Advancement in Structural Health Monitoring System using Next-Generation Materials for Local and Global Building Investment

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Abstract. The advancement of smart phones, HD cameras, drones, and sensors has led to smart construction monitoring systems. Vibration-based criterion evaluation is becominga popular approach for evaluating extensive facilities. Fiber reinforced polymers, such as polypropylene, glass, steel fibres etc. are increasingly used in civil engineering to improve structural health. Wearable smartphones with configurable frameworks enable the capture of vibration statistics through integrated sensors. Affordable cameras record images and videos to study structural activity using modern signal processing methods. This study provides a comprehensive overview of smart-sensing technologies deployed in structural health monitoring.

Keywords: Structural health monitoring (SHM), SHM device, Sensors, Mobiles, Cameras, UAV, Fibres.

1 Introduction

The dwelling built by humanity includes a complex and massive structural system with rich details and expensive constructions. Multiple codebooks are favored in various design domainsand has proven successful on a large scale in preventing local and global failures in the structuralsystem. Vibration caused by earthquakes, wind, temperature, or human-made excitation initiatesstructural damage during their service lives and subsequently, triggers catastrophic failure SHMaims to detect different types of damage imposed on numerous structures so that structures safety, reliability, and cost can be effectively improved. SHM systems convey the changes or damage related to the designs. SHM devices significantly monitor the condition of large structures such as building structures, pipelines, bridges, airplanes, etc. The primary goal is to detect the different types of damage causes and the location where the damage is caused, additionally the type of damage to measure the damage's end and predict the service life of structures. In accordance to SHM, wireless surveillance has emerged as a promising technology that appears to be bumping into structure surveillance and infrastructure asset management. This featured work summarizes the research efforts that have led to the design of numerous SHM systems. Structural Health Monitoring has become an excellent alternative to quantify all behavior from manufacture to end of life. **Figure 1**. shows the advancements in structurnal health monitoring.

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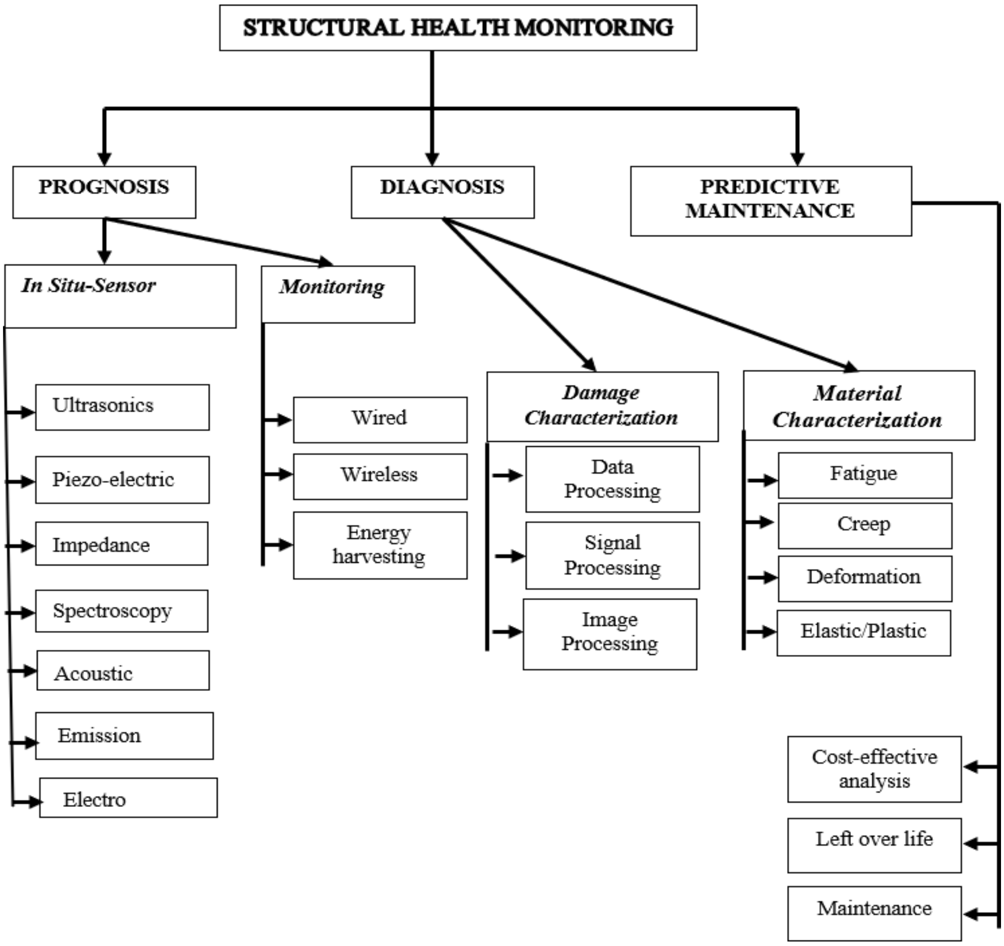

Fig. 1. Advancement in SHM

As per **Figure 1.** Structural Health Monitoring (SHM) is performed for diagnosis, prognosis, and predictive maintenance, in which numerous advances have taken place

2 Next-Generation Sensing Method

Noncontact sensors developed in last three decades using GPS for challenges Implemented remote, nonintrusive SHM approach for easy installation[16][17][18][19][20].The GPS is reasonably accurate and gives dynamic measurements of 20 Hz or more in case of high-rate GPS[17][21].However, the GPS can be very sensitive to electromagnetic noise, environmental interference, and weather conditions[22][23][24][25][26][27]. Unlike the GPS, noncontact laser vibrometers and radar interferometry provide high-quality measurements. However, these instruments are expensive and have restrictions on weather conditions and maximum 2 of 22 SONY ET AL. required measurement distance because longer distance measurements require alight with higher intensity. They could also be dangerous to human health that is present in the structures under inspection during in-service data collection. This paper reviews modern sensors, including cameras, UAVs, smartphones, and mobiles, for their labor-saving capabilities.

2.1 Camera-based Sensing Method

With the use of picture and video analysis, it is now possible to conduct remote condition assessments of structures that are of high quality. There has been a considerable increase in the development of low-cost vision-sensing technologies. For the purposes of data collection, both consumer-grade DSLR cameras and highly advanced high-speed cameras have been used.The digital image correlation (DIC) and motion magnification (MM) approaches are just two examples of the wide variety of camera-based methods that are currently available. Table 1.elaborates type of cameras and its finding from the study.

Table 1. Camera based structural health monitoring

Literature	Type of camera	Findings of the study
Acikgoz et al., 2018[1]	Allied Vision GigE video Camera	Bridge dynamics: dynamic displacements.
Khuc and Catbas, 2018[2]	Logitech webcam	HOG and UIS are tools for analyzing data.
Zhou et al., 2017[3]	Monochrome CCD with GigE Vision Inteface	Wavelet decomposition is a fundamental concept
Kromanis and Al-Habaibeh, 2017[4]	Lenevo A806	Image processing
Yoon et al., 2016[4]	GoPro Hero and LG Pro smartphone camera	Kanade-Lucas-Tomasi, MLESAC, and eigenvalue realization algorithm
Zaurin et al., 2016[5]	Digital video camera	Lagrange interpolation algorithm
Feng et al., 2015[6]	Point Grey	Up-sampled cross-correlation

2.2 Unmanned Aerial Vehicle Sensing Method.

Conventional contact-associated sensors provide an issue if the surface is not accessible, or many sensors should have to be deployed, restricting the price of contact- associated sensors. Drone has lately been recognized as a substitute portable instrument in non-associated measuring technology. A sample of UAVs is displayed in **Figure 3.** Lei et al., 2018 utilized the quadrotor model for predictive bridge maintenance. Identifying cracks in the bridge structure has presenteda novel crack detection methodology to enhance weaker image-processing techniques of imagesobtained by Algorithms. The procedure, notably the fracture center point method, was demonstrated on a concrete bridge. The suggested approach assessed the fracture width correctly with an error smaller than 5 percent.

Germany et al., 2018 developed a method for SHM employing UAV video with a Canon EOS M camera using the ISTI-CNR model to know the varied cracking patterns in ancient buildings. The test set was done in a lab employing markersto imitate crack openings, and these markings were relocated during the test for simulating long-term cracks. Duqueet al. 2018 assessed a wood bridge utilizing the DJI Phantom technique employing 4 GoPro cameras to measure bridge degradation. "Omar and Nehdi, 2017" said thatDJI Inspire 1 Pro thermal imaging camera FLIR Vue Pro Remote Sensing of Bridge Deck Bridge employed UAVs equipped with thermal image entity to detect deterioration to concrete bridge decks. The acquired thermal pictures were processed using an algorithm that blends the photos into a mosaic of the bridge deck. The K-Means clustering approach would classify the problemsinto serious groups. Table 2. elaborates type of cameras and its finding from the study.

Table 2. Unmanned Aerial Vehicle structural health monitoring

Literature	Type of camera	Findings of the study
Germanese et al., 2018[7]	Canon EOS M	Historical structures exhibit crack patterns.
Kim et al., 2017[7]	LS-20150	Identifying concrete cracks.
Chiu et al., 2017[8]	Sony WX220	Assessment of floating cover condition.
Hallermann et al., 2015[9]	Sony Alpha7R/Sony Camcorder/Panasonic TZ61/FLIR therma	Aging buildings and dams monitored.
Metni and Hamel, 2007[10]	N/A	Identifying bridge deck defects.
Na and Baek, 2016[11]	N/A	Non destructive testing in the structure
Ortiz et al., 2013[12]	Canon IXUS i130/Raytheon 2500 AS infrared	Analyzing building walls' weathering.

2.3 Smartphone Sensing Method

Modern cellphones are integrated with acceleration sensors, gyroscopes, and GPS, which may be effectively utilized to check the status of buildings. With the popularity and availability of inexpensive cellphones, it has become mainstream to use them to monitor and modernize buildings. Owing appealing qualities of cellphones, they offer tremendous promise for SHM applications for large-scale installations. Shrestha et al., 2018 in their study, presented and confirmed the seismic reaction of a building to solve the issue of high-quality vibration monitoring, avoiding data loss utilizing various technological systems. Feldbusch et al., 2017 have created a programi Dynamics. For employing SHM for semi-professional vibration monitoring. Ozer et al., 2017 designed and verified a hybrid sensor system for modelling. 3 distinct iPhone 3GS, 5, 6 coupled with piezoelectric accelerometers and laser vibrometers wereemployed as a hybrid process to handle the vision-based building deflection problem. Table 3. elaborates type of cameras and its finding from the study.

Table 3. Smarth Sensing structural health monitoring

Literature	Type of camera	Specifications
Feng et al., 2017[13]	iPhone 3GS, iPhone 5, with iOS and Samsung Galaxy S4 with Android 5.0.1, “Lollipop.	Generate big data from smartphone accelerometers.
Ozer and Feng, 2016[13]	iPhone 5	Synthesizing sparse sensor data spatiotemporally.
Ozer et al., 2017b[13]	iPhone 3GS and iPhone 5 and iPhone 6 with iOS	Hybrid smartphone-based sensing system combines accelerometers and other sensors.
Wang et al., 2018[13]	iPhone 6	Smartphone camera and DIC.
Shrestha et al., 2018[13]	Multiple smart device systems	Building's earthquake-induced response.

2.4 Mobile Sensor Method

Further, devices enabled in robotic technology, mobile capture may be utilized to do precise, real- time statistics collecting with low setup expenses. It is considered as an improvement and sophisticated use of wireless sensor technology (i.e., the following wireless sensor technology revolution) that may provide greater data rates and precise time synchronization. Like devices, mobile sensors provide various enticing characteristics available to SHM apps. Aside from becoming economical, time-saving, and small, these sensors may be simply applied with cameras and wireless sensors for easier and quicker data collecting. In line with the work done,evaluating of the usage of a mobile sensor to comprehend compression of modal dimensions instead of a broad variety of sensors. The suggested spatial compression approach uses a mobilesensor consisting of “Imote2” and a “stationary sensor” termed SHM. The portable sensor travelled over the building and was fastened with an accelerometer at certain spots where modal coordinates were needed. The robustness of this technique was evaluated by doing a sensitivityanalysis regarding the mistakes in detecting natural frequencies, the location of the stationary sensor, and the signal-to-noise ratio. Some of them designed and verified a novel mobile sensorsystem as proof-of-concept research for the SHM. The suggested mobile sensor structure consists of two 2-wheeled automobiles linked to a truss carrying the accelerometers. Each wheeled car utilized “two infrared sensors and two Hall effect sensors” detecting angular velocity. The tiny magnets encircled the wheels to create magnetism amongst the indicator & the steel portal frame. Following research aimed towards determining the structural degradationin steel portal frames. Multiple-damage scenarios were explored to assess the effectiveness of mobile sensor devices.

3 Next-Generation Materials

Quite a large varienty of materials are available in todays market as a form of advancements. Fibres are contributing alot in compressive strength, flexural strength etc ofa concrete structure.

3.1 Steel Fibres

In general, adding steel fibres to concrete will increase the mix's importance whereas decreasing the concrete's workability. Concrete with steel fibre reinforcement (SFRC) could be a stuff created of hydraulic cements. each coarse and fine mixture are present. Since steel and cement both have smart tensile and compressive strengths, they'll stand up to the forces of wind and earthquakes. though the thought of mistreatment fibres to bolster brittle materials isn't new, it absolutely was solely begun within the early 1960s. Steel fibre concrete (SFRC), that improvesflexural strength, tensile strength, and impact resistance, is formed by adding steel fibres to concrete. As it additionally will increase structural stability and guards against crack deformation, that affects the length of the structures' lives, creating advantage of the employment of Steel fibre concrete (SFRC) needs correct configuration dissent from traditional concrete andworkability of the concrete would be affected because the amount of fibres increasing. Still SFRC Structures are limited, and a steel fibre is not thought about to be economical and fewer stable as they usually employed in tunnel and underground steel fibres principally developed toseveral small cracks to few macro cracks. The Effects of Steel Fibre on the Mechanical Strengthand Durability of Steel Fibre Reinforced High Strength Concrete.

The maximum compressive strength of 61.5 MPa as well as flexural strength of 11.45 respectively are when steel fibre at varying dosage were mixed with concrete [18].Further reflected in **Figure 2.**

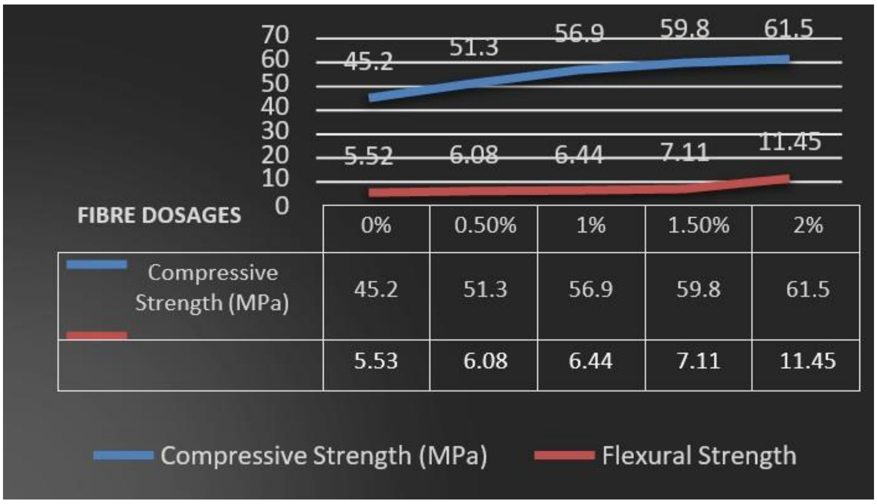

Fig.2. Strengths obtained after 7 days of curing

The maximum compressive strength of 24 MPa as well as flexural strength of 11.78 respectively are when steel fibre at varying dosage were mixed with concrete. As demonstrated in **Figure 3**

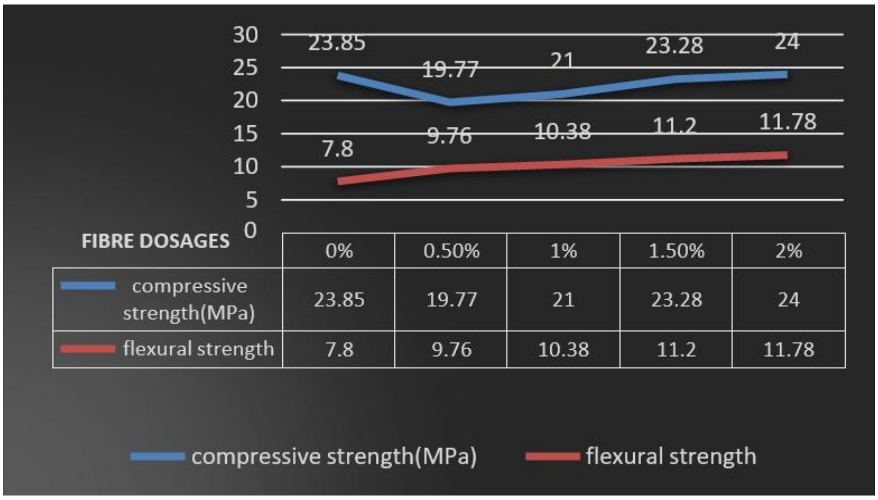

Fig. 3. Strengths obtained after 7 days of curing

The maximum compressive strength of 20.1 MPa as well as flexural strength of 3.97 respectively are when steel fibre at varying dosage were mixed with concrete. As demonstrated in **Figure 4.**

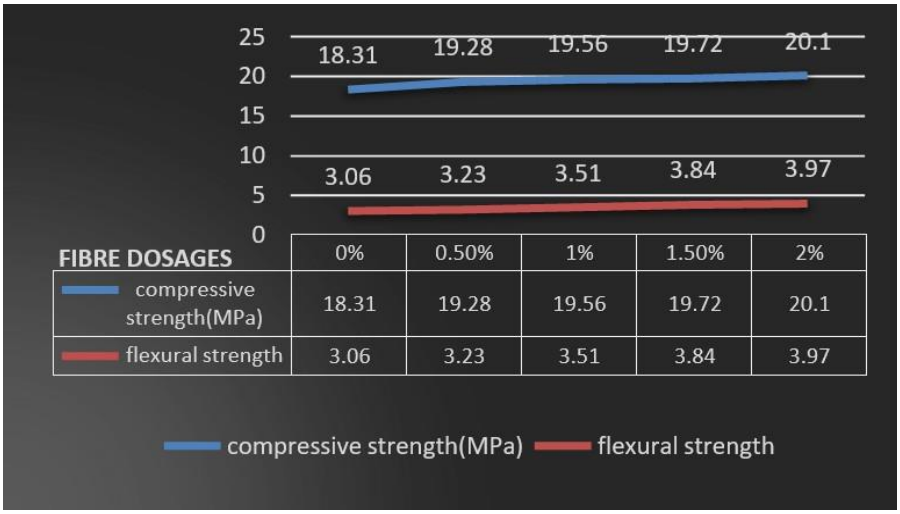

Fig. 4. Strengths obtained after 7 days of curing

3.2 Polypropylene Fibre

There is a detailed discussion of the polypropylene fibre concrete's qualities. Polypropylene is employed as a fibre material in a variety of civil engineering applications in addition to being used in textile products “P. Sathe et al (2013)” Polypropylene Fiber Reinforced Concrete with Artificial and exploratory work of trial examination on polypropylene fibre reinforced cement by substituting river sand for manufactured sand with and without admixture. Mention in Table 4.

Table 4: Compressive Strength achieved after 28 days

Curing Time	Fibre Dosages (in %)	Compressive Strength(MPa)
28 DAYS	0	39.91
	0.5	49.56
	1	43.36
	1.5	37.44
	2	48.5

Milind V. Mohod (2015)” an experimental study has been carried out to check the effect of polypropylene fibre reinforced concrete. In this the impact of polypropylene while adding polypropylene fibers at different dosages has been demonstrated as presented in Table 5.

Table 5: Compressive and Flexural Strengths achieved after 28 days

Curing Time	Fibre Dosages (%)	Compressive Strength (MPa)	Flexural Strength (MPa)
28 DAYS	0	38.50	4.34
	0.5	42.14	5.21
	1	44.61	5.48
	1.5	46	5.71
	2	41.72	4.82

4 Conclusions

Sensor technology advancements, such as cameras, UAVs, mobile phones, and adaptable sensors, are transforming local and global investigations and SHM. Advanced materials like steel and polypropylene fibres increase compressive strength and flexural strength, with the highest strength achieved at 2% fibre dosage. Intelligent detection systems are increasingly used for inspecting, retrofitting, and controlling large designs, with non-contact sensors for remote design verification. Real-time tracking of buildings in inclement weather requires examining their durability. These developments in structural health monitoring and surveillance are currently evolving, just like everything else, but with the aid of accessible, affordable, and effective computing tools. The use of cloud computing to capitalise on the benefits that can be gained from using computationally efficient smart sensors for online monitoring is still in its infancy stage.

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