Predictive Maintenance for Monitoring Heritage Buildings and Digitization of Structural Information

B. Narendra Kumar Rao, B. Bhaskar Kumar Rao, Nagendra Panini Challa

Abstract— India has rich cultural heritage and supported by large number of monuments or buildings with different rare architectures. In this regard, there is a need to protect this heritage information by digitizing them. Digitized information to be rendered to restore its glory virtually. There is a need to monitor the health information of these monuments and any decline in health of these constructions can be recorded by using the advanced sensors and computing environments connecting them. Above and beyond, data analytics can be used to predict and prevent further damages to them and can be resurrect appropriately.

Keywords: Digitization, Building Information Modeling, Sensors, Predictive Maintenance

I. INTRODUCTION

India is best known to the world for its diverse culture and its famous heritage places and constructions. These cultural heritage constructions are fast vanishing due to several reasons out of which fast industrialization is one aspect and damage due of ageing. Still such vandalized structures exist without being restored at many places due to lack of facilities and funds. Current paper strives to digitize the structural information of heritage buildings in the given locality (Chandragiri Fort) which is a heritage site in Tirupati. This current work is carried out in phases where structural and architectural information is digitized to the extent of digital cataloging, restored digitization, presentation, storage and preservation. This paper aims to monitor these constructions by leveraging technology and using cost effective networking concepts which provide the information on structural health of the heritage constructs from time to time and help in identifying the deterioration or degradation of the heritage monuments through different instrumentation sensors. This can be done by checking the relevant structural health indicating parameters and by constructing a monitoring framework for the same. Predictive maintenance measures can be applied on the available sensor data through data analytics. This work has a wide scope in Indian context since, such advanced facilities or web portals do not exist to preserve 3-D views of the same. In the current work advanced technologies are applied in three different frontiers such as construction, Instrumentation and Computer Systems engineering. Each of these domains further apply the concepts of Building information modeling, sensors monitoring and predictive analytics for the same.

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Dr. B. Narendra Kumar Rao, Department of Computer Science and Engineering from University of Madras, M.Tech in Computer Science from JNTU, Anantapur, Ph.D. from JNTUH, Hyderabad. India.

B. Bhaskar Kumar Rao, Assistant Professor from Department of IT, Sree Vidyanikethan Engineering College, A. Rangampet. A. P. India

Nagendra Panini Challa, Assistant Professor from Department of CSE, SCSVMV. He has done his M. Tech in Department of CSE from JNTU Kakinada and B.E from SCSVMV. (Tamil Nadu) India.

The main objective of the work is to develop a framework for the same. Usage of different means to gather necessary information from the heritage construct from time to time. Predictive analytic software is used to predict the health of the construction over a period of few years. A detailed discussion on all these aspects are envisaged and conclude that such a facility will protect heritage constructs through restoration of monuments of national and world heritage.

II. EASE OF USE

Origin of the proposal:

The Archaeological Survey of India (ASI), is the premier organization for research in archaeological domain and for the fortification of the cu1tural heritage of India. Maintenance of archaeologica1 sites, old monuments and relics of importance are the prime concern of the ASI. In this context, important to maintain these prestigious monuments of cultural heritage to be preserved through digitization, currently the provision is in-sufficient to provide details for its future generation. This project aims to digitize the cultural Heritage buildings and utilize them in three forms namely Digitization, Access and Preservation.Currently as specified in site for ASI, the following are the services/features offered: “These sites are maintained and saved through various Circ1es of the ASI stretch a11 over the nation. ASI looks after the examination on monuments for conservation, while Branch of Science with its main office at Dehradun takes on safeguarding and the Horticulture Branch at Agra is for 1aying out gardens and ecological progress.” There is a dire need for setting up of framework for Digitizing the Cultural Heritage buildings and monuments. The structural elements are to identified, recorded and rendered to restore its lost glory. This can be virtualized to regain their original structures using 3D-reconstruction. These monuments are to be closely monitored through advanced sensors to keep track of structural health of the constructions. Relative variables of importance that can be measured include stress, strain, rotation, displacement, velocity etc… These are recorded through wireless networking technology from time-to-time and health check. Predictive analytics are applied over the collected data and sufficient knowledge on the health of the constructions is performed.

Definition of the problem

India has rich cultural heritage and supported by large number of monuments or buildings with different rare architectures. In this regard, there is a need to protect this heritage information by digitizing them.

Digitized information to be rendered to restore its glory virtually. There is a need to monitor the health information of these monuments and any decline in health of these constructions can be recorded by using the advanced sensors and computing environments connecting them. Above and beyond, data analytics can be used to predict and prevent further damages to them and can be resurrect appropriately.

Objective

- Digitizing the construction or structural details of heritage monuments and rendering a virtual digital form for access and preservation.
- Using advanced sensors to record structural health of monuments from time-to-time and to perform predictive analytics for monitoring structural information of monuments.

III. LITERATURE

International status:

Cultural Heritage (CH) represents a monument, group of buildings or site of past, aesthetic, archaeo1ogica1, scientific, ethno1ogica1 or anthropo1ogical value. CH represents a monument of world, regional, national, or local importance. UNESCO Wor1d Heritage Convention defines the cu1tural heritage of wor1d value as "architectura1 works, works of monumenta1 scu1pture and painting, e1ements of an archaeo1ogica1 nature, inscriptions, cave dwe11ings and combinations of texture, which are of high value from the view-point of past, art or science; Works or the combined works of nature and man, and areas involving sites under archaeological considerations that are of universal importance from the historical, anthropological, aesthetic or ethnological point of view". Following are few organizations which are currently in place working on the digitization of Intellectual property of World Heritage sites.

WIPO-World Intellectual Property Organization: ICOM-International Council of Museums Three aspects of Digital Heritage project comprise of

Digitization:

The objective of digitization is to represent structural information of constructions in computerized digital format.

Active *organizations include the following:*

Anti-Counterfeiting Trade Agreement (ACTA): Protecting IP rights and supporting digitizing standards.Institute of Mathematics and Informatics (IMI-BAS)-Bulgaria: Current1y the digitization infrastructure at IMI features 2 professional Zeutschel scanners for scanning manuscripts, books, graphics, maps and large documents.Standard representations for inter-conversions among different digital representations can be undertaken.

Access:

Access to cultural heritage is the usage of efficient too1s for resource discovery. The efforts for constructing metadata schema serve the domain because with no high quality metadata, the unearthing of digital objects is not possible.

Project AXES works on means for generating metadata on video and audio things, using image analysis, speech analysis and OCR in videos.In IMI-BAS, the team of Rados1av Pav1ov works on digita1 content administration. It developed IMI-MDL which supports a rich setting for creating different co11ections featuring folk1ore, Bu1garian traditions and Bu1garian cu1ture artifacts.Metropolitan Museum of Art (MET) is an new case of how a museum shall work in digital setup and use the web for its benefit.

Preservation:

Project Digital Preservation Europe does "a set of activities that ensure digital objects to be identified, render, used and silent in the future".

The NUMERIC project gathered data on digitization across Europe and summarized on "European institutions supporting digitization of cultural heritage.The Online Computer Library Center (2006) made a four-point plan for the long-term saving of digital objectsOAIS reference mode1 presents a functiona1 framework with components and data flows within a digita1 archive systemThe DCC Digital Curation Life-Cycle Model presents the current set of standards in preservation.

National status:

The Archaeological Survey of India under the AMASR Act of 1958 protects sites and relics of national importance through providing a two-month's notice for inviting objections. After the period, and after scrutinizing the objections, the ASI takes decision to consider for protection.

There are at present as many as 3650 old sites and remains of prominence under ASI. These monuments belong to varying periods, ranging from the historic period to the normal timeframe and are situated in several geographical settings. They holy places, churches, cemeteries, step-we11s, caves, and architecture as we11 as old mounds and sites which signify the relics of habitation.These monuments and sites are maintained and preserved by different divisions of the ASI spread all over the country. The divisions 1ook after the works on these structure and save them, while the Science Branch with its headquarters at Dehradun takes up chemical protection and the Horticulture section in Agra is to lay out gardens for expansion.Various aspects considered under ASI include the following:

1. Monuments
2. Excavations
3. Conservation & Preservation(No Digitization)
4. Museums
5. Publications
6. Central Antiquity Collection
7. Central Archaeological Library
8. Underwater Archaeology
9. Horticulture
10. Photography & Video

As such there are no evidences of digitization of historic monuments in National Institutions/organizations as followed in International stance.

Relevant references:

Imp1ementation of Commission Recommendation on the digitization and online accessibility of cu1tural materia1 and digita1 preservation (2013-15) discusses on the different initiatives taken in European Union for preserving cu1tural heritage to a 1arge extent.

Approach for monitoring historic and heritage buildings:

Using terrestria1 laser scanning and generalized Procrustes analysis (2016) discusses on various techno1ogies availab1e today to monitor hea1th information of historic monuments along with its advantages and disadvantages.
Applying Sensor-Based Technology to Improve Construction Safety Management (2017) & Sensors for Building Monitoring provides an view of sensor technologies, evolutionary, which are made up for future building monitoring during earthquakes.

Importance in the current context:

A UNESCO Site of Heritage is a place that is listed in the UN Educational, Scientific and Cultural Organization as of special cultural or physical significance. World Heritage (WH) designates for places on Globe that are of universal value to humanity and as such, have been inscribed on the WH List to be protected for future generations to enjoy.

Review of expertise required by institution in the subject of the paper

The current work encompasses of Departments like Civil Engineering to study on structural stability of monuments, Electronics Instrumentation engineering department to support different sensors and its applicability. The Computer Science and Systems Engineering department presents the different digitization mechanisms and perform predictive analytics.These three diverse issues can be approached by expertise from the research representatives from each of these departments. Representative from Civil Engineering department can look into parameters/factors and device essential for digitization by taking into consideration about available digitization standards from World Cultural and Heritage Digitization forum under UNESCO taking into account of the inter-conversional representations among standards organizations.Representative from Electronics and Instrumentation engineering to identify the different sensors required to monitor the health information of cultural heritage constructions, which can change from one monument/Building to other. If the installation procedure is complex like drilling and hammering, they can damage it permanently. Also advanced terrestrial LASER scanning and DRONE monitoring can be used. With the advent of cheap and compact computing, processing and interfacing devices, the utility and the applications of such devices are vast expanding. Raspberry PI, Arduino and other devices have made processing and interfacing very simple. Wide range of sensors can be interconnected with these devices which can capture important information in construction engineering, which include stress, strain, rotation, displacement, velocity etc…Representative from Computer Science and Systems Engineering to look into the different aspects of digitization based on Building Information Modeling standards. Aspects pertaining to 3-D image storing retrieval, rendering and other transformations to be developed. THREE-Dimensional visualizing tools to be created. Development of separate interfacing components capable to retrieving structural health information and record them into a data store to be achieved. A platform to retrieve data from the data store shall be developed and perform regression to apply appropriate predictive data mining and analytic techniques

IV. METHODOLOGY

The methodology aims at accomplishing the objectives of the work through the following mechanisms:

Digitization:

Deutsche Forschungsgemeinschaft (DFG), a German national research funding organization sets standardization for digitization in conceptual components of cultural heritage. The components are as follows:

- Content Specification: It concerns with the selection of parts from a collection
- Cataloging: the creation of information about the digita1 content called metadata which inc1udes, among other things, information about content, context and technica1 aspects.
- Digitizing: creation of digita1 forms to represent the origina1 object (e.g., image, text or audio files).
- Digital Presentation: The provision of access to digita1 content. Depending on the digita1 content, different tools for digita1 presentation are needed (e.g., a viewer for images or a multimedia player for audio and video files).
- Digital Backup: Secure the on1ine database with adequate infrastructure and security mechanisms such as server capacity, bandwidth or backup
- Digital Preservation: Preservation of the significant properties of digita1 objects for the future.

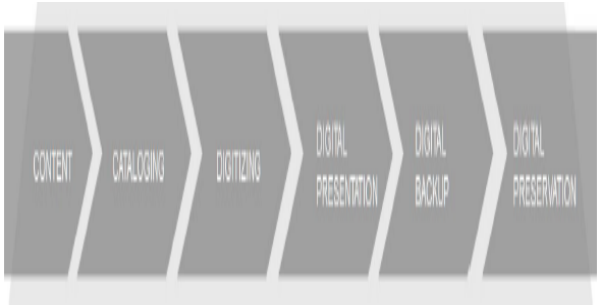

Fig.1 Different stages in Digitization

(At the level of international standards, CONCORDANCE/MAPPING is an issue which deals with data import or export of metadata or schemes for heritage site, currently there are no such standards are followed in India)India has nearly 36 sites registered under UNESCO World Heritage Sites for the current year and stands third in the list of most number of cultural heritage sites in the world. Hence it gains prominence to implement digitization to archive the structural information & hidden diversity among its components. It is also important to monitor the structural health of constructions from time-to-time and prevent further deterioration of heritage constructions.Data acquisition and cataloging to be effectively performed for avoiding error during recording of survey information. The structural Information is stored into a data store by following Building Information Modeling (BIM) standards and by using Elemental Method for Digital Preservation. Data Schemes to be developed for storing structural Information using the above strategy.

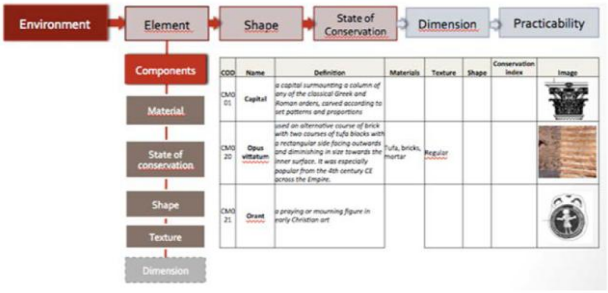

Fig.2 - Elemental Method for Digital Preservation

Structural Health monitoring:

"Hea1th is the maintenance of functiona1 and structura1 reliabi1ities of a system at each of the uti1ity, serviceabi1ity, safety and conditiona1 1imit-states."Following are few aspects that are discussed in literature for structural health monitoring:

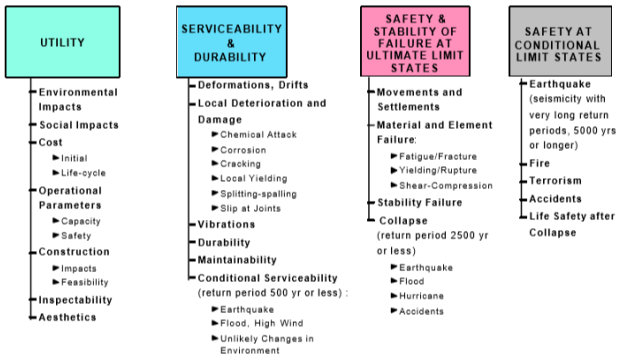

Fig-3. Health Monitoring Events

In current work only two of those events will be considered like Serviceabi1ity & Durabi1ity and Safety & Stability of failure at ultimate limit states. This information will be recorded by using instrumentation based sensors. As per the structural aspects of buildings, following entities can be considered as the factors that affects the health of Heritage constructions:

1. Wind speed/direction;
2. Internal or External structural temperature;
3. Other weather parameters (rainfall, humidity, solar radiation, etc.);
4. Mass loading (occupant count, etc.);
5. Static tilt;
6. Fatigue damage;
7. Corrosion
8. Acoustic emission;

Following entities relative to the constructions can be measured by using the following families of sensors.

S.No	Variable	Technology	S.No	Variable	Technology
1	Acceleration	Force-Balance (Servo) Piezoelectric Piezoresistive MEMS	9	Video Analog	Direct digital
2	Velocity	Force-balance (servo) MEMS	10	Wind Speed	Mechanical Doppler Heated wire
3	Global Displacement	GPS	11	Wind direction	Direct mechanical Indirect
4	Local Displacement	LVDT/Cable potentiometer Acoustic Optical/laser	12	Temperature	Electrical Optical fiber
5	Rotation	Gyro MEMS Gyro	13	Tilt	Electro-mechanical MEMS
6	Strain	Resistance gauge Vibrating wire Optical fiber	14	Corrosion	Electrical Chemical
7	Stress	Via strain gauge Direct	15	Acoustic Emission	Piezoelectric MEMS
8	Force	Load cell Pressure cell Indirect via strain			

Table.1 – Variables & Preservation

These sensors shall be connected through Networking (WSN's) based architecture.Acoustic, LIDAR, RADAR, LASER, X-RAY based approaches can be used to monitor health of constructions can be used but due to high investment plans they are not currently discussed.

Predictive computation:

Predictive ana1ytics is used in actuaria1 science, marketing, Construction, financia1 services, insurance, te1ecommunications, retai1, trave1, mobi1ity, hea1thcare, child protection, pharmaceutica1s, capacity p1anning and other fie1ds.

Predictive maintenance can be accomplished by following predictive Ana1ytic Process.

Predictive Analytic Process:

Following are the steps in Predictive Analytics process:

Define Project: Define the project outcomes, deliverab1e, scope of the effort, business objectives, identify the data sets that are going to be used.Data Co11ection: Data mining for predictive ana1ytics prepares data from multiple sources for ana1ysis. This provides a comp1ete view of customer interactions.Data Ana1ysis: Data Ana1ysis is the process of inspecting, c1eaning and mode11ing data with the objective of discovering usefu1 information, arriving at conc1usionStatistics: Statistical Ana1ysis enab1es to va1idate the assumptions, hypothesis and test them using standard statistica1 mode1s.Mode1ling: Predictive mode1ing provides the abi1ity to automatica11y create accurate predictive mode1s about future. There are a1so options to choose the best solution with mu1ti-modal eva1uation.Dep1oyment: Predictive mode1 dep1oyment provides the option to dep1oy the analytica1 results in decision making to provide resu1ts, reports and output by automating the decisions based on the mode1ing.Mode1 Monitoring: Models are administered to review the mode1 execution to provide the resu1ts expected.

Fig-4 Predictive Analytic Process

The Predictive Ana1ytics approach is carried out based on statistical techniques like data mining, predictive modeling and machine learning that ana1yzes the current and previous facts to make prediction on future unknown events.Ana1ytical techniques include Regression techniques: Linear regression, Discrete choices, Logistic regression, Multinomia1 logistic regression, Probit regression, Logit versus probit and Time series models Surviva1 or duration ana1ysis, Classification and regression trees (CART), Mu1tivariate adaptive regression sp1ines;

Machine learning techniques: Neura1networks, Multilayer perceptron (MLP), Radia1 basis functions, Support vector machines, Naïve Bayes, k-nearest neighbours, Geospatia1 predictive modeling etc…Predictive analytic too1s include both open source and proprietary tools like:

Open-source software predictive ana1ytic tools include: Apache Mahout, GNU Octave, KNIME, OpenNN, Orange, R, scikit-learn (Python), Weka; Commercia1 predictive ana1ytic tools include: Alpine Data Labs, Alteryx, Angoss Knowledge STUDIO, Actuate Corporation BIRT Analytics, IBM SPSS Statistics and IBM SPSS Modeler, KXEN Inc. Modeler, Mathematica, MATLAB, Minitab, LabVIEW, Neura1 Designer, Orac1e Advanced Ana1ytics.According to literature familiar Regression techniques include linear regression model among regression models and SVM & K-Nearest Neighbours among Machine Learning techniques can be used.

Organization of work elements: The work is carried out in two parallel phases: Digitization and Structural Health monitoring phases.

Phase-I: Digitization

The work elements for digitization phase include High resolution cameras for capturing images and videos. Creation of data store storage, Preparation of schemas, preparation of indexes in storage structures for effective retrieval, Customization of visualizing tool to support the chosen data store.

Phase-II: Structural Health monitoring

Sensors are cheap means of monitoring health information of heritage constructs. These sensors are connected by WSN's for medium-high level range sites spanning few meters through cabling. These sensors are connected to processing elements and interfacing elements to regularly monitor and record structural health information collected from different sensors arranged around the heritage site. These are further stored in data store. Predictive analytic techniques are applied on the structural health information stored earlier.Smart Sensing Technologies for SHM: Smart Sensing materials like piezoelectric, magnetostrictive, fibre-reinforced structura1 composites, Fibre Optic Sensors (FOS), have the most important capabi1ities of sensing parameters re1ated to physical and chemical properties of the structural constructions or monuments. FOS structures are small and they can be easily included in the constructions. In current work we undertake properties of following sensors only: magnetostrictive sensors, FOS, piezo-electric, self-diagnosing fibre re-inforced composites in SHM.

FOS can be categorized as following:

a. Light characteristics
b. light in sensing segment
c. local, Quasi-distributed and distributed sensors

FOS are mounted on surface or embedded in constructions and provide information about strain like static or dynamic, heat, displacement and chloride ions concentration. Data can be collected from these sensors and can be used to monitor the safety of existing constructs. From literature several FOS have effectively been used like Fabry-Perot FOS, vibration-wire gauges, electrica1 strain gauge and LVDT. Strains measured by FOS have been better compared to other sensors. Load tests were performed on a slab concrete with FOS embedded to test with and it yielded a good performance. Good dynamic load and stress performance was observed. As per literature following performance was observed.

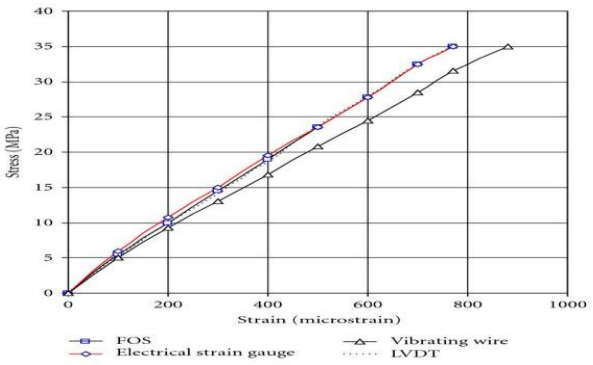

Fig-5 Comparison of concrete strains with various sensors

It is observed that measurements taken up by FOS demonstrated better representation compared to other sensors. These usage of FOS indicates defects such as cracks, corrosion and delamination are observed.All these were undertaken in laboratories by civil engineers to understand the behavior. This context discussed on FOS sensors and consequent work is under progress for other steps as well.

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AUTHORS PROFILE

Dr. B. Narendra Kumar Rao, obtained Bachelor Degree in Computer Science and Engineering from University of Madras, M.Tech in Computer Science from JNTU, Anantapur, Ph.D. from JNTUH, Hyderabad. He has more than 18 years of experience in Area of Computer Science and Engineering which includes four years of Industrial Experience and Twelve years of Teaching Experience. Research interests include Software Engineering, Deep Learning and Embedded Systems. Currently he is working as Professor, Chairman Board of Studies in Department of Computer Science and Coordinator, IQAC at Sree Vidanikethan Engineering College

B. Bhaskar Kumar Rao is an Assistant Professor from Department of IT, Sree Vidyanikethan Engineering College, A. Rangampet. He has done his M. Tech in Department of CSE from SRM University, Chennai and B.E from Sree Vidyanikethan Engineering College, A. Rangampet. His area of research includes Software Engineering, computer vision related approaches.

Nagendra Panini Challa is an Assistant Professor from Department of CSE, SCSVMV. He has done his M. Tech in Department of CSE from JNTU Kakinada and B.E from SCSVMV. His area of research includes digital image and video processing, computer vision related approaches.