have reduced this error, but this strategy only allows monitoring over two points in time and therefore does not monitor transitions or trends that contribute to eventually detected phenomena. It is more likely that human detection of CPs will be made only if the CP evolution has progressed sufficiently (over an undeterminable amount of time) to cause a defect in a PS (e.g. crack, delamination) and/or the new CPs are noticeable due to a new aspect (e.g. colour, shape). From experience, this is especially true for CPs having sufficient time to develop and penetrate through and above an applied PS. These new CPs can appear optically lighter or less saturated.

From a consistent experimental methodology perspective, the high subjectivity of data acquisition via periodic human observations increases significant uncertainty in data acquisition and results analysis. The long duration (1 year) of the test and the high number (45) of coupons to monitor multiplies this uncertainty.

Practically, in terms of staff-time management, the testing in-situ at the museum makes regular inspection via commuting a time-consuming activity and would have prevented the experiment's regular inspection. *Protection system failure detection time* would have again lengthened due to the difference in time between successive site inspections. Furthermore, the potential scenario of two or more PSs failing after the previous inspection would therefore make it impossible to rate the systems on a relative scale of performance.

4. PROPOSITION

4.1 Remote Monitoring Photographic Capture System

The RMPCS project, initially a 3-month internship project by optical engineering student Quentin Glorieux [13] forms the foundations of the currently continued standardisation of the system by the authors.

The project's aims and objectives are:

Aims:

- To monitor (qualitatively and semi-quantitatively), objectively via digital photography and signal processing analysis, the efficiency of 4 metal corrosion PSs over 1-year in-situ in the PA museum environment.
- To develop a prototype system and methodology potentially transferable to the non-destructive in-situ monitoring of other material conservation research over time.

Objectives:

- To increase the accuracy, precision and frequency of data-acquisition for reliable real-time (daily) PS performance monitoring.
- To regularly monitor the experimental configuration from a remote location and to intervene on-site if disturbance occurs.

5. EXPERIMENTAL CONSIDERATIONS

5.1 Reproducible photographic conditions

To obtain consecutive images that are comparable over time the following conditions must be satisfied:

i. Standard camera to subject geometry (Figure 4):

- Camera-coupon rack perspective & distance.

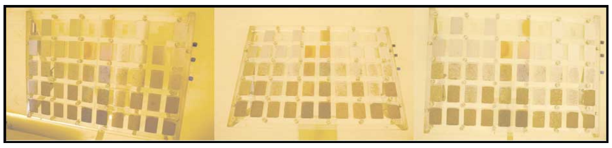

Figure 4 - Photographs from differing perspectives & distances

ii. Standard conditions of illumination (Figure 5):

- Lighting levels; angle of lighting incidence; & lighting colour temperature.

Figure 5 - The Palace Armoury does not feature conditions for standard illumination during day/opening hours

iii. Standard photographic camera hardware:

- Camera & lens

iv. Standard photographic camera operating parameters:

- Shutter speed; film (ISO) speed; aperture value; white balance; light metering mode; focal distance; exposure compensation; image resolution; & image size.

If these conditions are satisfied then the images can be automatically analysed digitally for variations over time – an important consideration when generating large volumes of data (section 6.4 Data Processing).

5.2 Experimental, museum & corrosive environments

Some additional practical experimental considerations dictated that the RMPCS be sympathetic and durable with the experimental, museum and corrosive environment. For example, the RMPCS's installation and operation should not interfere with the experimental environment (e.g. contribute to infrared/ultraviolet radiation damage of PSs from light sources or affect aerosol deposition by creating a dust shadow).

Also, important practical considerations such as ensuring access for direct human inspection of the coupons must be made; meaning RMPCS equipment should not physically impede access. Not to overlook the significant consideration of performing research in a museum, the visitor access (1000 visitors daily in high season) in the in-situ museum environment requires that the RMPCS is inaccessible and is not a negative visual diversion from the armour exhibits.

Consistent with the corrosive environment under study, precautions to protect the electronic circuitry of the most indispensable and vulnerable components of the RMPCS against corrosion were considered.

6. EXPERIMENTAL SOLUTIONS

6.1 Data acquisition - experimental components & configuration

The strategies designed to cater for the various imposed experimental conditions and thereby achieve the RMPCS's stated aims and objectives include:

Strategies:

- Installation of a fixed camera mounting support in front of the test rack enables capturing, with a reproducible geometry, images of the 45 test coupons (Figure 6).
- Installation of a high-resolution digital photographic camera (Figure 6).
- Corrosion protection of the camera's circuitry via the installation of a basic underwater housing with replaceable desiccant (Figure 6).
- Monitoring the relative positions of the camera, rack & wall by survey markers (Figure 6).

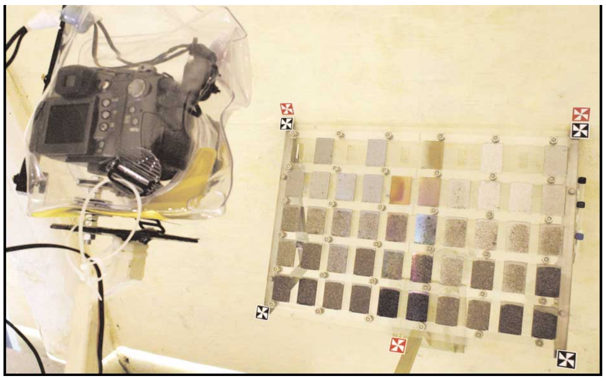

Figure 6 - Digital camera in anti-corrosion case mounted to monitor PS coupons on rack with survey markers

- Connection of the camera to a personal computer with software-controlled remote operation and image downloading.
- Programming (PerlScript) of the camera remote operation software (PSRemote by BreezeSystems) for scheduled standard photographic operating parameters.
- Installation of lights to provide illumination for night photography.
- Connection of the computer to 512/256K ADSL internet to control the camera and lights in real time and to download and assess high resolution images at the ex-situ conservation laboratory via VNC (Virtual Network Computing) (Figure 7).

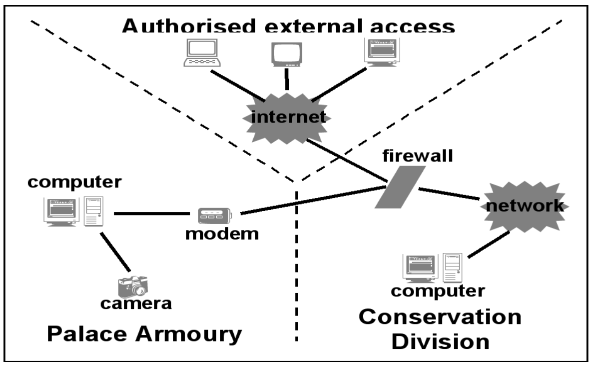

Figure 7 - Remote operation architecture (Abela & Zammit)

- Monitoring of the relative positioning of the lights & rack by laser tape-measure (Leica DISTO^{TM}) and shadow indicators.
- Installation of a web camera to survey the overall experimental set-up in real-time.
- Colour balance and exposure variation monitoring/correction via a calibrated photographic colour chart (Gretag Macbeth).
- Physical protection of the computer peripherals from museum visitors is achieved via enclosure in a lockable cabinet.
- Positioning of the system's computer monitor at the museum visitor's eyelevel enables interpretation of the RMPCS installation and PROMET project via an on-screen explanation; the RMPCS effectively becomes a museum exhibit complementing the visitor experience.
- Electrical protection of the camera, lights, computer hard-drive and monitor against power failure and power surges is achieved with an Uninterruptible Power Supply (UPS).
- Risk of potential digital data corruption or loss is lessened by automatic data backup.

6.2 Technologies & practicalities - camera & lights

The two most obvious fundamentals for any photography are the camera and lights and therefore warrant elaboration. Key to obtaining conditions for reproducible photography is the ability to capture images at night when the Armoury is closed, dark with all exhibition display lights switched off. To control PA lighting conditions at night, external light sources (e.g. streetlights, moonlight) from the windows are eliminated with light impermeable curtains. The necessary controlled light sources adjacent to the camera are automatically operated by web-based software. The remotely operated camera and lighting each required a series of specific features:

i. Camera

Obtaining a digital camera including all of the following features was paramount:

- High-resolution sensor to capture sufficient detail on each coupon (50 x 75mm) while the lens focal length is set at a wide field of view to simultaneously capture the whole rack (540 x 735mm) of 45 coupons.
- Reasonable maximum aperture (depth of field) so as to accommodate for varying curvature of field/plane of focus across the rack.
- Compatible with a remote operation software capable of capturing at 24 hour intervals.
- Remotely activated from & deactivated to stand-by mains power (alternating current) via software to avoid damage to the camera sensor caused by permanent power supply.
- Local authorised technical support in case of urgent repairs so as to minimise period of data acquisition loss.
- Affordable.

The 6 mega-pixel Canon PowerShot S3 IS digital camera satisfies the criteria.

ii. Lighting

Since preliminary evening photography tests (i.e. without display lights and without strong daylight) confirmed that ambient illumination variations (i.e. intensity levels and angles of incidence) were still significant an independent purpose-built light source enabling night photography for the RMPCS was proposed as the solution for lighting standardisation.

PrevARTI - Engineering Solutions for the Preservation of Cultural Heritage, designed and developed the lighting system suitable for the experimental needs. PrevARTI Remote Lighting System (RLS) features:

– Remote control via internet.

- Individual bulb control (0-15 dimming levels).
- Automatic on/off scheduled timer.
- Synchronisation with camera schedule.
- Manual unscheduled control for experimentation and illumination optimisation

PrevARTI RLS consists of 2 x 4 Philips Lumileds Luxeon Star/C Light Emitting Diodes (LED) (Figure 8a) and features the following advantages over conventional light systems (e.g. incandescent and fluorescent):

- No instant bulb failure.
- No ultra-violet & very low infra-red radiation.
- Compact-lightweight.

Recent technologies have meant that LEDs became useful as a *light source* (a light output in order of tens to hundreds of lumens) rather than as a *light indicator* (one to several lumens) [14]. Significantly, new technology LEDs offer superior lumen maintenance compared with conventional light sources: essential for standard photographic lighting [15].

With an array of LEDs housed in custom-built photographic "softboxes" more regular light distribution is achievable (Figure 8b).

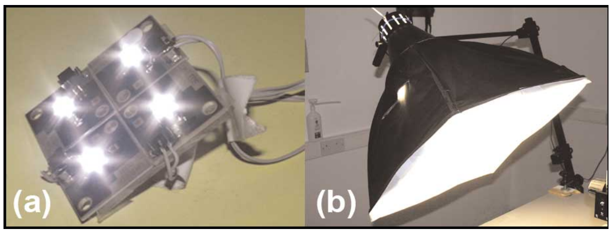

Figure 8 - a PrevARTI RLS LED array
and b a commercially available "softbox"

The softbox dimensions are designed to cast light over the whole coupon rack when installed at a maximum angle of incidence of 45^o (Figure 9).

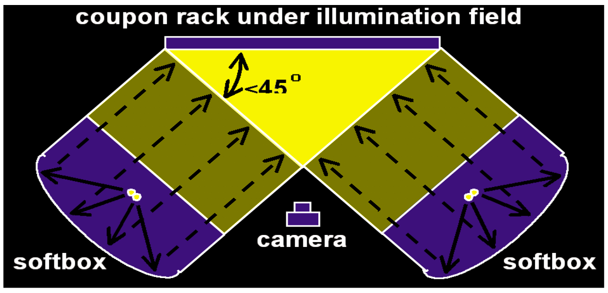

Figure 9 - Schematic of photographic installation

This angle was chosen as the most likely to provide the best compromise for conditions that minimise *glare path* into the camera lens as can happen with wide subjects and without causing loss of captured surface detail as with raking light [16]. Laboratory tests replicating the in-situ experimental dimensions will be undertaken to verify these assumptions before application to the test in-situ. At the time of submission for publication the presented research had advanced to this point.

6.3 Instrumentation calibration

The photographic exposure parameters will be optimised according to the lighting and subject conditions at the start of the experiment's RMPCS monitoring. For the standardised image analysis to be effective the photographic parameters will need to remain the same throughout the test duration. For the layout and type of samples under documentation significant aspect changes (particularly light reflection levels) are not expected. Despite the lighting hardware design and variable software control to produce even light distribution over the rack surface area, it is expected that illumination will not be even in practice. A photographic lightmeter will be used to initially dis/prove any differences. Any significant variations will be corrected via an initial post-capture calibration procedure. Summarising, a series of coupon-sized grey cards (circa 18% grey) will be inserted onto the rack. The photographic and environmental conditions to be used during the experiment's monitoring will be established and a calibration image will be captured. Using this calibration image, the varying light intensity over the rack will be checked and normalised for illumination brightness with ImageJ software (section 6.4 Data Processing). Lens distortion correction will also be performed with ImageJ to aid rectilinear coupon cropping during post-capture image processing. Both these procedures will be scripted so as to create a standardised image correction protocol that will be applied to all subsequent image files taken during the test period.

6.4 Data Processing – post-capture image analysis

Interpreting the visual images (i.e. photography) of the coupon surfaces as numerical digitised values (0 & 1 binary numeral system) enables more sensitive and *relatively quantifiable* assessments indicating PS efficiency over time. This facility enables producing more results that can be scrutinised with greater confidence – an objective of any scientific research. Integrated data capturing and processing in digital format ensures that data is not lost or varied through an analogue conversion process from colour photography made by silver halide-dye emulsion films. Image J (version 1.3+) programme (software based on Java programming language) will be used with a standard protocol to analyse the resulting images via a system of cooccurrence matrix and autocorrelation. An ImageJ application macro will crop the coupons from the photos of the overall rack, stack (i.e. superimpose) the respective coupon images and analyse for any changes (Figure 10).

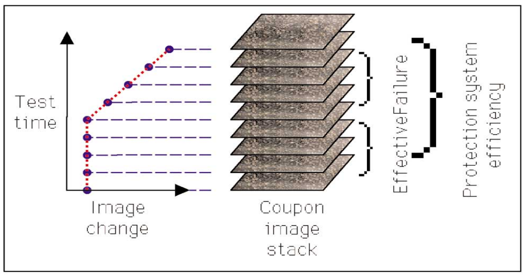

Figure 10 - Schema of image analysis via stacking [17]

The use of an application macro to automate a frequently used action is advantageous not only since it undertakes laboriously repetitive and time consuming work, but it also ensures protocol standardisation.

Rather than using an absolute measure of an image's "digital construction" a relative scale will be produced between images of like coupons. When making comparisons between coupons over time the data sensitivity will be of high consideration. There is a possibility that an acceptable margin of tolerance (e.g. percentage change in the area of an image) or a sensitivity adjustment level might need to be introduced into the programming. This could be required since, for example, the presence of airborne particulates (i.e. solid aerosols) depositing on the surface could misleadingly indicate corrosion activity. It is possible that when change repetitively occurs locally, or in identifiable patterns, that PS failure is detected. A linked automatically prompted email alert could provoke a direct on-site human inspection.

The uncoated reference coupons are expected to provide an invaluable resource for testing these considerations, as their corrosion activity should resume before any protected coupons. In the case of a detected PS failure, the way in which corrosion propagates could be monitored over long periods of time, if required, so the corrosion propagation mechanism/morphology (e.g. filiform corrosion) related to PS failure is documented.

7. RESULTS ANALYSIS, LIMITATIONS & IMPROVEMENTS

At the time of submission for publication it was too early to conclude on the performance of the RMPCS. However, it was possible to make general remarks about the experimental methodology's anticipated limitations and the scope for future improvements.

7.1 Two-dimensional macro surface imaging

It is important to stress the obvious point that PS efficiency/corrosion propagation is only assessable via visible surface observations, and the corrosion sites of many of these precorroded coupons could actually occur in areas not evident in the visible light spectrum (that which photography is possible) i.e. subsurface. The time between initial PS failure and observed PS failure (i.e. *PS detection time*) remains unknown, however the relative efficiency of each PS could be reliably determined.

The substitution, or complementary use, of other non-destructive testing (NDT) optical imaging techniques (e.g. infrared thermography and holographic interferometry) could also be used to characterise the surface (CPs and/or PSs) in-situ over time, but would require the extra expense and training. These techniques are potentially more accurate and are also theoretically capable of detecting subsurface phenomenon, such as discontinuities caused by corrosion [18].

7.2 Magnification & resolution

The microscopic levels that corrosion initiates further lengthens the *PS failure detection time*. The large number of samples required for valid statistical analysis requires that the camera field of view records the whole rack surface area. To increase magnification, and therefore sensitivity, a precisely automated X-Y translatable mechanism could be installed for closer imaging with a camera &/or microscope. Such elaborate approaches would require the application of a cost-benefit assessment, and pragmatism, especially if conducting research in-situ in a museum environment.

In the advent that digital video resolution becomes comparable to that currently obtainable with digital still cameras the temptation to advance to this medium would need to be tempered by the practical & financial costs of storing such great volumes of data over long experimental periods. The advantage of having such data would be to have the ability, if the need arises, to review the video for the occurrence of a specific sudden phenomenon (e.g. human interference). The constant use of a video camera over long periods would not be within the expected design intention, and failure from prolonged use must be considered. Moreover, the highly variable lighting conditions in a museum would make the proposed standardised data analysis procedure impossible during daylight/opening hours.

8. COMPLEMENTARY STRATEGIES

8.1 Corrosion and environmental monitoring

The RMPCS is one method in a complementary suite of corrosion and environmental monitoring strategies. Another approach for determining corrosion PS performance is periodic direct in-situ human macro observation (i.e. comparison with printed photographs of coupons before exposure). Referenced laboratory photomicroscopy will also be performed at 3-month intervals. After exposure, resistance polarisation (RP) tests are planned for the PSs' assessment. Meanwhile strategies for environmental monitoring include data-loggers for temperature and relative humidity (exhibition hall & external atmosphere), diffusion tubes for the gaseous pollutants NO_2, SO_2 & O_3 and microscope slides with adhesive samplers for solid aerosols.

9. CONCLUSION

Interval digital macrophotography is suited for the comparative monitoring of corrosion PS tests over a long duration of in-situ exposure in a museum context. The large number of samples including differing protective systems with statistical replicates necessitates the use of a wide angle of view for simultaneous monitoring. This is only currently possible at high resolution via macrophotography. The digitisation of the whole data acquisition and data processing protocol permits its standardisation since digital files are faithfully reproduced and transferred from the in-situ museum environment for the data analysis phase. The digital format can be analysed due to each file's distinct binary code. Furthermore process automation, possible with digital technologies, contributes to the efficiency of data analyses and the reliability of results since the significant variable of human error is omitted and standardisation is achievable.

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