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A ROBOTIC CRACK INSPECTION AND MAPPING SYSTEM FOR BRIDGE DECK MAINTENANCE

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ABSTRACT

One of the important tasks for bridge maintenance is bridge deck crack inspection. Traditionally, a human inspector detects cracks using his/her eyes and marks the location of cracks manually. However, the accuracy of the inspection result is low due to the subjective nature of human judgement. We propose a crack inspection system that uses a camera-equipped mobile robot to collect images on the bridge deck. In this method, the Laplacian of Gaussian (LoG) algorithm is used to detect cracks and a global crack map is obtained through camera calibration and robot localization. To ensure that the robot collects all the images on the bridge deck, a path planning algorithm based on the genetic algorithm is developed. The path planning algorithm finds a solution which minimizes the number of turns and the traveling distance. We validate our proposed system through both simulations and experiments.

I.INTRODUCTION

F OR MANY engineered transportation structures, including civil, mechanical and aerospace structures, timely awareness of their structural health can prevent functional failures which may lead to catastrophic consequences. On August 1, 2007, the collapse of the I-35 W Mississippi River Bridge that carried Interstate 35 W across the Mississippi River in Minneapolis left 13 dead and more than 100 injured [1], not to mention its big impact on the traffic and businesses in the surrounding areas. This accident has clearly demonstrated the catastrophic results of structural failures and the importance of timely awareness of structural health. Bridge decks are typically the elements of first maintenance on a bridge. Since the surface of a bridge deck is exposed to the environment, direct loading from vehicles and exposure to deicing chemicals, constant maintenance is a must. Therefore, bridge deck inspection is helpful and can provide owners warning to the future deterioration of the bridge deck. Currently, bridge decks are inspected with very rudimentary methods in the form of visual inspection by a trained engineer. The inspectors usually walk though the bridges and measure the crack sizes and locations. This manual approach has several disadvantages. First, it is prone to human errors. Second, it has limited accuracy due to the limited visual capability of human inspectors. Third, it cannot guarantee the full coverage of the whole bridge deck. Additionally, conducting visual crack inspection of a bridge deck is a dangerous job with passing traffic. Therefore, it is highly desirable to develop a robotic crack inspection and mapping (ROCIM) system for accurate assessment of cracks on bridge decks. This system can outperform human inspectors in several ways. First, the ROCIM system can achieve high accuracy of crack detection if equipped with a high-resolution camera. Second, the ROCIM system can localize itself precisely, which facilitates accurate crack localization. Finally, by using a robot, the ROCIM system can greatly reduce the safety risk of human inspectors.

II.LITERATURE SURVEY

C. R. Farrar, H. Sohn, and S. W. Doebling, "Structural health monitoring at Los Alamos National Laboratory," in U.S.-Korea Conf. Sci. Technol., Entrepreneurship and Leadership, Chicago, IL, USA, Sep. 2–5, 2000, pp. 1–11.

This paper presents a study of the variation of natural frequencies and damping ratios of a reinforced concrete building identified from earthquake records during a period of four years. The three storey reinforced concrete building is instrumented with five tri-axial accelerometers. The state-space subspace system identification technique was used to ascertain the natural frequencies and damping ratios considering 50 recorded earthquake response time histories. Correlations were developed between the peak ground acceleration at the base level and peak response acceleration at roof level with identified frequencies and damping ratios. It was found that modal characteristics of the building are sensitive to the level of excitation and response. A general trend of decreasing fundamental frequencies and increasing damping ratios with increased level of shaking was observed. A three dimensional finite element model of the building was developed to study the influences of soil and various structural and non-structural components. To incorporate real in-situ conditions, soil underneath the foundation was modeled using spring elements and non-structural components (cladding, in-fills and partitions) were also included. It was concluded from the investigation that participation of soil and non-structural components towards the seismic response of the building is significant and these should be considered in models to simulate the real behavior. The characterization and prediction of the response of civil structures under extreme loading events such as earthquakes is a challenging problem and has gained increasing attention in recent years. The challenges associated with the civil structures such as buildings, bridges and dams include modeling their complicated interaction with the surrounding ground, varying environmental and loading conditions, and complex material and structural behavior which preclude the study of a complete system in a laboratory setting. An approach to tackle these issues is to use the recorded responses from instrumented structures and extract the dynamic characteristics using a process known as system identification1,2. The in-situ measured responses reflect all the real physical properties of the structure and can be useful for structural health monitoring and model updating studies3,4. In characterizing the dynamic response of buildings, natural frequencies and damping ratios are very important parameters. Permanent instrumentation of buildings makes possible studying of these parameters under different earthquakes excitation. Studies have shown that the dynamic characteristics tend to vary with vibration amplitude5,6,7. It is, therefore, important to examine the behavior of buildings under different excitation scenarios. The trends of variation of dynamic characteristics like modal frequencies and damping ratios thus developed will provide quantitative data for the variations in the behavior of buildings. Moreover, such studies will provide invaluable information for the development and calibration of realistic models for the prediction of seismic response of structures in model updating and structural health monitoring studies.

H. Sohn, C. R. Farrar, M. L. Fugate, and J. J. Czarnecki, "Structural health monitoring of welded connections," in Proc. 1st Int. Conf. Stell Composite Structures, Pusan, Korea, Jun. 14–16, 2001.

Bridge deck crack inspection is one of the important tasks for bridge maintenance. Traditionally, a human inspector detects cracks by using his/her eyes and marks the location of cracks manually. However, the accuracy of the inspection result is low because of the subjective nature of human judgement. A crack inspection system that uses a camera-equipped mobile robot to collect images on the bridge deck is proposed. In this method, the Laplacian of Gaussian (LoG) algorithm is used for detecting cracks and a global crack map is obtained through camera calibration and robot localization. In order to ensure that the robot collects all the images on the bridge deck, a path planning algorithm based on the genetic algorithm is developed. The path planning algorithm finds a solution which minimizes the number of turns and the traveling distance. The proposed system is validated through both simulations and experiments. In an engineered transportation structures, including civil, mechanical and aerospace structures timely awareness of their structural health can prevent functional failures which may lead to catastrophic consequences. On August 1, 2007, the collapse of the I-35 W Mississippi River Bridge that carried Interstate 35W across the Mississippi River in Minneapolis left 13 dead and more than 100 injured [1], not to mention its big impact on the traffic and businesses in the surrounding areas. This accident has clearly demonstrated the catastrophic results of structural failures and the importance of timely awareness of structural health. Bridge decks are typically the elements of first maintenance on a bridge. Since the surface of a bridge deck is exposed to the environment, direct loading from vehicles and exposure to deicing chemicals, constant maintenance is a must. Therefore, bridge deck inspection is helpful and can provide owners warning to the future deterioration of the bridge deck. Currently, bridge decks are inspected with very rudimentary methods in the form of visual inspection by a trained engineer. The inspectors usually walk though the bridges and measure the crack sizes and locations. This manual approach has several disadvantages. First, it is prone to human errors. Second, it has limited accuracy due to the limited visual capability of human inspectors.Third, it cannot guarantee the full coverage of the whole bridge deck. Additionally, conducting visual crack inspection of a bridge deck is a dangerous job with passing traffic. Therefore, it is highly desirable to develop a robotic crack inspection and mapping (ROCIM) system for accurate assessment of cracks on bridge decks. This system can outperform human inspectors in several ways. First, the

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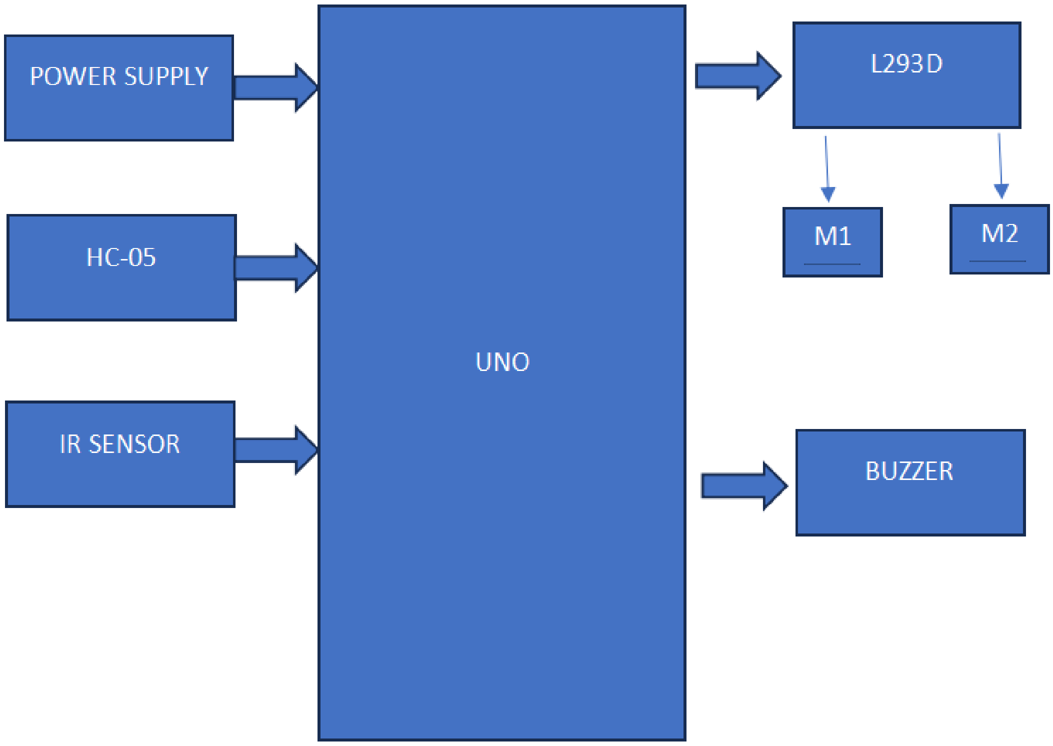
ROCIM system can achieve high accuracy of crack detection if equipped with a high-resolution camera. Second, the ROCIM system can localize itself precisely, which facilitates accurate crack localization. Finally, by using a robot, the ROCIM system can greatly reduce the safety risk of human inspectors. In the ROCIM system, a mobile robot is utilized to create a two-dimensional (2D) map of the bridge deck using a laser sensor, while a camera is used to collect images of the bridge deck surface. The collected images are then processed using image processing techniques to detect the cracks. We store the crack locations in this 2D map, therefore obtaining a crack map, which can be used to measure, classify and monitor cracks periodically. In order to implement the ROCIM system, there are several challenging problems that should be addressed. • Crack detection: To detect cracks on the bridge deck using computer vision, we need to develop an effective edge detection algorithm to distinguish cracks and noncracks. • Coordinate transformation: To create a crack map, the crack location has to be pinpointed in the global coordinate system, or the coordinate system of the 2D map of the bridge deck. Since the cracks are detected in the image coordinate system, we have to map the crack locations from the image coordinate system to the global coordinate system.

Block diagram



III.PROPOSED SYSTEM

The **Robotic Crack Inspection and Mapping System for Bridge Deck Maintenance** is designed to automate the process of identifying and mapping structural cracks on bridge decks, ensuring timely and accurate maintenance. By using robotic technology combined with advanced sensors and imaging systems, the system enhances the efficiency and reliability of bridge inspection, reducing the need for manual labor and increasing the safety of maintenance personnel.

1. Robotic Platform:

The system is based on a mobile robotic platform capable of navigating across the bridge deck. The robot is equipped with sensors for motion control, allowing it to autonomously move over large surfaces. The robot is designed to adapt to varying terrain and environmental conditions typical of bridge surfaces, ensuring smooth operation during inspections.

2. Crack Detection Sensors:

The robotic system is equipped with high-resolution cameras, laser scanners, and ultrasonic sensors that scan the bridge deck surface for cracks and structural anomalies. The system uses computer vision techniques to analyze the images captured by the cameras and detect even the smallest cracks. Ultrasonic sensors are employed to assess the depth and severity of these cracks, providing detailed information on their structural impact.

3. Real-time Data Processing and Analysis:

The data collected by the robot's sensors is processed in real-time using onboard computational units. The system uses machine learning algorithms and image processing techniques to classify cracks based on their size, depth, and severity. This real-time analysis enables the system to identify critical areas that need immediate attention, allowing for prompt maintenance actions.

4. GPS-based Mapping and Localization:

The robot is equipped with GPS and other localization systems to create accurate maps of the inspected bridge deck. As the robot moves, it generates a comprehensive map of the bridge, marking the locations of identified cracks and structural weaknesses. This GPS-based mapping helps maintenance crews prioritize areas that need repairs and provides a visual representation of the overall health of the bridge.

5. Wireless Data Transmission and Remote Monitoring:

The robotic system is integrated with a wireless communication module that allows it to transmit inspection data in real-time to a central monitoring station. Engineers and maintenance teams can remotely monitor the robot's progress and analyze the crack data as it is being collected. This remote monitoring capability minimizes the need for personnel to be physically present on the bridge during inspections, improving safety and efficiency.

6. Autonomous Navigation and Obstacle Avoidance:

The robot is equipped with advanced navigation algorithms that allow it to move autonomously across the bridge deck while avoiding obstacles. Using lidar sensors and cameras, the robot can detect and avoid obstacles such as debris, barriers, and other objects on the bridge surface. This feature ensures that the inspection process is uninterrupted and that the robot can safely navigate complex environments.

7. Data Storage and Reporting:

All inspection data, including images, crack measurements, and location coordinates, are stored in a central database for future reference. The system generates detailed reports that include the locations and severity of cracks, which can be used by engineers to schedule maintenance activities. These reports are essential for long-term monitoring of the bridge's structural integrity and for identifying patterns of deterioration.

8. Integration with Maintenance Systems:

The crack inspection data collected by the robotic system can be integrated with existing maintenance management systems used by infrastructure authorities. This integration allows for the automation of maintenance scheduling and ensures that critical repairs are carried out promptly. By connecting the inspection data to maintenance systems, the overall lifecycle of bridge maintenance is improved, reducing costs and preventing potential structural failures.

9. Scalability and Future Enhancements:

The system is designed to be scalable and can be deployed across various types of infrastructure, including roads, tunnels, and other structures. Future enhancements may include the use of drones for aerial inspections of hard-to-reach areas, as well as incorporating AI algorithms for predictive maintenance, which would forecast potential crack formations before they become critical.

The **Robotic Crack Inspection and Mapping System** revolutionizes bridge deck maintenance by providing an automated, efficient, and precise method of detecting and mapping cracks. By using advanced robotic technology, real-time data analysis, and wireless communication, the system significantly reduces the time and effort required for inspections while improving the accuracy of maintenance planning and execution.

IV.CONCLUSION

In this paper, we introduced a robotic crack inspection and mapping (ROCIM) system. The ROCIM system provides an overall solution to bridge deck crack inspection. First, the crackdetection algorithm works well for real cracks through the experiment and simulation evaluation. Second, we propose robotic inspection path planning based on a genetic algorithm (RIP-GA) to ensure the mobile robot collects all the images efficiently in the area of interest. We also validate the proposed RIP-GA algorithm and then compare it with the Greedy algorithm in obstacle free and obstacle environments. The results show that the genetic algorithm performs better than Greedy algorithm. Third, both indoor and outdoor tests are conducted to validate the proposed ROCIM system. In the future, we will further improve the crack detection algorithm, especially in various ambient lighting conditions. We need enhance the robustness of the crack detection algorithm in such conditions. On the other hand we will utilize Non-Destructive Evaluation (NDE) sensors such as Impact Echo and Ultrasonic Surface Wave to detect vertical cracks (crack depth) and delamination of the bridge deck [33]. Also, we will address the problem of degraded localization accuracy due to moving objects. One of the best solutions is using Extended Kalman Filter (EKF) to fuse various data from different sources such as Differential Global Positioning System (DGPS), Inertial Measurement Unit (IMU), and robot wheel encoders to output the accurate and smooth localization of the robot on the bridge [34], [33].

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