AUSTRALIAN NETWORK OF STRUCTURAL HEALTH MONITORING

Newsletter

Issue 9, September 2016

Contents

President Message

Tommy Chan

Professor in Civil Engineering, Queensland University of Technology

Dear All,

As mentioned in the last updates, we are excited to know that there are quite a number of bridges in Australia planning to install different SHM systems to different scales as we are having more and more of the asset managers in Australia realising the importance of installing SHM systems in their assets to facilitate management and maintenance and enhance the safety of the structures and the public. Actually it is a worldwide trend to implement SHM technologies to assist infrastructure asset managers to effectively monitor, manage and maintain their assets - the 3'M's. We are glad that more and more asset managers could now appreciate the significance using SHM for the 3'M's.

One of these bridge instrumentation projects was arisen from the successful development of a low-cost accurate Bridge Weigh-in-Motion (BWIM) system collaborating between Data61 and Western Sydney University (WSU). Prof Bijan Samali is so kind to provide the details of this project through his postdoctoral Research Fellow, Dr Maria Rashidi.

The project basically is a three stage project aiming to develop a framework for structural life cycle assessment with particular focus on bridge structures. The system will demonstrate to provide useful information not only on the health state of the structure, but also on the functionality of the structure e.g. the remaining life or capacity of the bridge. Stage I of the project is mainly to instrument a cable-stayed bridge over Sydney's Great Western Highway (Figure 1) to verify the BWIM Algorithm developed by Data61 to characterise passing traffic, i.e. speed, number of axles, and distance between axles and to identify the gross and axle weights. Stage II will be for exploiting further the SHM data collected from the bridge to assess structural capacity and to predict bridge deterioration over time. Stage III aims to apply the outcomes of the first and the second stage to other bridges with different designs in NSW to be collaborated with RMS or local councils as appropriate.

Figure 1. The cable stayed bridge at the intersection of Second Avenue and the Great Western Highway Werrington NSW (Image from Google Earth)

This project is not only demonstrating the success research collaboration between ANSHM members and the industry. It also helps demonstrate the effectiveness of using SHM for the 3'M's. Bijan is also aiming to release the data collected from the instrumented bridges for other ANSHM members to use for the SHM research and development. The progress of the project will be updated at various appropriate stages through various communication platforms of ANSHM and how the data could be shared will also be provided in due course. I believe more and more ANSHM members will participate in various projects of instrumenting Australian bridges for SHM in the near future. ANSHM will try our best to release such exciting news to our members as well as the coordination of the data collected for the development of SHM technologies.

Below are other updates of the month.

Organising SHMII-8 (December 2017)

We have identified a list of potential conference dinner venues. Saeed and I visited a number of potential conference dinner venues in mid-August. We would like to find something which the delegate could spend a memorable night in Australia. We have short listed a few and will visit one more and then we could make a decision. Below are some updates of the organising of the event:

- As mentioned before, we need to form Five subcommittees including: sponsorships and fund raising, exhibitions and industry contributions, budget, papers processing and tutorial/ training courses. We have identified the main coordinators of each of these committee and the main coordinators will also invite his/her subcommittee members to plan and carry out the corresponding duties.
- Openconf hosting service is the preferred software for handling papers. It has been used and recommended by SHMII2014 organiser.
- The ISHMII Contract has been drafted and the registration fees are being checked by QUT conferences.
- Conference Sponsorship Prospectus draft is finalised and will be released soon. It is appreciated if all EC and Advisory board members help to distribute the prospectus to potential exhibitors, industries and sponsorships in order to secure their contributions
- Conference website was updated and the ISHMII logo was uploaded onto the conference website. A mailing list and an online form were set up in order that people can register their interests for any further event information.
- Information for the instructions for authors and for registration will be developed. Once an abstract system has been decided on and templates/guidelines have been developed, they will be added to the website.
- Keynotes speakers will be invited soon
- Key persons from industry will be invited to join the LOC

A warm welcome to Ricky, Yee Yan and Evan!
We look forward to your participation to ANSHM activities and your contribution to ANSHM.

ANSHM WebForum

I am so pleased to know from Lei that we have received 6 topics so far from the academics and industry for ANSHM Webforum:

- Application of SHM to inverse problems
- Benefits, challenges and risks of using SHM on the sub-standard, prohibited and strengthening bridges (i.e. the bridge does not meet to current bridge design standards, insufficient capacity to accommodate on the latest vehicle loading, monitor the bridge after the strengthening, reduce the inspection frequency, etc.)

- Cost and Benefits of development and maintenance for SHM tools and resources
- Damage quantification and real time imaginary
- Uncertainty analysis of SHM
- Smart materials based SHM

We find that these topics are very interesting and we could select one of them to be the topic of our 1st ANSHM Webforum. We are planning to conduct it in the near future. This kind of Webforum will also be scheduled in a regular basis so as to discuss these topics one at a time. We will also invite ANSHM members, especially those from the industry to be the Forum facilitator with the assistance of one of our Executive Members. All the discussions will be summarised and presented in the Newsletter. At the moment, we are dealing with the technical and practical arrangements of such forum. We will announce the details for the 1st WebForum in due course. I would like to thank Lei for all his effort.

ANSHM Special Issues

Earthquake and Structures

The review process of 12 full papers has finished. We are collecting the final manuscripts, copyright forms and other documents, for the final submission to the Publisher for publication soon. We should thank again all the reviewers for their effort in returning the reviewer reports timely.

International Journal of Lifecycle Performance Engineering

Three papers have been received and under review now. Now we only need two papers more to have a standalone special issue. As mentioned in my last update, the journal has not been SCI indexed or ranked in SCImago because of being a very new journal. However, this is a very good journal and the editorial board consisted of prominent experts in the related fields (http://www.inderscience.com/jhome.php?jcode=ijlcpe). The journal has a very good potential and will be very likely to be ranked in SCImago in future. Therefore, if we have papers published in it eventually they will still become ranked or indexed papers. Any papers reporting SHM research in Australia or related to SHM researchers in Australia are welcome. All papers must be submitted online by the deadline of **31 October 2016**. Please indicate clearly you are submitting to this Special Issue. Please go to the link (http://www.inderscience.com/info/ingeneral/cfp.php?id=3120) for details.

8th ANSHM Workshop 29-30 November 2016

Colin and the local organising team in the Monash University have been working hard in organising the workshop. They are working on the workshop brochure and aiming to have it ready in early September. The deadline for abstracts will be on Friday 30 Sept. They have also identified hotels and some restaurant near the venue and will have this information in the brochure.

ANSHM mini-symposium at ACMSM24

Nine full papers have been reviewed and finalized. Please kindly note that the early bird registration deadline is 15 September and the registration deadline is 31 October. Regarding the Young Research Award and the Stan Shaw Award mentioned in last monthly update, we have also nominated one person for each award and notified the persons, as the awards will go towards an individual instead to all the authors. Prof Ian Gilbert will lead the panel to review those nominated papers again and decide who will win.

ANSHM Homepage

The page is being looked after well under the team of Hong Guan. Some routine updates have been carried out, including the following items:

(1) Created "Highlights of Industry Collaboration";

(2) Updated Member Institutions and Executive Committee.

In this issue of ANSHM Newsletter, we will have three interesting articles related to SHM techniques. Dr Yang Yu and Prof Jianchun Li of University of Technology Sydney report a novel method based on multi-sensor data fusion for evaluating the health condition of timber utility poles. Advanced signal processing techniques such as Ensemble Empirical Mode Decomposition (EEMD) is used and the method is shown to increase the assessment accuracy and reliability. Dr Vincent Wang of Victoria University introduces an expectation-maximization (EM) algorithm embedded statistical damage prognosis paradigm for in-service civil structures to examine their future safety performance. A link is provided in the article for those who are interested and would know more about the details of the study. Dr Saeed Mahini of University of New England, together with his colleagues, A/Prof Chris Fellows and Mr Sameer Awad present a very interesting study on how the rehabilitation of timber-adhesive system for timber bridges could be improved and how monitoring techniques could be incorporated to investigate the effectiveness of the system.

With kind regards,

Tommy Chan

President, ANSHM

www.ANSHM.org.au

Condition assessment of in-service timber utility poles using multi-sensor data fusion technique

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Introduction

Utility poles made of timber are extensively used all over the world since they are relatively low cost and environmentally friendly. Especially in Australia, timber utility poles represent a significant part of the country's infrastructure for power distribution and communication networks. There are nearly 7 million timber poles in the current network in Australia, and among them, 5 million poles are used for power and communication supply with an estimated value of more than $10 billion. Each year, $40-$50 million is spent on maintenance and asset management to prevent utility lines from failure. The lack of reliable tools for assessing the condition of in-situ poles seriously jeopardizes the maintenance and asset management. For example, about 300,000 electricity poles are annually replaced in the Eastern States of Australia. However, about 80% of them are still in a very good serviceable condition, resulting in massive waste of natural resources as well as money.

To address the requirements of the utility pole asset management industry, several stress wave (SW)-based non-destructive evaluation (NDE) techniques have been developed as potential solutions for detecting internal damage and evaluating the soundness condition of non-accessible areas of pole structures. The principle of SW-based technique is that an impact force is initially generated and the response from the pole structure is recorded by a sensor deployed on the head or side of the structure. By analysing the reflective signals, estimation of health condition can be made. Although SW-based technique has been used for many years for NDE of pole structures, the results are still inconsistent due to many issues associated with complexity of wave propagation in the structure, including material property, soil effect and uncertainties. One the other hand, challenges also can stem from practical field testing conditions, in which sensor measurements are influenced by noise submerging the actual wave propagation information. Moreover, if testing data originates only from on source, it is non-inclusive and may be subject to errors from operators and environmental factors. Hence, to achieve comprehensive and reliable assessment of poles, multiple types of signals should be recorded and analysed. Furthermore, using a multi-sensing system instead of only a single sensor or device can facilitate higher identification accuracy. In such cases, however, sensors deployed at different locations may result in conflicting assessment results, making a final decision difficult. As a result, current SW-based NDE methods fail to fully interpret wave features and patterns, and to produce accurate and reliable health status assessment of in-service poles, which is vital for the power and energy management industry.

Methodology

To solve existing problems mentioned above, this study proposes a hierarchical data fusion strategy to process the captured SW signals for reliable and accurate assessment of health conditions of utility poles. Figure 1 shows the configuration of the proposed method, which consists of three phases: feature extraction, initial recognition and decision making. In the phase of feature extraction, advanced signal processing techniques will be employed to extract damage-sensitive patterns, which are used as inputs for the information processing of next phase. In the phase of initial recognition, a statistical learning model will be established at each sensor to intelligently analyse the extracted feature parameters, facilitating the initial evaluation of the pole condition. In the phase of decision making, the initial recognition result corresponding to each sensor and excitation location is regarded as independent evidence, and all the results including conflicting evidences will be combined using Dempster-Shafer (D-S) evidence combination rule, solving the problem of conflicting and inaccurate identification of pole condition using only one sensor. The whole model employs a hierarchical configuration, in which the outputs of the former phase are used as inputs of next phase. Therefore, via multiple phases of information processing, the proposed method is able to improve the robustness and accuracy of the assessment results.

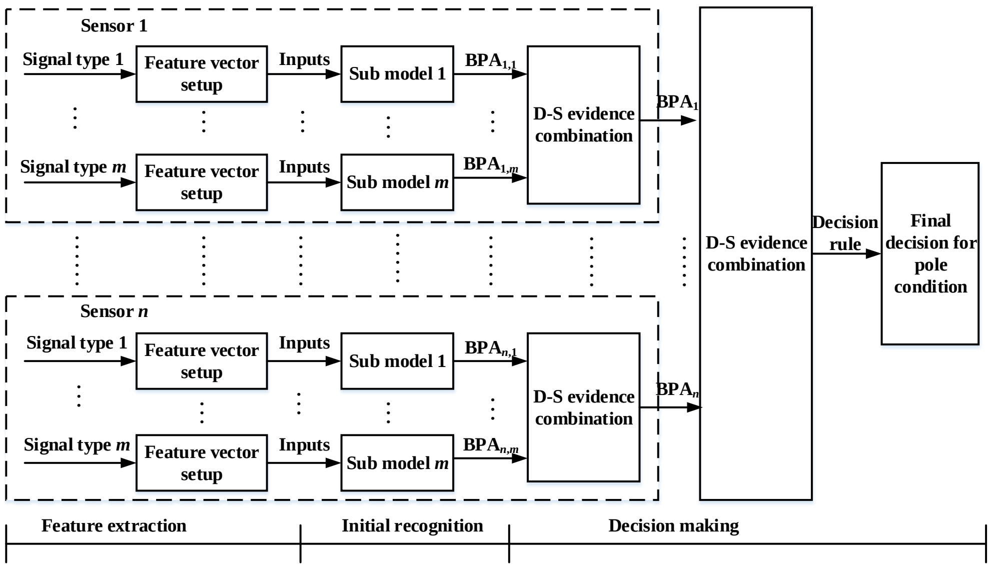

Figure 1. Configuration of data fusion model

Case study

A portable multi-sensing NDE system, developed by UTS *Civiltronics* Group, is used to implement field testing of utility poles. This system consists of a sensor bar with seven accelerometers, two 4-channel USB DAQ modules, an impact hammer and a laptop for signal collection and analysis. Figure 2(a) shows the makeup of the portable NDE system. The impact hammer is a PCB 086D05 model with 1 mV/lbf sensitivity. The sensor is the ceramic shear ICP accelerometer of 352C34 model with 100 mV/g sensitivity and 0.5 Hz to 10 kHz frequency bandwidth. The DAQ system is composed of two 4-channel modules of 9234 model incorporated in USB chassis of cDAQ-9171 model, the system therefore has eight channels for data transmission, where the first channel is connected with impact hammer and the remaining channels are for seven accelerometers. The sensor bar is designed to closely fix the accelerometers to the surface of the tested structure. The spacing between two neighbouring accelerometers is 200 mm. The data collection is realised using software LabVIEW, the surface of which is shown in Figure 2(b).

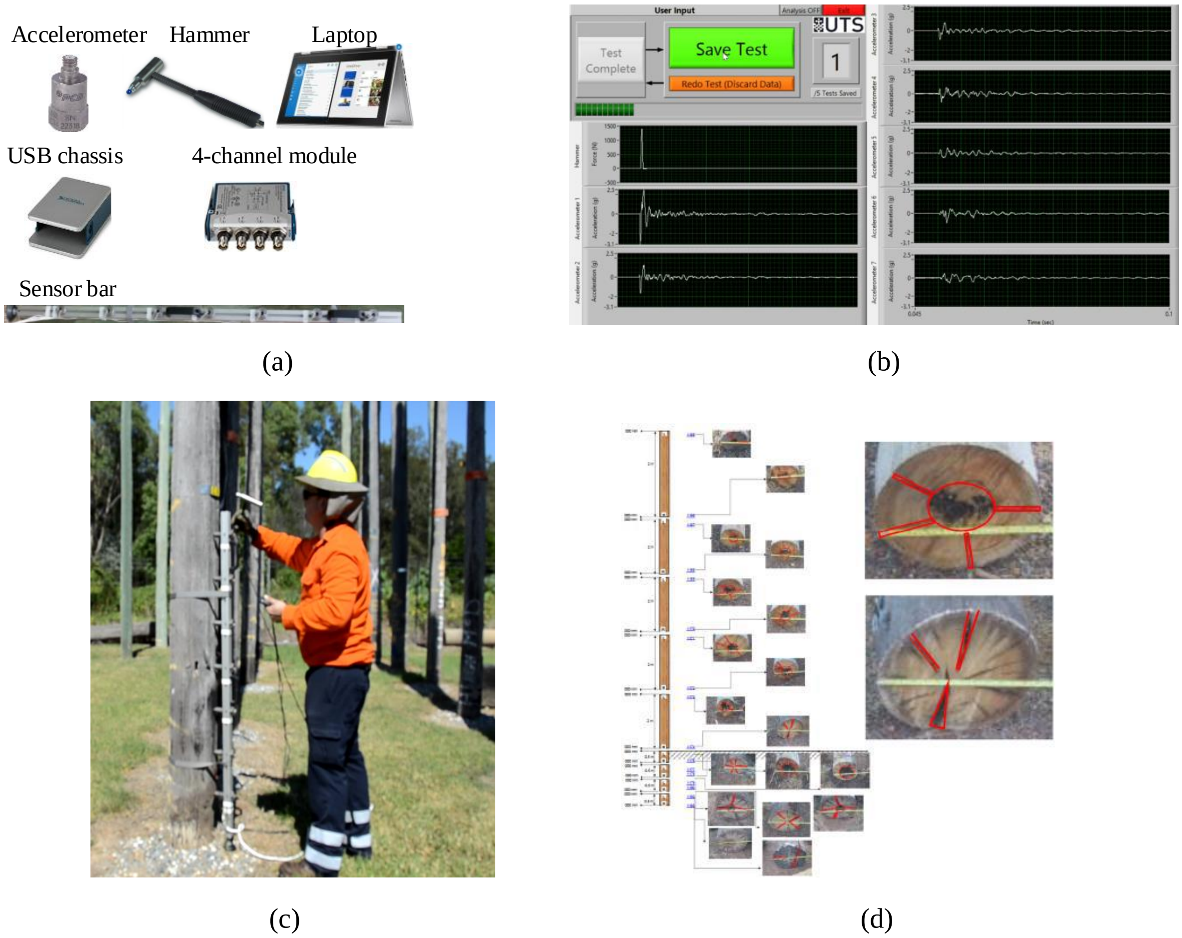

Figure 2. Testing system, field testing and autopsies of utility poles: (a) system makeup, (b) DAQ interface, (c) execution of field testing, and (d) autopsy result of sectioned pole

Using this portable system, 26 timber utility poles were tested at Mason Park in Sydney. For the testing, the sampling frequency was set as 51.2 kHz with half a second duration. To investigate the effect of excitation location on the identification of pole condition, two different impact locations are considered in this study, i.e. front top at 1.8 m height and back bottom at 0.2 m height. For each tested pole, five hammer hits were executed in the transversal direction. As measurements of seven accelerometers were obtained for each test, a total of seventy groups of wave signals were captured for each utility pole. After the testing, the poles were disconnected from the electricity lines and removed from the soil. To determine the individual health status, each pole was cut into multiple small sections along the cross-section using a chain saw. The exposed cross-sectional areas were photographed and analysed, and according to the seriousness of the found damage and deterioration, the poles were divided into two groups: intact and damaged. An intact pole was defined as having only minor or medium damage. A damaged pole was defined as having medium to severe damage with an estimated minimum service life of less than five years. Figure 2 (d) gives an example of the autopsy of a damaged pole.

To process the SW signals, advanced signal processing technique, ensemble empirical mode decomposition (EEMD), is adopted to decompose the original signal into a series of intrinsic mode functions and a residue. For each IMF, feature analysis and extraction should be conducted to get damage-related patterns. In this study, two important parameters of EEMD, amplitude and number of added white noise, are set as 0.2 times of signal standard deviation and 100, respectively. Figure 3 shows an example of EEMD of SW signal collected from front top excitation. After signal decomposition, the captured IMFs are able to portray a series of stable signals on the characteristic dimension, which have their own energy features. Accordingly, first ten energy ratios of IMFs are used as the feature vector to represent damage-sensitive patters of signals.

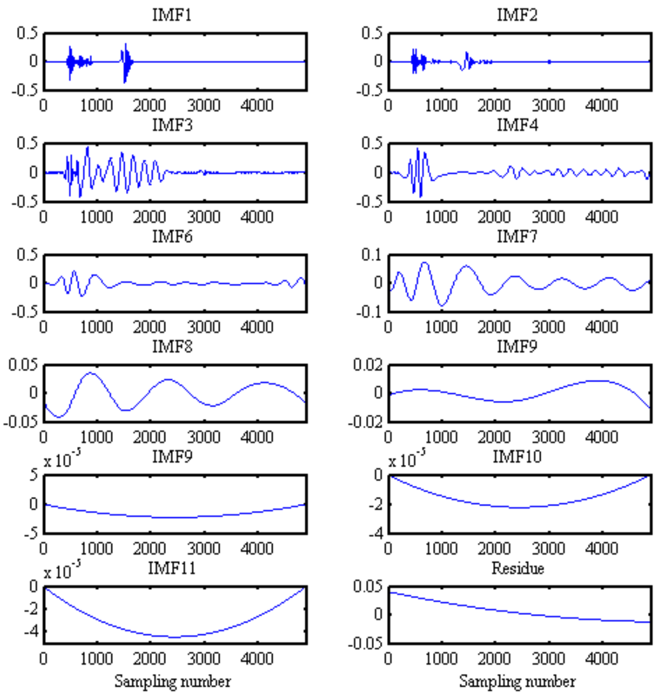

Figure 3. EMD of SW signal of intact pole

Then, the multi-level back propagation neural network (BPNN) is considered to establish the evaluation model corresponding to each sensor and each excitation type, which consists of an input layer, a hidden layer and an output layer. The neuron number in the input layer is set as 10, corresponding to first ten energy ratios of IMFs in the feature vector. The neuron number in the hidden layer is selected as 12 according to the empirical equation. The neuron number in the output layer is 2, denoted by (y1, y2), where y1 and y2 represent the probabilities of damaged and intact conditions, respectively. Consequently, (0, 1) denotes the intact condition while (1, 0) denotes the damaged condition. During the model training, the log-sigmoid function and tan-sigmoid function are selected as transfer functions in the hidden and output layers due to perfect nonlinear prediction abilities. Besides, the heuristic BP algorithm is employed to adjust the learning rate in the course of the training.

In the phase of decision making, the D-S evidence theory was used to combine the results from all the evaluation models related to different sensors and excitations together to get a final decision on pole status. The frame of discernment should be defined first as θ={A1, A2}, where A1 and A2 respectively denote damaged and intact states, corresponding to outputs of ANN model. However, in the evidence theory, the uncertainty Θ is also an important issue to be fixed. In this study, the uncertainty values corresponding to different excitation cases are set as 0.25 and 0.22 according to a great number of simulation trials. Hence, the basic probability assignment (BPA) of evidence can be obtained based on the neural outputs and uncertainty. In this work, two levels of evidence combination are considered: in the first level, the evidences from different excitation sources are combined at each sensor; in the second level, the evidences from different sensors are combined to get a final result of condition assessment.

Table 1. Initial recognition results (BPAs)

BPA	A1	A2	Θ
$m_{1,1}$	0.3652	0.3848	0.2500
$m_{1,2}$	0.4437	0.3363	0.2200
$m_{2,1}$	0.4391	0.3109	0.2500
$m_{2,2}$	0.4506	0.3294	0.2200
$m_{3,1}$	0.3672	0.3828	0.2500
$m_{3,2}$	0.3883	0.3917	0.2200
$m_{4,1}$	0.4122	0.3378	0.2500
$m_{4,2}$	0.5376	0.2424	0.2200
$m_{5,1}$	0.3583	0.3917	0.2500
$m_{5,2}$	0.3928	0.3872	0.2200
$m_{6,1}$	0.4941	0.2559	0.2500
$m_{6,2}$	0.5479	0.2321	0.2200
$m_{7,1}$	0.4575	0.2925	0.2500
$m_{7,2}$	0.5606	0.2194	0.2200

Table 2. First evidence combination

BPA	A1	A2	Θ
m_1	0.5001	0.4220	0.0779
m_2	0.5692	0.3539	0.0769
m_3	0.4529	0.4694	0.0777
m_4	0.6217	0.3017	0.0766
m_5	0.4492	0.4731	0.0777
m_6	0.6931	0.2331	0.0738
m_7	0.6760	0.2492	0.0748

Table 3. Second evidence combination

BPA	A1	A2	Θ
m	**0.9450**	0.0550	0

A damaged pole is randomly selected as the validation sample to assess the performance of the proposed method. Table 1 gives the BPA results after initial recognition from all the sub-ANN models. It is noticeable that part identification results from sensors 1, 3 and 5 disagree with the practical status of the tested pole (damaged). Besides, most differences between 'damaged' proposition A1 and 'intact' proposition A2 are less than 0.1, which makes the models difficult to make robust decisions. The main reason contributing to this phenomenon are limited training samples that cannot comprise all damage cases. Table 2 shows the BPA combination results at each sensor. It is clearly seen that $m_3(A1) < m_3(A2)$ and $m_5(A1) < m_5(A2)$, which means that the results from sensors 3 and 5 are still in contradiction with that from other sensors. As a result, it is still difficult for the system to make a final decision. Table 3 displays the combination result of BPAs from all the sensors. It is noted that the BPA of right proposition (A1) has increased from around 0.4 to 0.9450 via two evidence combinations. In the meanwhile, the uncertainty has decreased from 0.25 to 0. Obviously, the final assessment result is A1 (damaged). As a result, it follows that the confidence probability of final decision is greatly improved via multi-level evidence combination.

Conclusions

This study proposed a novel method based on multi-sensor data fusion for evaluating the health condition of timber utility poles. First, advanced signal processing method, such as EEMD, is employed to process the noise-polluted SW signals for the extraction of damage-sensitive patterns. Then, ANN models were established for initial recognition of the pole status. Finally, D-S evidence combination method was used to combine initial results from all the sensors to make a final decision. To validate the capacity of the proposed method, timber utility poles were evaluated in the field using a portable NDE system with the proposed method for signal processing. The result shows that the data fusion method can effectively enhance the identification accuracy and avoid the inaccurate recognition by a single sensor.

Expectation-Maximization (EM) Algorithm Embedded Statistical Structural Damage Prognosis

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Structural damage prognosis is a technique by which the future performance of an in-service structure can be predicted. Conventionally, it was frequently carried out by resorting to the knowledge of fracture mechanics as typically the problems in issue were related in some way to the propagation of cracks. Examples include the fatigue performance of aircraft, the prediction of the remaining service life of boilers, the structural integrity evaluation of pipelines, etc. As far as a wide variety of civil structures are concerned, apparently there is a need to complement the existing approach and look for a relatively uniform way to form the damage prognoses. Probabilistic and statistical techniques make a niche in this regard.

A salient feature of structural damage prognosis is that it often involves structures that have been in service for some time and may thus have varying degrees of structural damage. Although structural damage diagnosis in general provides an effective way to detect, locate, and quantify the existing damage, it has been recognized that on some occasions only incomplete structural damage diagnosis data are available. Indeed, the relevant damage diagnosis data may become incomplete when an unexpected breakdown happens in the data acquisition system, when outages occur during the data transmission, or when vandalism arises. A recent study showed that the data missingness events

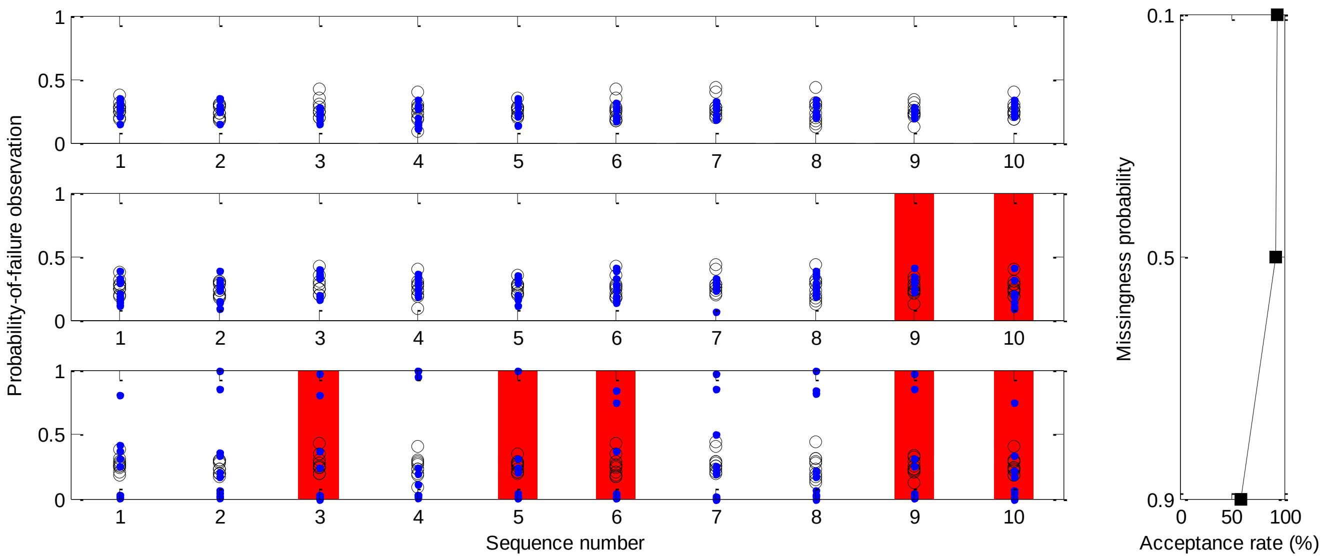
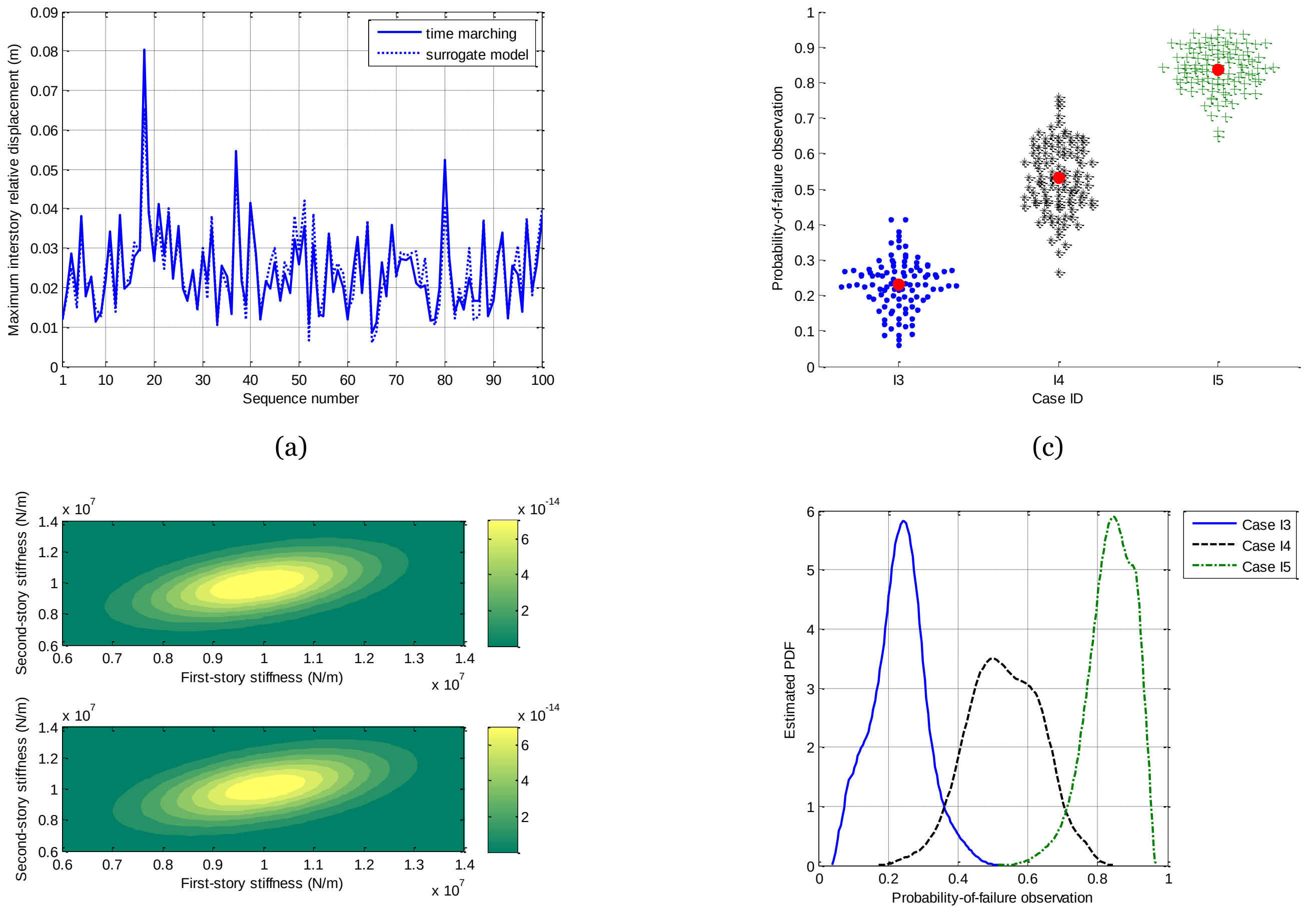


Figure 1. Validation using a generic performance function
(Reproduced with permission from ASCE)



(a) (c)

(b) (d)

Figure 2. Damage prognosis performed for a nonlinear hysteretic structure subjected to catastrophic wind loads (Reproduced with permission from ASCE)

possibly associated with the structural damage diagnosis can, for the purposes of the ensuing structural damage prognosis, be allowed for and dealt with by using a statistical procedure known as the expectation-maximization (EM) algorithm. Figure 1 illustrates the validation of the EM algorithm embedded damage prognosis scheme based on a generically formulated performance function. A specific application of the scheme, viz. the damage prognosis with respect to a nonlinear hysteretic structure under catastrophic wind loads, is demonstrated in Figure 2: The efficacy of the constructed surrogate model for improved computation efficiency is shown in Figure 2(a); Figure 2(b) compares the joint probability density functions of two critical structural parameters in the complete- and incomplete-data scenarios; the resulting probability-of-failure samples are presented in Figure 2(c); and finally the estimated probability density functions related to the safety performance of the hysteretic structure on different occasions are plotted in Figure 2(d). More details of this study can be found in the paper 04015090 in Issue 3, Volume 142 of Journal of Engineering Mechanics, ASCE (http://dx.doi.org/10.1061/(ASCE)EM.1943-7889.0000969).

Rehabilitation of timber -adhesive system by applying smart chemical fillers against environmental degradation

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[2] *Discipline of Civil and Environmental Engineering, The University of New England, Armidale NSW 2351, Australia.*

Timber bridges are exposed to different environmental stresses such as UV irradiation coming from sunlight and moisture coming from rainfall (Figure 1). There are several solutions to reduce environmental degradation, such as repairing or coating by epoxy in order to protect timber from UV irradiation and moisture. However, the durability of the solutions particularly the stability of structural adhesives applied to timber is not well understood. In addition, modifying structural epoxy systems and developing monitoring technique to reinforce and increase the longevity of the timber are necessary.

This project develops an experimental design to address those concerns in timber structure. The first part focuses on evaluation of two epoxy systems, saturated (HDGEBA) and unsaturated (DGEBA) respectively (Figure 2), under an artificial accelerated weathering cycle (UV irradiation and moisture condition) over different periods of time, followed by chemical and mechanical tests. The experimental setup for on-going long-term durability tests is shown in Figure 3. The results showed that saturated epoxy appears to be more resistant to UV irradiation and moisture but has lower tensile strength before exposure than unsaturated epoxy. However, the tensile strength of unsaturated epoxy is retained better on exposure to artificial weathering (Figures 4, 5, 6, and 7).

The second part of this project includes adding multi walled carbon nanotubes (MWCNTs, Applied Nano Technologies) which were treated with nitric Acid (70%) and refluxed overnight to provide a functional group (carboxylic group), microcrystalline cellulose (MCC, Asahi Chemical Industry), or calcium sulfate whisker (CSW, Sigma-Aldrich) to the two epoxy systems. This allowed comparison all exposed specimens before and after exposure to accelerated conditions. Preliminary results before exposure to accelerated weathering showed a significant improvement in strength with incorporation of 0.5% MWCNTs.

The two commercial epoxies employed were Sikadur 330A (diglycidyl ether of bisphenol A) as saturated epoxy and Epalloy 5000 (hydrogenated diglycidyl ether of bisphenol A) as unsaturated epoxy. The two epoxies were mixed with a curing agent Sikadur 330B (tri methyl 1,6-hexadiamine) by 4:1 ratio and cured in an oven in 50^{o}C, 5 h for unsaturated epoxy and 8 h for saturated adhesive. After curing epoxy adhesive samples were exposed to artificial weathering in a laboratory UV chamber (UVA-340nm fluorescent lamps) and a moisture chamber (50±5 °C). The exposure cycle started from 168 h, 336 h, 504 h, 720 h, and 1008 h respectively. The second stage includes adding different fillers (0.5% MWCNTs, 2%MCC, and 2%CSW) to two epoxy systems and exposed to artificial weathering for the same conditions that use for two epoxy systems. Tensile tests of the weathered epoxy and epoxy–filler composite samples were carried out by using a universal Instron machine according to ASTM D 638 in order to compare with weathered samples. The purpose of the tensile was to determine the relationship between tensile strength and increasing exposure of samples for different accelerated weathering times by UV irradiation and moisture conditions.

In summary, the accelerated environmental degradation tests carried out show that a saturated adhesive (Epalloy 5000) is more resistant to accelerated weathering, but its tensile strength is lower than that of the unsaturated adhesive (Sikadur 330A), while the incorporation of MWCNTs, MCC, and CSW fillers improves and gives more resistance against the loss in tensile strength before and after exposure compared with epoxy systems without fillers.

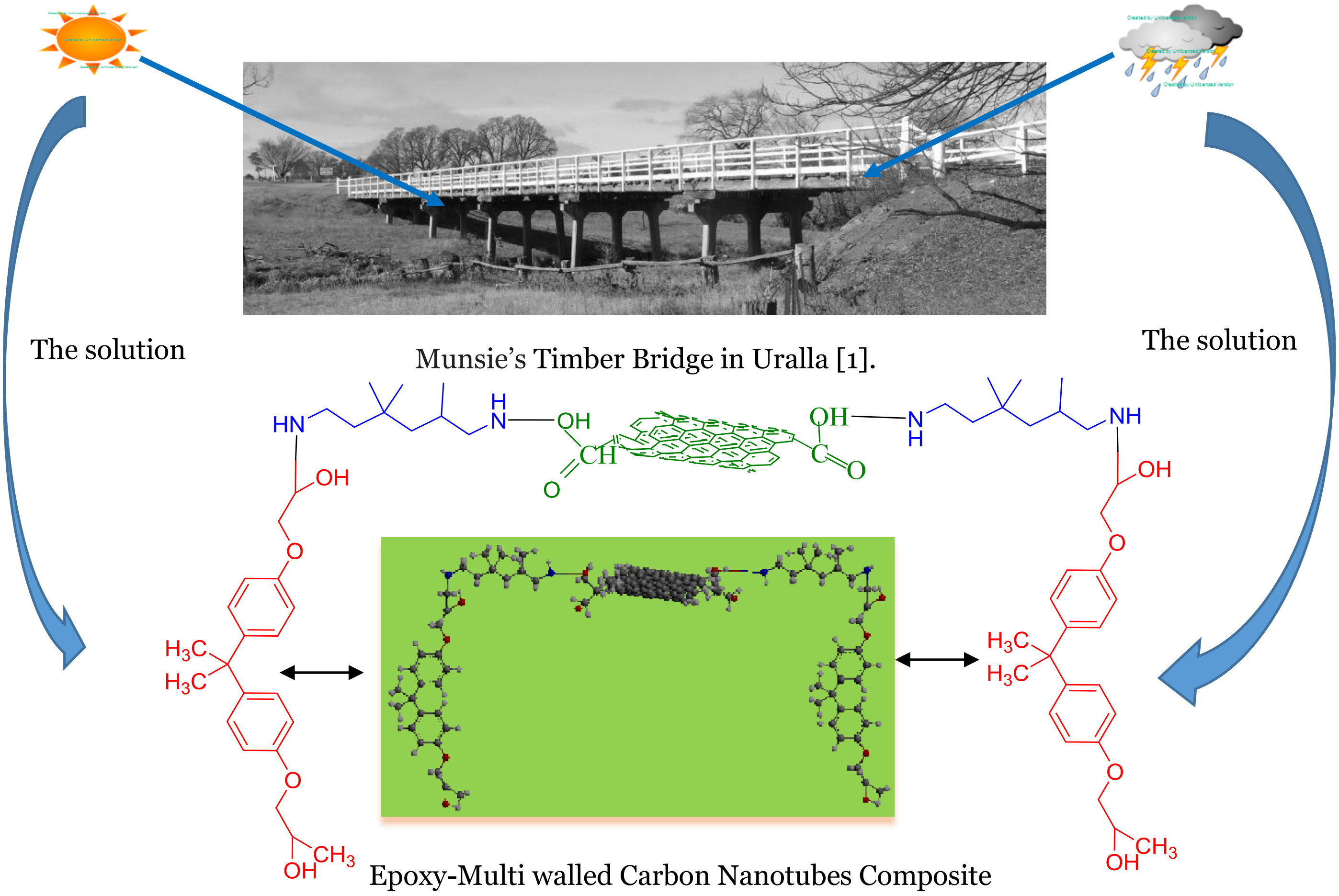

Figure 1: The problem of continued exposure to accelerated weathering and solutions

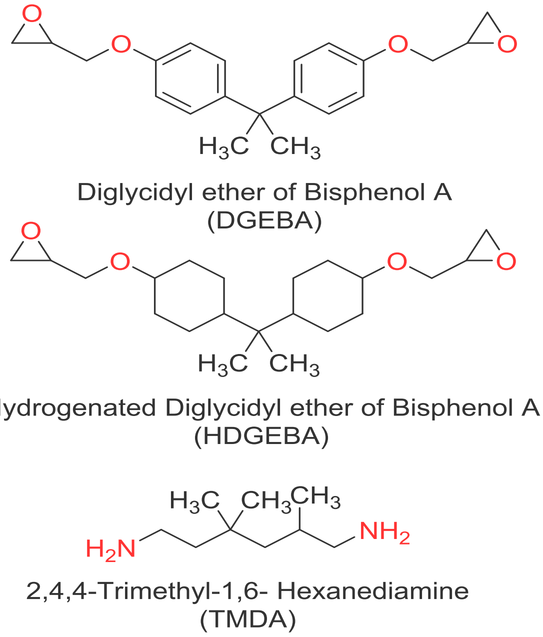

Figure 2: Chemical structures of experimental materials

Adhesives are reinforced by MWCNT [2]

UVA chamber

Moisture chamber

Figure 3: Scheme of artificial accelerated weathering cycle of adhesives during exposure to UV and moisture exposure

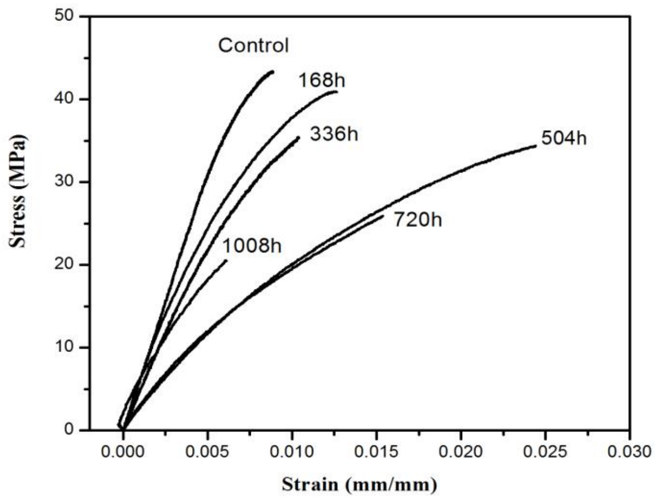

Figure 4: Tensile -stress curves of Sikadur 330 A with a curing agent for different accelerated times.

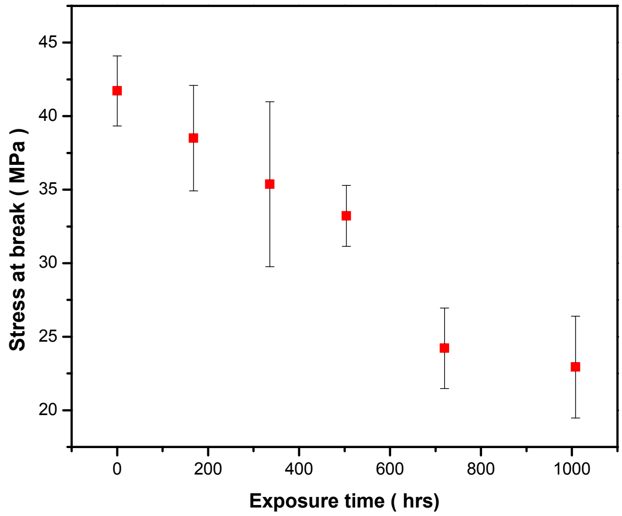

Figure 5: Stress at break curve versus different accelerated times

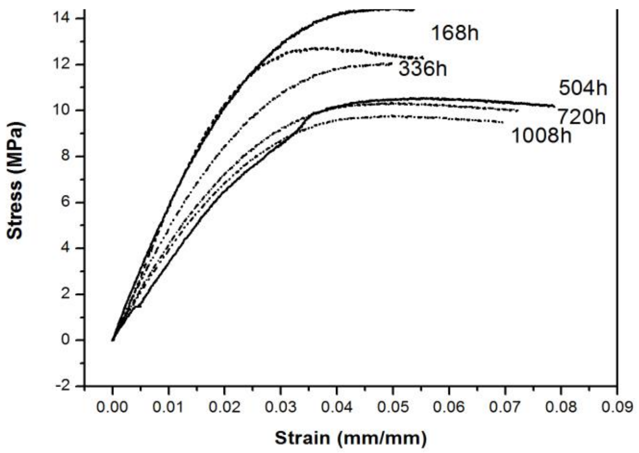

Figure 6: Tensile -stress curves of Epalloy5000 cured with curing agent (unsaturated epoxy) for different accelerated weathering times

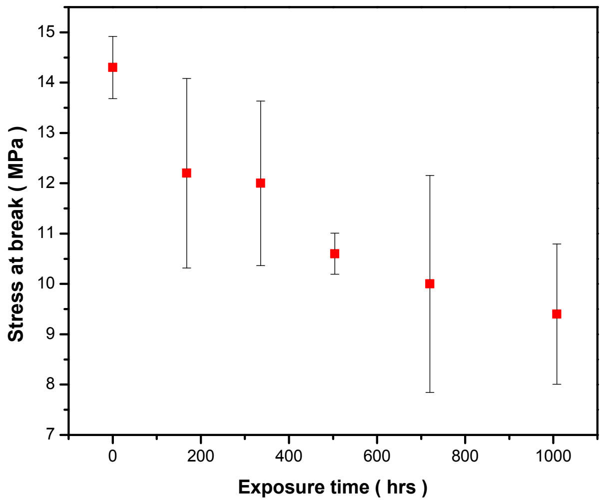

Figure 7: Stress at break curve versus different accelerated times

References

[1] JC. Moore, S. Mahini, R. Glencross-Grant and R. Patterson, Structural health monitoring of older timber bridge girders using laser-based techniques, *Austr. J. Structural Eng.*, 2015. 23: 14(1): p.28.

[2] N. Fasanella and V. Sundararaghavan, Atomistic modelling of thermomechanical properties of SWNT/Epoxy nanocomposites, *Modelling Simul. Mater. Sci. Eng.*, 2015. 23: p.1-16.

Conference Information

- ANSHM mini-symposium in the ***24th Australasian Conference on the Mechanics of Structures and Materials (ACMSM24),*** 6-9 Dec 2016, Perth, WA. Organized by Prof. Tommy Chan, Prof. Jianchun Li, and Dr. Jun Li.
- ***The 8th Annual ANSHM workshop***, 29-30 Nov 2016, Monash University, Melbourne, Australia. Organized by Dr. Colin Caprani of Monash University.
- ***Structural Health Monitoring of Intelligent Infrastructure Conference 2017,*** 6-8 Dec 2017, Brisbane, Australia. Organized by ANSHM. (http://shmii2017.org/)
- ***6th Asia-Pacific Workshop on Structural Health Monitoring***, Hobart, Tasmania, 7-9 December 2016 (http://eng.monash.edu.au/mechanical/shm/)
- Joint COST TU1402 - COST TU1406 – IABSE WC1 Workshop, ***The Value of Structural Health Monitoring for the reliable Bridge Management***, Zagreb, Croatia, 2-3 Mar 2017 (http://www.grad.unizg.hr/joint-zagreb-workshop)

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