**Wireless Carbon Nanofiber Aggregate Sensor System for Real-Time Water Level Monitoring and Flood Warning**

1. **Introduction**

Today, concrete is the second most used building material across the globe. It is a mixture of cement gel matrix with granular coarse-fine aggregates and water with the necessary amount of additive and mineral materials in the proper ratio. The researchers in this field of study have been working to improve the technical functions and performance of concrete by using a different proportion of its ingredients and different types of additives. Hydrated cement as a major constituent of concrete in itself is a brittle material, and the tensile strength is typically only one-tenth of its compressive strength. To compensate for this weakness, a reinforcement of rebars and fibers are added to concrete.

Increasing the strength of concrete has been one of the key fields of investigation. On the other hand, enhancing the sensing ability of concrete is another vast field of concrete research. The sensing ability of concrete that responds its environment and the changes in strain, temperature, moisture, pH, and electric or magnetic fields is an area of interest for a big fraction of scientists and researchers in the concrete study. These sensing abilities make the concrete smart enough to be used to monitor its health regarding stress-strain, temperature, pH, moisture, electrical/magnetic responses. The concrete can even obtain an awareness of damage on itself and its surroundings. This property is utilized in Structural Health Monitoring (SHM). The technology of structural health monitoring helps in providing the capability of non-destructive flaw detection allowing concrete to be repaired before it is too late. This evaluation of safety and the durability of a structure is essential during its lifetime.

The field of fiber reinforced concrete research has been much enthusiasm for the development of the self-sensing structural system with major implementation as a structural sensor. Short electrically conducting fiber pull-out that aids the slight and reversible crack opening which enables the short fiber composites to behave as a strain sensor. Mortar or concrete reinforced with well-dispersed fibers of a diameter smaller than crack width and conductance higher than that of the matrix have strain sensing ability independent of their orientation and contact with one another The electrical conductivity of the added fibers enables the magnitude of direct current in the composite to change in response to strain variation, allowing sensing.

1. **Goal and Objectives**

The objectives of this research can be shortened as follows:

1. Develop CNFAs and investigate its’ behavior in DC vs AC Circuit
2. To optimize the CNFs content and AC frequency for CNFAs implementation
3. Investigate the waterproofing of CNFAs and implement them for real-time water level monitoring.
4. Create a water level monitor with known technology
5. Allow real time wireless data monitoring of water levels
6. **Materials and Methods**

The material properties used in the mix are as follows:

1. Fine Aggregate: Quikrete ® premium play sand
2. Cement: Martin Marietta’s ASTM Type III Portland cement
3. Carbon Nanofibers: PR-19-XT-LHT-OX by Pyrograf ®-III Product Inc.
4. High Range Water Reducer (HRWR): Master-Glenium 3400
5. Silica Fume: Master-Life SF 100
6. Waterproofing Admixture: Krystol internal membrane (KIM)
7. Steel wire mesh
8. Wire: Commercial 24 gauge stranded speaker wire
9. External waterproofing agents: MasterSeal 581 (MS-581), MasterSeal 500 (MS-500), Xypex Concentrate and quick setting professional epoxy.
10. MCP3008 ADC chip
11. 10x17 solderable breadboard
12. Water level detection sensor
13. PETG
14. Garolite
15. Raspberry Pi Zero W
16. Raspberry Pi 3 B+
17. 1602 LCD display
18. 100kΩ potentiometer
19. 1kΩ resistors

**Methods**

1. Scanning and analysing 4-probe and 2-probe mesh structure with DC circuit using Keithley Source-meter.
2. Scanning and analysing 2-probe mesh structure and waterproofing with AC circuit using Keysight E4980AL Precision LCR Meter and CHI660E Electrochemical Workstation.
3. Uniaxial compression using INSTRON 5960 Series Universal Testing Systems up to 50 kN to detect maximum response to optimize frequency and CNFs concentrations.
4. Detecting water levels using generic sensor and resistor ladder to increase resolution
5. Reporting sensor data back to a master computer in real time using a wireless access point
6. **Results**
7. Stable response in 2-probe AC circuit over either of 4-probe or 2-probe DC circuit.
8. Frequency optimized in a range of 100Khz to 200Khz for CNFA.
9. CNFA sample with 0.8% concentration of CNFs by the weight of cement produced higher response at peak load.
10. Kim Krystol is inefficent in waterproof, so are MasterSeal 581 (MS-581), MasterSeal 500 (MS-500), Xypex Concentrate. However, quick setting epoxy was useful in waterproof CNFA.
11. Reliable and repeatable calibration of water level sensors was not possible
12. Water level sensors were able to give rough estimates of the level of water present
13. Real time reporting of water level sensor to master computer worked
14. **Summary and Conclusions**

A carbon nanofiber aggregate (CNFA) with two and four meshes was developed. The development of CNFAs with CNFAs’ response in DC and AC circuits were investigated. The study was further extended with the optimization of AC frequency and carbon nanofiber (CNF) content of CNFAs for practical implementation. The optimized CNFAs were then tested to develop waterproof CNFAs with the external coating for real-time water level monitoring.

CNFA with 2-probe in AC circuit has more stable response in the frequency range of 100Khz to 200Khz in the both case of loading the sample with stress and without any stress. CNFA with 0.8% CNFs concentration produced maximum response among tested samples with different concentrations at its peak load. The electrical impedance variation (EZV) ranged from 24% to 30% in a frequency band between 500Hz and 300Khz. The scanning of optimized, externally epoxy coated, CNFA sample showed only 12% drop in response, whereas, other agents used for externally coating were inefficient as the drop in response was around 90%.

1. **List of publications, posters and presentations**

* Carbon Nanofiber Aggregate Sensors for Sustaining Resilience of Civil Infrastructures to Multi-Hazards

**7. List of students, postdocs and other research personnel involved in project**

* Avinash Gautam (Student)
* Bhagirath Joshi (Student)
* Jinghong Chen (Advisor, University of Houston)
* Yuhua Chen (Advisor, University of Houston)
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**8. Proposals submitted**

**9. Proposals awarded**

**10. References cited**

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