To study importance of Structural Health monitoring for Concrete members

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Abstract : Global construction market has huge potential and concrete play key role in most of construction projects. Concrete strength depends on many parameters i.e. strain, humidity, temperature, cracks and vibrations etc. These parameters when monitored in real time will help to get insight of these parameters. SHM (Structural health monitoring) is based on NDT (Non-destructive testing) here sensors will be used colleting real time data so as to find weakness or issues in structures and take informed decision. Hence in this study main objective to study various properties of SHM and how it can help concrete structures.

Key words: Concrete, SHM, Sensors, WSN

I. INTRODUCTION

Global construction market has potential to grow around $25928.27 by 2032 (https://www.thebusinessresearchcompany.com/report/construction-market). Prefabrication can solve may issue of construction site like productivity, safety, quality etc. and has main phases like production (include storage); Transportation (delivery and shipping) phase; and assembly phase (DTU, 2019). Precast can be used for residential project (Great Magtech electric, 2024) also has ability to use embedded electronic for new functionalities (Michaël David et al, 2024). As precast industry uses concrete as main element hence concrete play an important role. It is also possible to integrate various high technologies like BIM, AR and VR; Data accusation RFID, barcode, GPS, image recognition, CCTV; Data integration cloud computing; and during decision making AI, simulation etc. in precast construction (Zhuo Cheng, et al, 2023).

SHM (Structural health monitoring) is based on NDT (Non-destructive testing) (Yoann Hebrard, 2019) here sensors will be used colleting real time data so as to find weakness or issues in structures and take informed decision (Forough Farhadi, 2024). Hence in this study main objective to study various properties of SHM and how it can help concrete structures.

II. LITERATURE REVIEW

A. SHM

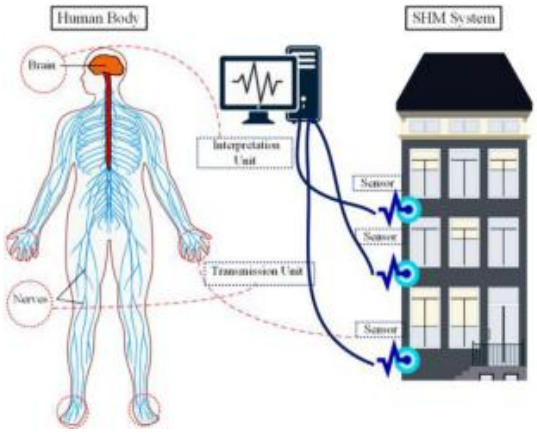

Fig 1: Comparison between Human body and SHM system Source: (Vahid Reza Gharehbaghi, et al, 2022)

SHM is based on NDT (Yoann Hebrard, 2019) and considers real time monitoring of structures (Vinamra Bhushan Sharma et al, 2021) with help of embedded sensors (Forough Farhadi, 2024). It is similar to human structure as shown in figure 1, just like human has brain, nerves and senses to collect information regarding their environment (may be internal or external) so as to maintain their health. In SHM system also sensor will used to collect information and then computers will be used for data analysis as well as take decision.

(Vinamra Bhushan Sharma et al, 2021) observes that IoT will help in case of continuous monitoring. IoT will include four main components i.e. Wireless sensor network (WSN); gateway; RCSR (Remote control and service room); and OPC (Open Platform

communication) client server. As per (Adam B. Noel et al, 2017) WSN will be powerful as well as low-cost platform to connect large network of sensors which can be used in SHM also as there will be distributed throughout structure for assessing structure health. As per (Ni solution, 2024) SHM will combine different physical sensing and measurement technique with continuous and remote processing so as to capture real time data and log it for historical record and then analyses continuously. As per (Vinamra Bhushan Sharma et al, 2021) AI can be used along with DL (deep learning) models in case of SHM and IoT as well as cloud computing can help.

IoT helps in monitoring in real time for early age compressive strength of concrete (Dane Miller et, al, 2023), or to find cracks inside concrete structure; concrete crack width; corrosion of steel reinforced steel bars. location of crack and its width for various structures; damage due to cracks and loosening of bolts; fatigue crack detection etc. (Mayank Mishra et al, 2022). As per (Fatheali A. Shilar, et al, 2024) sensor-based study in concrete will help to understand concrete.

B. SHM process

SHM process has many steps as shown in fig 2.

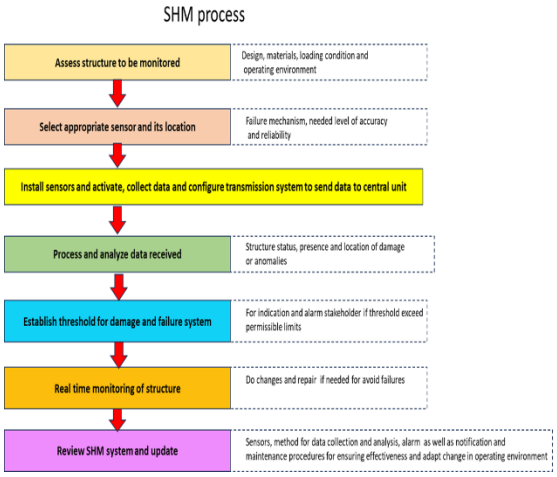

Fig 2: SHM process source: Fatheali A. Shilar et al, 2024

C. Components of SHM

As per (Vinamra Bhushan Sharma et al, 2021) SHM, IoT as well as cloud computing will result in sophisticated data diagnosis and cloud platform will act as storage as well as used for intelligent monitoring device on SHM system. Here real time health status can be communicated to internet server and captured as well as saved data on server will be viewed as well as interpreted by ML remotely from mobile device. As per (Imad Jawhar, et al, 2018) cloud will help many advanced services in case of distributed application which need real time, low latency, mobility, data streaming, coordination, synchronization, and interaction support services due to transmission delay which are imposed due to large distance to be covered and it will be difficult for cloud to manage large number of heterogenous sensors, and actuator and other devices which are distributed to large area. Fog computing will give more localized, and low latency and mobility service and permit to move some functionalities from cloud closer to device.

As IoT can be used for SHM hence it will include Wireless sensor network (WSN) (Vinamra Bhushan Sharma et al, 2021) also as per (Adam B. Noel et al, 2017) WSN will be powerful as well as low cost platform to connect large network of sensors which can be used in SHM also as there will be distributed throughout structure for assessing structure health.

Hence WSN as well as sensors are considered in detail.

D. WSN (Wireless sensor network)

WSN is collection of devices which communicate through wireless channels and WSN includes distributed devices with sensors which can monitor environmental and physical condition (Suryateja Pericherla, 2024). As per (Adam B. Noel et al, 2017) during WSN for SHM sensors will be deployed at various locations throughout structure and collect information regarding surrounding like accelration, load, ambient vibration, stress at sampling frequencies upwards of 100 Hz (Adam B. Noel et al, 2017).

As per (Shivamkumar, 2024) generalized WSN architecture will have sensor node with onboard processor which will among and monitor environment in specific area and this node is connected to Base station that will act as processing unit in WSN system. Then base station in WSN system will be connected by Internet to share data and WSN may be used for processing, storage, analysis, and mining of data. As per (Víctor Sámano-Ortega, et al, 2024) in case of IoT based WSN three layers will be there i.e. PL (preparation layer); NL (network layer); and AL (application layer). Here PL has wireless nodes (WSn) that read information from their work environment and share information through common wireless network i.e. WSN. NL holds routing devices and internet network for transmitting collected information from PL to cloud. Then AL will organize, analyse and display recorded

data by using cloud services, thus data will be understood by end users (Víctor Sámano-Ortega, et al, 2024).

WSN has many topologies like Bus topology; star topology; tree topology; Ring topology; mesh topology and hybrid topology. In case of mesh topology nodes will be connected with each other and form mesh like structure and data will travel through multiple paths from one node to other till it reaches to destination (Shivamkumar, 2024). In this study to scale up system this topology can help.

WSN can be five types as per (Kingsley Eghonghon Ukhurebor, et al, 2020), these include: WPAN (wireless personal area network); WLAN (wireless local area network); WMAN (wireless metropolitan area network); WWAN (wireless wide area network); WGAN (wireless global area network) (Kingsley Eghonghon Ukhurebor, et al, 2020).

WSN uses many wireless standards (wikipedia$_a$, 2024) i.e., IEEE standard 802.15.4 (wikipedia$_b$, 2024); Thread (wikipedia$_c$, 2024); Zigbee (wikipedia$_d$, 2024)); Xbee (also known as Digi XBee (wikipedia$_e$, 2024)); WiFi direct (wikipedia$_f$, 2024)); Z wave (Wikipedia$_g$, 2024)); MiWi (Wikipedia$_h$, 2024)); WirelessHART (Wikipedia$_i$, 2024)); 6LoWPAN (Wikipedia$_j$, 2024)); BLE (wikipedia$_k$, 2024)); LoRa (Long Range) (Wikipedia$_l$, 2024)).

WSN uses many operating system (OS) i.e. TinyOS (Wikipedia$_k$, 2024); OpenWSN (Wikipedia$_l$ 2024)); LiteOS (Wikipedia$_m$ 2024)); Contki (wikipedia$_n$ 2024)); RIOT (Wikipedia$_o$, 2024)).

WSN can have many applications like logistics system to real time monitoring of different parameters and handle packages; used by robots for cooperation and combat main problem; in SHM (Dionisis Kandris, 2022).

WSN has many advantages like low cost; wireless communication; energy efficiency; scalability and real time monitoring. But faces many challenges i.e. limited power and energy; processing and storage capabilities; installation; has heterogeneity; problem of security; interference; and reliability (Shivamkumar, 2024).

E. Sensors

Sensors will be used for measuring various parameters which are relevant in SHM. Also, when SHM will be used for concrete structure than various important parameters can be monitored include:

- Stress: material will have stress due to force and this stress include: tensile, compressive and shear stress. Over stressing in members can affect structural performance and safety of members. These effects include: structural failure, cracking, reinforcement yielding, deflection, reduced service life etc. For real time monitoring sensors can include: Fiber optic sensors (Article by FPrimeC solution, 2020).
- Strain: is deformation of concrete as well as steel under stress and as per (Forough Farhadi, 2024) in case of SHM strain gauge can be used for capturing stress-strain relationship within materials. Many sensors can be used for strain measuring i.e. Fiber optic sensors, Load cell, Strain gauge (Article by FPrimeC solution, 2020, Ni solution, 2024, Adam B. Noel et al 2017).
- Humidity: as per (Shima Taheri, 2019) continuous presence of water and moisture can accelerate corrosion and reduce resistance of concrete (Shima Taheri, 2019). It is also noted that low humidity results in faster evaporation from surface of fresh concrete and result in surface cracking and thus reduce strength. Very high humidity can result in delayed setting time and difficulty in finishing. Thus, ambient humidity level will be 50-70%. There are many sensors which can be used i.e.: CMOS humidity sensor uses passive wireless humidity senor, and UHF (Ultra high frequency) RFID technology for low power application (Shuangxi Zhou et al, 2016).
- Temperature: concrete curing is hydration reaction also as variation in temperature can disturbed curing process which leads to drying, cracking, shrinkage as well as thermal stress and then loss of integrity as well as durability (Shima Taheri, 2019). High temperature (above 30^0C) though accelerate strength gain initially but has risk of excessive evaporation of moisture and hence surface cracking thus reduces ultimate strength of concrete. Low temperature (below 10^0C) will result in delayed strength gain and also may have risk of freezing. Hence ambient temperature for curing will be 10^o-30^oC. There are many sensors which can be used i.e.: Fiber optic sensors, Temperature sensor (Article by FPrimeC solution, 2020).
- Crack: Crack in case of concrete will impact its strength as well as durability. Cracks can be measured by many sensors i.e.: LVDT, Crack sensors (for crack width), Fiber optical crack detection system for crack detection and localization (Arvid Hejill, 2007).

- Vibration**:** it will have both effects i.e. beneficial (improved compaction, reduced segregation, improved strength etc.) and negative effect (crack, formation of voids, delamination, aggregate movement etc.). There are many sensors used to measure it i.e.: Fiber optic sensors, Piezoelectric accelerometer (Article by FPrimeC solution, 2020).
- Corrosion**:** concrete properties degradation can results because of combination of internal and external factors and thus results in corrosion of reinforcing steel and other embedded materials. Here rust will be byproduct of corrosion and oxidation of reinforcing steel which leads to expansion and then tensile stress will be developed in concrete (Shima Taheri (2019). There are many sensors which can be used i.e.: MicaZ mote (Guofu Qiao, et al, 2014); and corrosion wafer (Adam B. Noel et al, 2017).

III. CONCLUSION:

As global construction market is growing and concrete elements plays important role. Precast industry can use many high technologies like BIM, AR and VR; Data accusation RFID, barcode, GPS, image recognition, CCTV; Data integration cloud computing; and during decision making AI, simulation etc. SHM is based on NDT and uses sensors for collecting data in real time to find weakness or issue in structure for taking informed decisions. IoT based SHM is possible which has two main components i.e. WSN and sensors. Also, SHM can help to real time monitoring of compressive strength of concrete (in Lab and at site), plastic shrinkage cracks, crack inside concrete structure, corrosion of steel, material tracking for precast construction project, monitor personals on construction site etc. in case of concrete project.

This shows that SHM can play important role in concrete construction works and in future there is need to develop a system which can be used to monitor real time properties of concrete and steel properties.

REFERENCE

[1] Adam B. Noel, Abderrazak Abdaoui, Tarek Elfouly, Mohamed Hossam Ahmed, Ahmed Badawy, and Mohamed S. Shehata (2017), "Structural Health Monitoring Using Wireless Sensor Networks: A Comprehensive Survey", IEEE COMMUNICATIONS SURVEYS & TUTORIALS, VOL. 19, NO. 3, THIRD QUARTER 2017

[2] Article by FPrimeC solution (2020), "Sensor for structural health monitoring", report by FPrimeC solution available at https://fprimec.com/sensors-for-structural-health-monitoring/

[3] Arvid Hejill (2007), "Civil Structural Health Monitoring -Strategies, Methods and Applications", PhD thesis, Division of Structural Engineering, Department of Civil and Mining Engineering, Luleå University of Technology

[4] Dane Miller, Nhat-Minh Ho, Nima Talebian & Zia Javanbakht (2023), "Real-time monitoring of early-age compressive strength of concrete using an IoT-enabled monitoring system: an investigative study", Innovative Infrastructure solutions, Volume 8, article number 75, (2023), Springer

[5] Dionisis Kandris (2022) "Applications of Wireless Sensor Networks", Scholarly Community Encyclopedia, available at https://encyclopedia.pub/entry/17294

[6] DTU (2019)."SWOT analysis for Prefabrication Housing Production", This page was last modified on 3 March 2019, at 13:32., available at http://wiki.doing-projects.org/index.php/SWOT_analysis_for_Prefabrication_Housing_Production

[7] Fatheali A. Shilar, Sharanabasava V. Ganachari, Veerabhadragouda B. Patil, T. M. Yunus Khan, Abdul Saddique Shaik and Mohammed Azam Ali (2024), "Exploring the Potential of Promising Sensor Technologies for Concrete Structural Health Monitoring", Materials 2024, 17, 2410. https://doi.org/10.3390/ma17102410

[8] Forough Farhadi (2024), "Types of sensors in construction industry; 2024 Review", Construction Magazine, available at https://neuroject.com/types-of-sensors/

[9] Great Magtech electric (2024), "Precast Concrete Buildings Are Booming Around The World", available at https://www.precastconcretemagnet.com/news/precast-concrete-buildings-are-booming-around-74476675.html#:~:text=Precast%20concrete%20is%20widely%20used,is%20about%2030%2D40%25

[10] Guofu Qiao, Guodong Sun, Yi Hon, Tiejun Liu and Xinchun Guan (2014), "Corrosion in

Reinforced Concrete Panels: Wireless Monitoring and Wavelet-Based Analysis", Sensors 2014, 14, 3395-3407; doi:10.3390/s140203395

[11] Imad Jawhar, Nader Mohamed and Jameela Al-Jaroodi (2018), "Networking architectures and protocols for smart city systems", Journal of Internet Services and Applications, (2018) 9:26, https://doi.org/10.1186/s13174-018-0097-0, Springer open access

[12] Kingsley Eghonghon Ukhurebor, Ituabhor Odesanya, Silas Soo Tyokighir, Rout George Kerry, Akinola Samson Olayinka and Ayodotun Oluwafemi Bobadoye (2020), "Wireless Sensor Networks: Applications and Challenges", FROM THE EDITED VOLUME, Wireless Sensor Networks - Design, Deployment and Applications, Edited by Siva S. Yellampalli. SRM University, India, Intech open

[13] Mayank Mishra, Paulo B. Lourenço, and G.V. Ramana (2022), "Structural health monitoring of civil engineering structures by using the internet of things: A review", Journal of Building Engineering, Volume 48, 1 May 2022, 103954

[14] Michaël David, William Derigent, Gaël Loubet, Alexandru Takacs, Daniela Dragomirescu (2024), "Communicating materials: Communicating concrete development for construction industry", IEEE Transactions on Industrial Informatics, 2024, 20 (4), pp.6983-6994.

[15] Ni solution (2024), "New Technologies for Structural Testing and Health Monitoring", available at https://www.ni.com/en/shop/compactrio/new-technologies-for-structural-testing-and-health-monitoring.html

[16] Shima Taheri (2019), "A review on five key sensors for monitoring of concrete structures", Construction and Building Materials, Volume 204, 20 April 2019, Pages 492-509, Elsevier

[17] Shivamkumar (2024), "Wireless Sensor Network (WSN)", available at https://www.geeksforgeeks.org/wireless-sensor-network-wsn/

[18] Shuangxi Zhou, Fangming Deng, Lehua Yu, Bing Li, Xiang Wu and Baiqiang Yin (2016), "A Novel Passive Wireless Sensor for Concrete Humidity Monitoring", Sensors 2016, 16, 1535; doi:10.3390/s16091535

[19] Suryateja Pericherla (2024), "IoT enabling technologies", available at https://www.startertutorials.com/blog/iot-enabling-technologies.html

[20] Vahid Reza Gharehbaghi, Ehsan Noroozinejad Farsangi, Mohammad Noori, T. Y. Yang, Shaofan Li, Andy Nguyen, Christian Málaga-Chuquitaype, Paolo Gardoni & Seyedali Mirjalili (2022), "A Critical Review on Structural Health Monitoring: Definitions, Methods, and Perspectives", Arch Computat Methods Eng 29, 2209–2235 (2022). https://doi.org/10.1007/s11831-021-09665-9, available at https://link.springer.com/article/10.1007/s11831-021-09665-9

[21] Víctor Sámano-Ortega, Omar Arzate-Rivas, Juan Martínez-Nolasco, Juan Aguilera-Álvarez, Coral Martínez-Nolasco and Mauro Santoyo-Mora (2024), "Multipurpose Modular Wireless Sensor for Remote Monitoring and IoT Applications", Sensors 2024, 24, 1277. https://doi.org/10.3390/s24041277

[22] Vinamra Bhushan Sharma, Saurabh Tewari, Susham Biswas, Bharat Lohani, Umakant Dhar Dwivedi, Deepak Dwivedi, Ashutosh Sharma and Jae Pil Jung (2021), "Recent Advancements in AI-Enabled Smart Electronics Packaging for Structural Health Monitoring", Metals, 2021, 11, 1537. https://doi.org/10.3390/met11101537

[23] Yoann Hebrard (2019), "Structural Health Monitoring from Sensing to Processing", Advances in Structural Health Monitoring, Edited by Maguid H.M. Hassan, InTech Open.

[24] Zhuo Cheng, Shengxian Tang, Hexu Liu and Zhen Lei (2023), "Digital Technologies in Offsite and Prefabricated Construction: Theories and Applications", Buildings, 2023, 13, 163.

[25] https://www.thebusinessresearchcompany.com/report/construction-market

[26] wikipediaa, (2024), "Wireless sensor network", available at https://en.wikipedia.org/wiki/Wireless_sensor_network

[27] wikipediab, (2024), ""IEEE 802.15.4", available at https://en.wikipedia.org/wiki/IEEE_802.15.4

[28] wikipediac (2024), "Thread", available at https://en.wikipedia.org/wiki/Thread_(network_protocol)

[29] Wikipediad (2024), “ZigBee”, available at https://en.wikipedia.org/wiki/Zigbee
[30] Wikipediae (2024), “XBee”, available at https://en.wikipedia.org/wiki/XBee
[31] Wikipediaf (2024), “Wi-Fi direct”, available at https://en.wikipedia.org/wiki/Wi-Fi_Direct
[32] Wikipediag (2024), “Z-Wave”, available at https://en.wikipedia.org/wiki/Z-Wave
[33] Wikipediah (2024), “Mi-Wi”, available at https://en.wikipedia.org/wiki/MiWi
[34] Wikipediai (2024), “WirelessHART”, available at https://en.wikipedia.org/wiki/WirelessHART
[35] Wikipediaj (2024), “6LoWPAN”, available at https://en.wikipedia.org/wiki/6LoWPAN
[36] Wikipediak (2024), “Bluetooth Low Energy”, available at https://en.wikipedia.org/wiki/ Bluetooth _Low_Energy
[37] Wikipedial (2024), “LoRa”, available at https ://en.wikipedia.org/wiki/LoRa#LoRaWAN
[38] Wikipediak (2024), “TinyOS”, available at https://en.wikipedia.org/wiki/TinyOS
[39] Wikipedial (2024), “OpenWSN”, available at https://en.wikipedia.org/wiki/OpenWSN
[40] Wikipediam (2024), “LiteOS”, available at https://en.wikipedia.org/wiki/LiteOS
[41] Wikipedian (2024), “Contki”, available at https://en.wikipedia.org/wiki/Contiki
[42] Wikipediao (2024), “RIOT (operating system)”, available at https://en.wikipedia.org/wiki/ RIOT_(operating_system)