

Low-Cost Sensors Used In Rcc Frame Structures

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Abstract: Reinforced cement concrete (RCC) buildings can develop internal cracks, corrosion of steel reinforcement, and loss of strength due to heavy loads, weather conditions, and ageing. Traditional inspection is usually done manually by trained engineers. This process takes time, costs more, and may not identify internal damage at an early stage. This review studies different low-cost sensor technologies used to monitor cracks and changes in RCC beams, columns, and walls. The methods include copper break-wire sensors, vibration and damping analysis, Fiber Bragg Grating (FBG) sensors, ultrasonic sensors, and IoT-based systems using affordable microcontrollers such as Arduino and ESP32. The review shows that these low-cost methods can detect crack formation and structural damage when proper calibration and data analysis are used. They can provide useful results at a much lower cost than conventional testing equipment. Overall, low-cost sensor systems can be a practical and scalable option for continuous structural health monitoring. They can help detect damage at an early stage, improve safety, and support better and more timely maintenance of medium-sized RCC buildings.

Keywords: Low-cost sensors, RCC frame structures, Structural Health Monitoring, Crack detection, IoT monitoring, ESP32

Introduction: RCC frame structures are widely used in commercial and institutional buildings because they are strong, long-lasting, and easy to construct. However, over time, these structures can develop issues such as cracking, rusting of steel bars, and weakening due to weather, heavy loads, and aging materials. Cracks are a major concern as they often start inside beams, columns, or walls long before they are visible on the surface. By the time a crack is noticed during an inspection, it might have already caused serious damage. Traditional methods of checking a structure's condition involve trained engineers inspecting it at regular intervals. This method has some drawbacks. It takes a lot of time, costs a lot of money, depends on the inspector's skill and judgment, and is not practical for hard-to-reach buildings. Because of these challenges, many medium-sized buildings don't get proper monitoring due to the high cost of professional tools. In recent years, low-cost microcontrollers like Arduino and ESP32, along with affordable sensors and wireless communication technology, have made it possible to monitor structures in new ways.

These systems can measure changes in vibration, movement, temperature, and moisture. They can send this information instantly for analysis. When combined with artificial intelligence and image-processing tools, these systems can even automatically identify cracks, reducing the need for manual checks. This review paper looks closely at how low-cost sensors are used in RCC frame structures. The goal is to gather information on low-cost sensing methods studied in recent research, understand how they work, and identify which ones are best for detecting cracks and changes in RCC beams, columns, and walls. This helps in developing simple and effective monitoring systems for everyday construction.

Literature Review

Komary et al. studied the use of low-cost sensors, such as DHT22, for monitoring temperature and moisture in concrete during the early stages of construction. The study showed that monitoring these conditions helps engineers understand the setting and curing of concrete. Changes in temperature and moisture can also indicate conditions that may lead to early crack formation. The researchers explained that traditional monitoring equipment is often expensive and requires skilled operators. Low-cost sensors can provide a more affordable option for small and medium-sized construction projects. With proper calibration and data processing, these sensors can

provide reliable information. This study is useful for the present project because it shows that inexpensive sensors can be used for continuous monitoring of concrete conditions and early damage detection.

Mobaraki et al. reviewed different low-cost sensing technologies for structural and building monitoring, with special attention to Fiber Bragg Grating (FBG) sensors. The study found that FBG sensors are highly sensitive and can detect small cracks, strain, and changes in structural shape. The researchers also discussed optical sensors that can monitor cracks in areas that are difficult to inspect visually. The study highlighted that low-cost sensing systems can make it possible to monitor several structural elements at the same time. This can reduce the cost of structural health monitoring. The researchers concluded that these technologies can help detect damage at an early stage and improve building safety. The study supports the idea of using affordable sensors for continuous structural monitoring.

Nguyen et al. developed a low-cost IoT-based monitoring system for construction sites. The system mainly measured environmental conditions such as humidity and soil moisture. Although the study did not directly detect structural cracks, it showed that moisture can affect concrete and contribute to long-term deterioration. The researchers used several low-cost sensors connected through a common network. This made the system easier and cheaper to install and manage. The study also showed that the same IoT system could be modified to connect other types of sensors. This makes the approach useful for structural crack monitoring. The research demonstrates that low-cost microcontrollers and wireless communication can be used to build practical monitoring systems for construction and structural applications.

Bagerzadeh Karim et al. proposed a low-cost structural health monitoring system using smartphone accelerometers and ESP32 microcontroller boards. The study focused on measuring vibration and damping changes in buildings. The researchers explained that cracks and other structural damage can change the vibration behaviour of a structure. By continuously measuring these changes, possible damage can be identified at an early stage. The system was much cheaper than conventional structural monitoring equipment and did not require highly specialised instruments. The study showed that commonly available devices, such as smartphones and ESP32 boards, can be useful for real-time structural monitoring. This research is relevant to the present project because it supports the use of an ESP32 and an accelerometer for detecting changes in concrete structures.

Komarizadehasl et al. studied three different low-cost distance sensors connected to an Arduino microcontroller for detecting structural movement and deformation. The researchers focused on identifying small changes in the position of structural elements that may occur when cracks develop. Their experimental results showed that inexpensive distance sensors can detect small structural movements. The study demonstrated that structural monitoring does not always require expensive professional equipment. Low-cost sensors can provide useful results when they are properly selected and connected to a suitable data acquisition system. The researchers concluded that these sensors can be used as an affordable option for continuous structural monitoring. This work is relevant to the present project because it shows how low-cost sensors and microcontrollers can be combined to monitor structural changes.

Wagh et al. developed an automated and low-cost structural health monitoring system using ultrasonic sensors, vibration sensors, Raspberry Pi, ESP32, wireless communication, and artificial intelligence. The system was designed to monitor crack development, displacement, vibration, and temperature. Sensor data was transmitted through the ESP32 to a central processing unit for analysis. AI-based image processing was then used to identify abnormal structural conditions. Experimental testing showed that the system could detect both low- and high-severity cracks in real time. The researchers found that the system could reduce the need for frequent manual inspections and provide early warnings of structural damage. This study is important because it demonstrates how different low-cost sensors, microcontrollers, wireless communication, and data analysis can be combined into one structural monitoring system.

Ganesh Prabhu et al. reviewed different structural health monitoring techniques, mainly focusing on ultrasonic methods for detecting damage in structural beams. The study discussed techniques such as Ultrasonic Pulse Velocity (UPV) and guided waves, which can identify surface and internal cracks without damaging the structure. The researchers also examined piezoelectric sensors and low-cost microcontrollers such as Arduino and ESP32. These components can reduce the cost of structural monitoring systems. However, the study pointed out that low-cost ultrasonic sensors may not always provide sufficient accuracy for professional structural testing. Environmental conditions, sensor connection, signal noise, and limited long-term testing can also affect the results. The study concluded that low-cost ultrasonic monitoring has good potential but requires proper calibration and testing.

Aruneshvar et al. reviewed different automated crack detection techniques used in civil engineering structures. The study covered traditional image processing methods as well as modern machine learning and deep learning techniques. Methods such as edge detection, texture analysis, Support Vector Machines, Random Forests, CNNs, YOLO, and U-Net were discussed. The researchers also examined technologies such as high-resolution cameras, infrared thermography, LiDAR, drones, and robotic systems. These methods can reduce the time and effort required for manual inspection and can improve crack detection. However, the study identified several

challenges, including changing lighting and weather conditions, limited training data, high computing requirements, and difficulty applying the same model to different structures. The research shows the growing importance of automated methods in structural health monitoring.

Pei et al. studied the long-term performance of low-cost sensors for monitoring indoor air quality in a commercial office building. The sensors were operated continuously for six months and measured particulate matter, carbon dioxide, and other environmental conditions. The study showed that low-cost sensors can provide useful data for continuous monitoring over a long period. Although the research was focused on air quality rather than structural cracks, it demonstrated the practical use of low-cost sensor networks in real buildings. The researchers also observed that environmental and human activities could affect sensor measurements. This finding highlights the importance of understanding environmental effects when using low-cost sensors. The study supports the use of affordable sensors for long-term monitoring applications.

Chojer et al. developed a low-cost indoor air-quality monitoring system called SENSINAIR Monitor. The system measured pollutants such as particulate matter, carbon dioxide, and ozone. The researchers compared the low-cost sensors with professional reference instruments under real indoor conditions. Calibration and a Kalman filtering method were used to reduce noise and improve measurement accuracy. Most sensors showed a strong relationship with the readings from professional instruments. However, the researchers found that sensor accuracy depended on the pollutant concentration and calibration method. The study concluded that low-cost sensors can provide reliable monitoring when they are properly calibrated and their data is processed correctly. This research is relevant because it highlights the importance of calibration and filtering when developing a low-cost structural monitoring system.

Raeisi et al. developed a low-cost copper break-wire sensor for detecting cracks in steel bridge girders. Fine copper wires were attached to the steel surface using epoxy adhesive. When a crack developed and propagated, the wire broke, causing a change in the electrical circuit. This change was detected by a simple data acquisition system. Experimental results showed that the sensor could detect very small cracks, approximately 0.09 to 0.16 mm wide. The sensors also worked over a wide temperature range from -30°C to $+40^{\circ}\text{C}$. Compared with expensive fibre-optic monitoring systems, the copper break-wire method was much cheaper. The study demonstrates that simple copper wires can provide an effective method for detecting crack formation. This research is directly related to the present project because it supports the use of copper break-wire sensors embedded in concrete for internal crack detection.

Methodology: The project aims to develop a low-cost sensor system to detect internal cracks in a 150 mm concrete cube. Thin copper break-wire sensors will be placed at different depths inside the cube during casting. These sensors will be connected to an ESP32 microcontroller to monitor the cube continuously. An MPU6050 accelerometer will measure vibrations and movement. Bluetooth will send an alert when a sensor wire breaks. The concrete cube will then be tested under controlled loads to create cracks. The sensor readings will be collected and analysed to check the system's accuracy, sensitivity, and reliability.

Conclusion: Low-cost sensors, when used with microcontrollers like ESP32 or Arduino and wireless communication, offer an affordable way to monitor RCC frame structures for internal cracks and structural changes. Methods such as copper break-wire sensors, vibration-based damping analysis, FBG sensors, and environmental monitoring each provide ways to detect early damage. With calibration and data processing, these low-cost systems can work reliably. This makes regular structural health monitoring possible and affordable for medium-sized buildings.

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