DESIGN OF AUTONOMOUS STRUCTURAL HEALTH MONITORING SYSTEM

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Abstract:

Inspection of defects in civil infrastructure and sites has been a constant field of research. In the majority of inspections, a technician is responsible to go physically to the field in order to detect and measure defects. Robotics in civil engineering are being used primarily in construction, maintenance, and inspection. Robots are being used in European countries for finding cracks in dams, looking at the composition of mixtures for construction. Through the measurement results, engineers are able to perform the Structural Health Monitoring (SHM) of a measured structure. The SHM task is automated and an architecture is developed for an autonomous robot system, allowing it to maneuver autonomously in the environment while acquiring data from structures through sensors mounted on the robot, in order to assess the civil infrastructure in real-time. Furthermore, a database is used to store and create a measurement history. This in turn results in the increased life span of civil infrastructures.

Keywords: SHM, robotics, infrastructure, Robot Operating System.

1. INTRODUCTION

Structural Health Monitoring (SHM) is defined as the diagnosis of the state of a structure and its constituent materials and components or even the whole structure as a system. The parameters that may affect the structural integrity of any structure may include ageing, loading, corrosion, and others. The assessment of structural integrity of civil infrastructure is an important task to identify and determine the reliability level of a structure to be used as requested originally. Structures such as bridges, buildings, tunnels, nuclear plants and others are monitored regularly in order to remain in an acceptable level of reliability. Therefore, to keep these structures' safety, an efficient plan of maintenance must be deployed, however, an effective plan can only be done using reliable data from structures monitored.

These data are acquired through regular monitoring and nowadays there are many techniques as mentioned in the literature, however qualified operators perform the majority of inspection manually. This process is subjective and the operators need to face uncomfortable and dangerous conditions, for instance dust environments, absence of light, or even toxic substance exposure. Due to this fact, a system able to be adapted to different operational needs and types of structures with different requirements is a crucial element to obtain success in the monitoring and deployment of an efficient maintenance plan.

Nowadays, autonomous robot system are becoming more popular and they are being used to replace humans in environments where human operations are difficult or dangerous, such as in high-rises, narrow places, outer space, underground mines, nuclear plants, among others. The application of an autonomous robot system for monitoring infrastructures is becoming feasible due to the development, enhancement, and merging of technologies such as computing, communication, instrumentation and others. The deployment of an autonomous system can overcome many disadvantages faced by human operators and it can bring advantages such as flexibility, integration and automation in inspection of civil infrastructure.

Here, the goal is to develop an architecture for an autonomous robot system, allowing it to manoeuvre autonomously in the environment while acquiring data from structures through sensors mounted on the robot, in order to assess the civil infrastructure in real-time, while the robot manoeuvres through the environment. Furthermore, a database is used to store and create a measurement history. Besides these advantages, a full integration from the moment that the inspection is happening in the field until the management of tasks, such as maintenance plan and allocation of labour, can be integrated in only one system. This approach combines different sub-systems for instance sensory techniques, autonomous robots, database and computing to automate and integrate all systems from the inspection in the field up to the management system. Finally, from the automated system proposed integration with a computerized maintenance management system (CCMS) could be deployed in order to support the decision-making.

2. LITERATURE REVIEW

A literature review is the synthesis of the available literature regarding the topic. Due to the growth in the number of civil structures around the world, many techniques to detect and measure defects have been studied over here. These techniques are used to assess and monitor structures in order to provide safety for users, as well as to reduce the cost of maintenance. Furthermore, it is desirable to use methods which do not create negative effects on these structures and this is why non-destructive inspection methods are far more commonly used than destructive ones. The various nondestructive methods have been studied here.This synthesis merges the conclusions of many different sources to explain the overall understanding of the topic, thus laying a foundation for both the research question and primary research.

2.1 Fibre Sensors Based System For Tunnel Linings' Structural Health Monitoring

K. Loupos, G. Kanellos, M. Bimpas, A. Amditis, O. Bursi, S. Frontistou,J. Meisner, D. Bairaktaris, V. K. Bruno, and A. O. Griffoni (2013) introduced a new technique for monitoring the structural health of tunnels[1].Structural engineering is a field of engineering dealing with the analysis and design of structures supporting or resisting various loads. Studies of structural engineering requirements, specifically for densely populated areas, have indicated the need for high safety standards particularly in structural monitoring having in mind latest shifts from construction costs to life cycle costs and lifetime performance including safety and use. Structural monitoring is now being supported by various emerging technologies especially in areas of high seismicity where structural monitoring can be regarded of particularly high importance. Optical sensing technologies have a lot to offer in the field of structural monitoring providing the basis for condition assessment before, during or after any event. Structural monitoring based on fibre-optic technologies provide real-time, wireless and remote deformation sensing capabilities making them ideal regarding safety of vulnerable tunnel cross-sections or sections where very high standards of safety are required. Quick and reliable structural assessment can be enhanced with integrated software that collects and processes the data and assesses the structural reliability of the lining. Optical sensing technologies are most of the times supported by the above algorithms and are technologically progressing day by day.

Tunneling activity is on the increase around the world, and it is not just the volume of work which is rising. The demands of modern transport networks mean that tunnels are longer and wider than ever before and being driven through increasingly difficult ground conditions. Moreover, several planned tunnels are in countries of high seismicity and a good part of the tunnel lengths will be under densely populated areas and require very high standards of safety. When talking about Structural Health Monitoring (SHM), we usually include any process involving damage identification in engineering sectors such as constructions. Any deviation or change to the material or the geometric-properties/boundary-conditions of the structure can be regarded as damage (responsible for altering the system proper operation or performance).

Here a system has been developed consisting of an optimized fibre optics based deformation-sensing system for real-time measurement of deformations of reinforced concrete linings in tunnels and a Decision-Support-System (including user interface and decision suitable algorithms) that can drive proactive maintenance and earthquake risk management and can assess the structural reliability of the monitored lining under operating and seismic loads.In this work, two different fibre optic deformation monitoring systems are combined with advanced algorithms in order to assess the condition and evaluate the safety of tunnel linings under operating and seismic loadings.

Advantages:

- Structural health measured
- Safety Increased

Limitations:

- Only for tunnels lining

2.2 A new non-contacting non-destructive testing method for defect detection in concrete.

The authorsintroduced a new non-destructive testing (NDT) method for defect detection in concrete structures[2].The method is based on the dynamic response of flawed concrete structures subjected to impact loading. Conversely to similar NDT techniques, such as the impact-echo method, the present method uses non-contacting devices for both impact generation (a shock tube producing shock waves) and response monitoring (laser vibrometers measuring concrete surface velocity). Experimental and numerical (finite element) studies have been carried out for concrete specimens containing artificial defects (penny-shaped cracks parallel to the free surface) with varying length and depth. According to the experimental and numerical results, it appears that the present method enables an effective detection of defects, particularly in the range of shallow defects.

Advantages:

- Shallow defects, plate like fluctual vibrations detected

Limitations:

- High cost
- Only for concrete structures

2.3Mechatronic Systems Design for an AutonomousRobotic System for High-Efficiency BridgeDeck Inspection and Evaluation

Here a new autonomous system is introduced for bridge deck evaluation[3].The condition of bridges is critical for the safety of the travelling public. Bridges deteriorate with time as a result of material aging, excessive loading, environmental effects, and inadequate maintenance. The current practice of non-destructive evaluation (NDE) of bridge decks cannot meet the increasing demands for highly efficient, cost-effective, and safety-guaranteed inspection and evaluation. In this paper, a mechatronic systems design for an autonomous robotic system for highly efficient bridge deck inspection and evaluation is presented. An autonomous holonomic mobile robot is used as a platform to carry various NDE sensing systems for simultaneous and fast data collection. The robot's NDE sensor suite includes ground penetrating radar arrays, acoustic/seismic arrays, electrical resistivity sensors, and video cameras. Besides the NDE sensors, the robot is also equipped with various onboard navigation sensors such as global positioning system (GPS), inertial measurement units (IMU), laser scanner, etc. An integration scheme is presented to fuse the measurements from the GPS, the IMU and the wheel encoders for high-accuracy robot localization. The performance of the robotic NDE system development is demonstrated through extensive testing experiments and field deployments.

Advantages:

- Inspection efficiency, accuracy
- Reduce the risk

Limitations:

- Remote execution is not possible

Only for bridges Although many inspection methods are available, the majorityof inspections are performed by inspectors who identifydefects visually and rate them based on their experience. Thisprocedure is slow and labor intensive, which makes it a goodcandidate for the application of autonomous systems. The useof autonomous systems to inspect civil infrastructure is inconstant evolution, and several studies have highlighted theadvantages of their use. For civil structures, visual inspectionby a human could be replaced by more precise and fastmethods based on processing data provided by cameras, lasers,sonars, and other sensors used to map abandoned mines ,a robot for inspection of pipes, and systems for bridgeiinspections using vision, laser and ultrasound sensors.

3. AUTONOMOUS ROBOT SYSTEM

The autonomous robot system is composed of multiple sub-systems, with standardized interfaces that allowtransfer of mechanical forces and moments, electrical powerand communication throughout the robot. The modular sub-systems consist of some additional specialized units such as cameras, grippers and others. The robot is equipped with a camera and Global Positioning System (GPS). These sensors perform measurements in a predetermined frequency and the data are inputted into the robots processor. In addition, a laser and ultrasonic sensors are used to acquire data from the environment. This data must be used to provide the robot with two capabilities: self-navigation, and detection and measurement of defects in structures.

Through the remote station, a path is established for robot navigation and it is determined by the engineering team, then the robot begins the navigation and the trajectory control is performed by a control algorithm embedded into robots processor. The algorithm receives the data acquired by the sensors, processes them and controls the robot actuators in order to ensure the self-navigation capability. Furthermore, through the same station, the engineering team is able to do the sensors data exploitation in real time.

The data acquired by the camera is inputted into the vision-based measurement algorithm (VBM), which provides the relative pose of the target in relation to the robot. When an object is detected, the image is inputted into the crack detection algorithm (CDA), the image is processed and whether a defect is detected the image is processed by the crack measurement algorithm (CMA) in order to measure the defect dimension. The results of this procedure ofmeasurement are stored into a database in order to create a measurement history.

3.1 Layered architecture

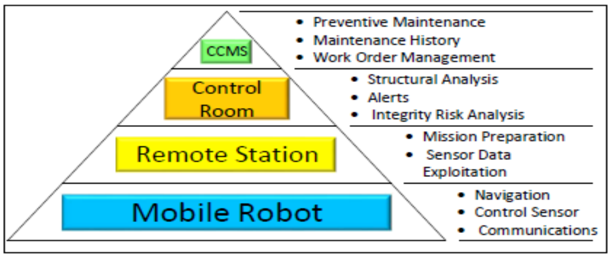

Fig 3.1:Layered robot inspection architecture

The sub-systems are integrated in four abstraction layers from mobile robot to the management system. The first layer deals with the motion of the mobile robot and controls the sensing components (sensors) that allow the robot to navigate in the environment, and detect and measure defects in thestructures.

The second layer is composed by a remote stationand is used by the engineering team to prepare the robot path, to receive data from robot sensors and also to carry out data exploitation.

The third layer is the control room that allows the engineering team to access data from the field and performs a structural analysis of the infrastructure. Furthermore, from the structure integrity analysis alarms can be processed and issued for infrastructure managers in order to prevent accidents or even disasters.

Finally, the fourth layer consists in integrating the management system in order to plan and schedule an efficient plan of maintenance to keep the structures safe for users.Therefore, through the full integration of the sub-systems,the data stored into a database may be accessed at the control room, and structural analyses of the structure measured may be carried out. From the results of this assessment, alerts can be triggered to inform the engineers about critical conditions of a structure, and to support the engineering team to plan an effective and efficient maintenance plan, enabling the efficient scheduling of material and labor resources. Besides these advantages, the authorities can also plan renovations or even the construction of new structures.

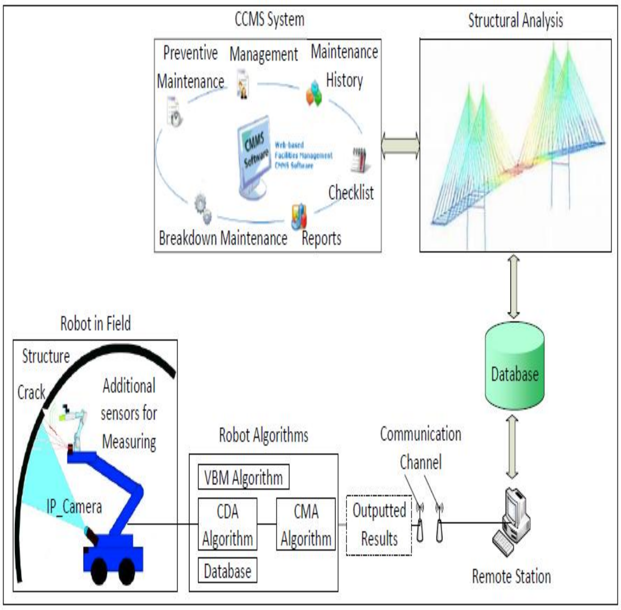

Fig3.1.1:Architecture of autonomous system.

3.2 Software Design

Robot Operating System (ROS) has been chosen to integrate the layers one (mobile robot) and two (remote station).ROS is an open-source software framework for robot software.It provides a middleware layer that allows communication between a set of executable software components (called nodes). Nodes can communicate with each other via either a remote procedure call, a publish-subscribe mechanism or via goal-feedback-result mechanism. ROS also provides some basic nodes (e.g. for navigation) and has a very active community that contributes to develop new nodes.

The main advantage of ROS is that many software nodes are reusable and configurable independently of the underlying architecture. Fig. 3.2 shows the software. The software is composed by ROS Master and nodes that control specific tasks such as robot navigation, defects detection and measurement, and also data storage. These nodes are distributed in a peer-to-per network architecture (P2P) that allows them to communicate each other using messages without the needed of a central coordinator.

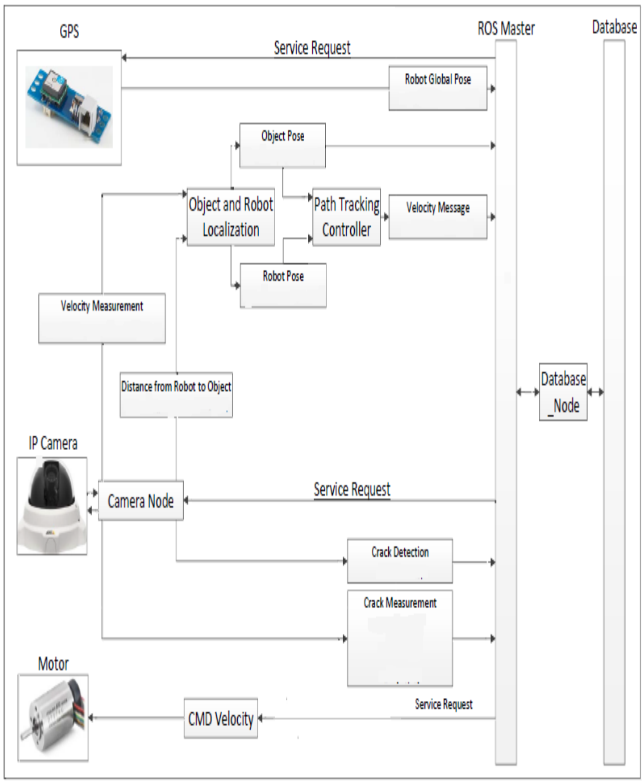

Fig 3.2: Software for the robot system

The task of navigation in an unknown environment is an important feature for any autonomous robot. From a predetermined path, the robot must be able to accomplish its trajectory using data processed by itself. Many techniques have been studying in order to provide a robot this capability for instance navigation using landmarks, navigation based in maps of the environment and others. Here, the technique of Visual Path Tracking has been selected andand deployed to control the robot trajectory. It consists of tracking a desired object in a sequence of frames to support the robot accomplish its trajectory.

The ROS Master registers the services and then the camera node request images from camera in a predetermined frequency. These images are processed in order to detect target objects and the results are inputted into the object and robot localization node and it estimates the robot and object pose.The robot's and object's pose are matrices that contain the pose of both elements and these matrices are inputted into the path tracking controller node, that calculates the distance to be traveled from the current robot pose to the object detected and it outputs a velocity message that is sent to the Command Velocity Node (CMD), which controls the robots motors directly.

While the process of navigation is going on, the object pose is available to be stored into the database.The robot global pose is used to compose the history of measurement and it is available in the moment that a defect is detected.

Likewise, when the camera node is carried out, the same sequence of images captured by the camera is processed by CDA and CMA in order to detect cracks in objects surface
and also to measure them. When cracks are detected, the node then outputs them as a matrix that contains its respective dimension [*width*, *length*] and also the crack center coordinate in X-axis and Y -axis respectively.

Finally, the database node has been deployed in order to store all data acquired in the field. In the moment that a crack is detected and measured, the database node receives a message, which allows a user to see data such as the object identification, object position, crack identification and crack measurement in order to create the measurement history.

3.3 Storage of Data

The autonomous robot system proposed produces a very large amount of run-time data (acquired from sensors or generated by actuators) that need to be processed so it can serve as the basis for decision-making or parameter estimation. Since the data may be useful later (for instance to analyze faults or evaluate the robots performance), it needs to be stored and accessible through efficient and flexible querying mechanisms.

A Client/Server architecture is then used (a user-interface front-end and a database server back-end). This architecture ensures data security and allows parallel access for several
users. It also offers a way to make data available both within a local area network (intranet) and in the internet to supportusers.

The architecture is based on a SQL server, which holds the database tables. The advantage of a SQL compatible database server lies in its performance scalability. It also has interfaces to different programming languages and it allows very complex programming with comprehensive possibilities.

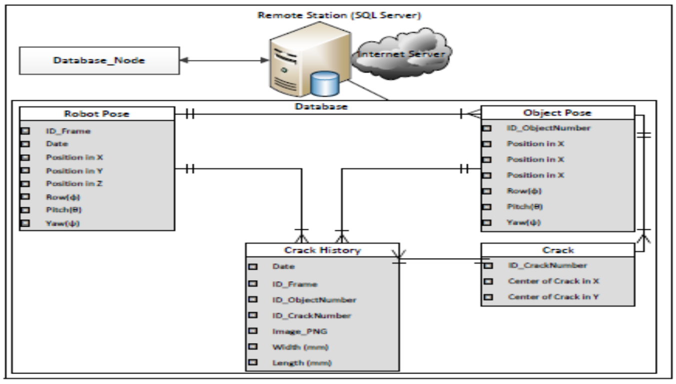

Fig 3.3:Storage of data

4. CONCLUSION:

The use of autonomous robot system for monitoring the structural health of buildings isfast, reliable and accurate than traditional methods to inspect civil infrastructure. Therefore, the application of autonomous system to monitor automatically the structural health monitoringfrom the moment that the measurement is going on in the field until the management of structures maintenance, has many technical and financial advantage.
For civil structures, visual inspection by a human could be replaced by more precise and fast methods based on processing data provided by cameras, lasers, sonars, and other sensors and can be used in various applications such as to map abandoned mines, a robot for inspection of pipes ,and system for bridge inspections using vision, laser and ultrasound sensors

5. REFERENCES:

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