MEASUREMENT AND SENSOR TECHNOLOGY

Department of Electrical Engineering and Information Technology

CHEMNITZ UNIVERSITY OF TECHNOLOGY

Project Schedule

Group 19

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Development of self-powered wireless strain sensor for Structural Health Monitoring

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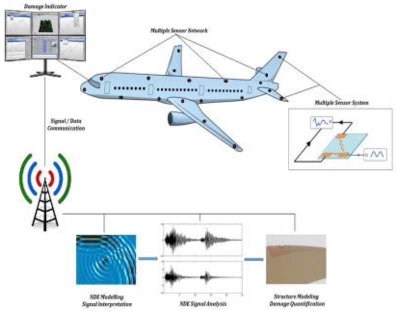
Outline

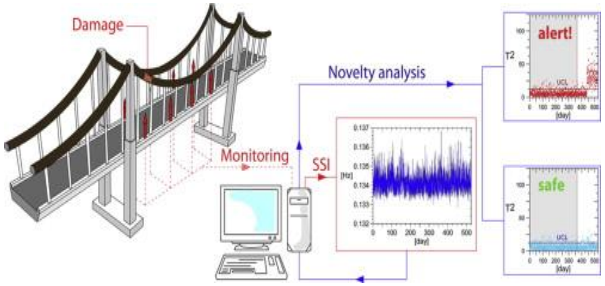
- Motivation and Challenges
- Approach
- State of the Art about flexible sensor
- The proposed self powered wireless strain sensor for Structural Health Monitoring
- Flowchart
- Experimental Setup
- Results
- Conclusion
- References

Motivation and Challenges

Motivation

Applications of SHM





Aeronautic | Civil | Mechanical structure

- Improving structural reliability
- Improving life cycle management
- Integrating various sensors used for measurements, computational power and processing ability
- Monitoring the status of structures in real time

Challenges

- Multiple sensor which consumes a lot of power
- For accuracy of the measurement, sensors needs to be flexible to be integrated within the structure , sensitive and reliable
- An appropriate power supply needs to be chosen to maintain continuous operation

APPROACH

- A self-powered wireless Strain Sensor Network (WSSN) design will be built to provide continuous monitoring of structural dynamic strain field:

✓ Selection of flexible and sensitive strain sensor that consume a very low power

✓ Implementation of wireless embedded solution that consume very low power

✓ Implementation of a energy harvester to realise a self- powered sensor with the required energy management circuit

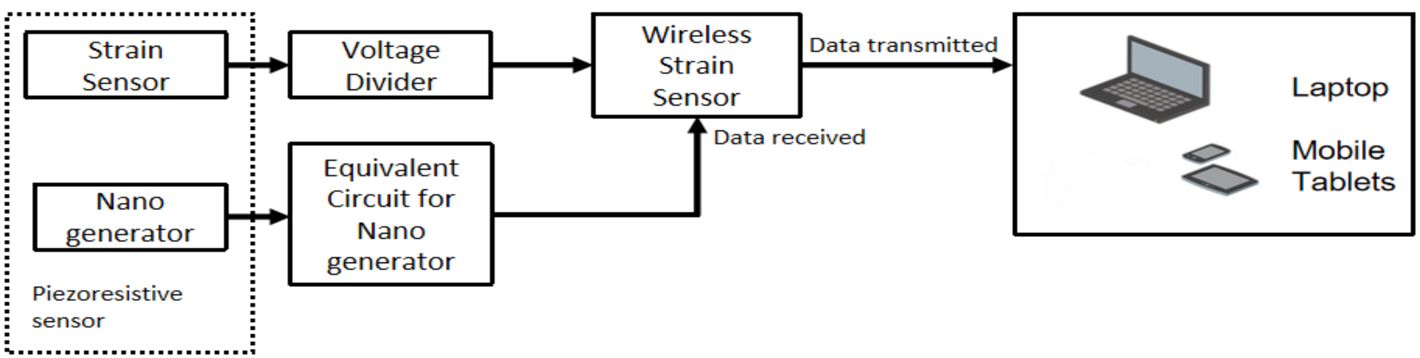


Fig 1:- Block diagram of Wireless Strain Sensor Network

State of the Art about flexible strain sensor

- **Strain Sensor for SHM**

Sensor	Material	Sensitivity	Flexibility	Power consumption	Working principle	References
Nanocomposite Strain Sensor (NCS)	Carbon Nanotubes (CNTs)	High (more than 15)	High	Low	Change in value of the resistance is due to change in resistivity	[2]
Metallic Strain Sensor	Nichrome, Nickel, Platinum	low (2-5)	low	Medium	Change in resistance is mainly due to the change in dimension	[3]
Wired Strain Sensor	Bonded Wire	low (0.5-0.85)	low	High	Requires very low resistance	[3]

Table 1:- Comparing Different types of Strain Sensors

- Resistance controls the strain sensitivity as the resistance becomes very large, the sensitivity of strain reduces.
- As the resistance becomes very large, the sensitivity of strain reduces.In order to avoid this polymer CNT are used to reduce the resistance to get long continuous strain sensor design.

Selection of Embedded Wireless Solution for Low Power Consumption

Board	ESP32[5]	ESP8266[5]	Arduino UNO[5]
Number of Cores	2	1	1
Architecture	32 Bit	32 Bit	8 Bit
CPU Frequency	160 MHz	80 MHz	16 MHz
Wifi	Yes	Yes	No
BLUETOOTH	Yes	No	No
RAM	512 KB	160KB	2KB
FLASH	16MB	16MB	2KB
GPIO PINS	36	17	14
Busses	SPI,I2C,UART,I2S,CAN	SPI,I2C,UART,I2S	SPI,I2C,UART
ADC Pins	18	1	6
DAC Pins	2	0	0

Table 2 :- Comparing different types of microcontrollers depending on low power consumption

- Therefore ESP 32 is the best option as it consumes very low power to perform operations.

Polymer/CNTs based strain sensor characterization

Working Principle:-

- Mainly focuses on the development of sensors and materials.
- Carbon nanotubes plays an important role.
- When it undergoes any stress, re-orientation and re-positioning of CNTs within the percolation network increases the base resistance of the strain sensors.
- Linear change in resistance of CNTs leads to piezo resistivity.
- Comparatively NCS sensor has higher sensitivity than conventional strain sensor.

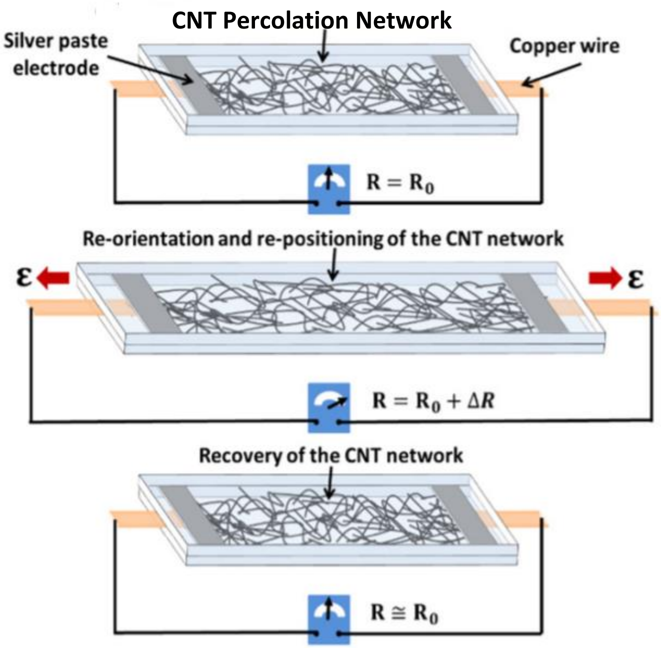
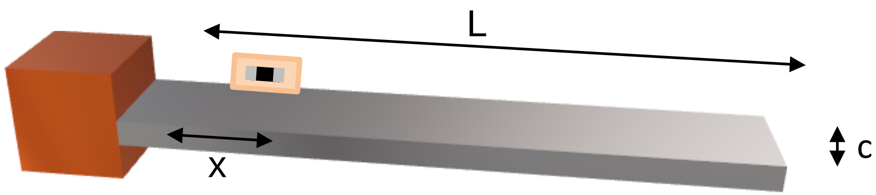


Fig 2:- Working of Nanocomposite

Polymer/CNTs based strain sensor characterization



Calculations of the sensitivity:-

- The change in relative resistance can be calculated by $\Delta R/R_0$
- Strain is given by $\varepsilon = \sigma/E = (3c(L - x)/L3)*\delta$
- Sensitivity can be calculated as:

Gauge Factor(GF)=$\Delta R/R0*\varepsilon$

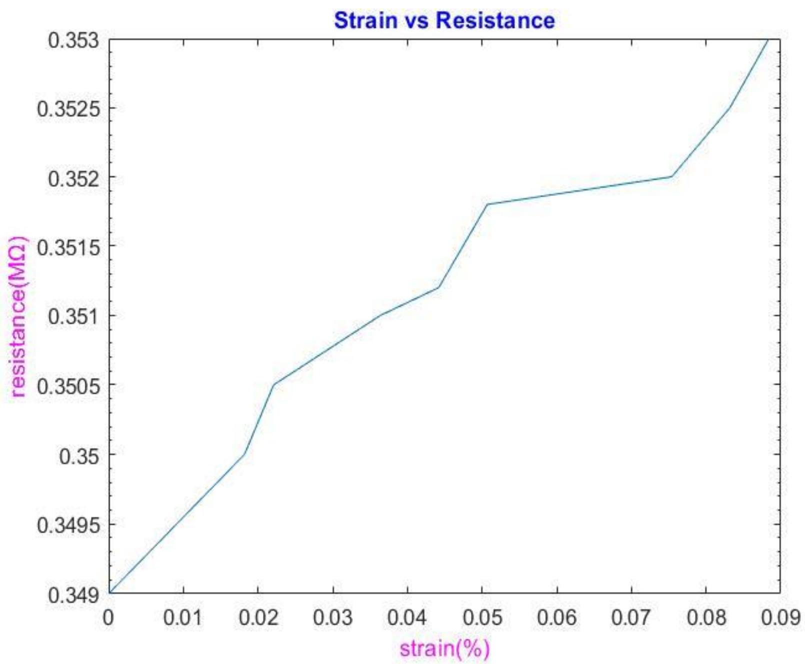


Fig 3 :- Change in Strain vs Resistance

R0 = Initial Resistance
ΔR = Change in resistance
ε = Strain
σ = Stress

c = Distance from the neutral axis to the surface of the beam
L = Length of the beam
x = Fixed end of cantilever beam to the sensor distance
δ = Deflection

Piezoelectric Nanogenerator

Working Principle:-

- It converts vibrational energy into electrical energy
- PDMS/BaTiO3/CNTs nanogenerator is used.
- As the energy conversion efficiency rate comparatively high.
- No change in functionality for longer duration.

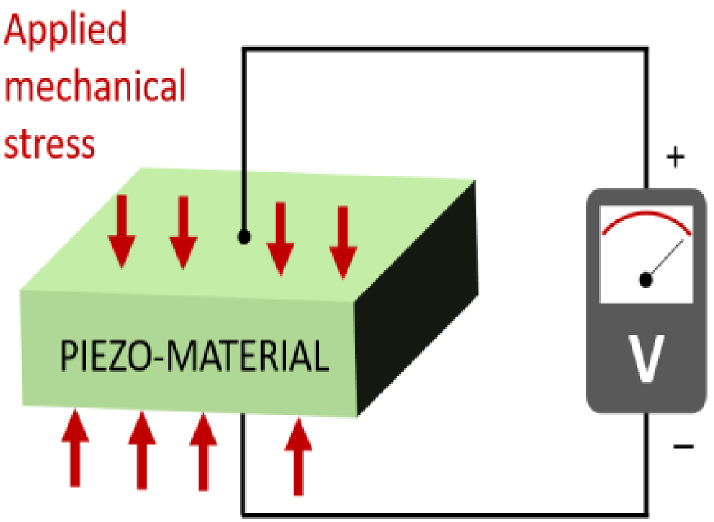


Fig 4 :- Working of Piezoelectric Nanogenerator

Piezoelectric Nanogenerator

Characterization of piezoelectric nanogenerator:-

Measurement Conditions :-
Input from frequency generator:
Frequency =30Hz
Voltage =10V

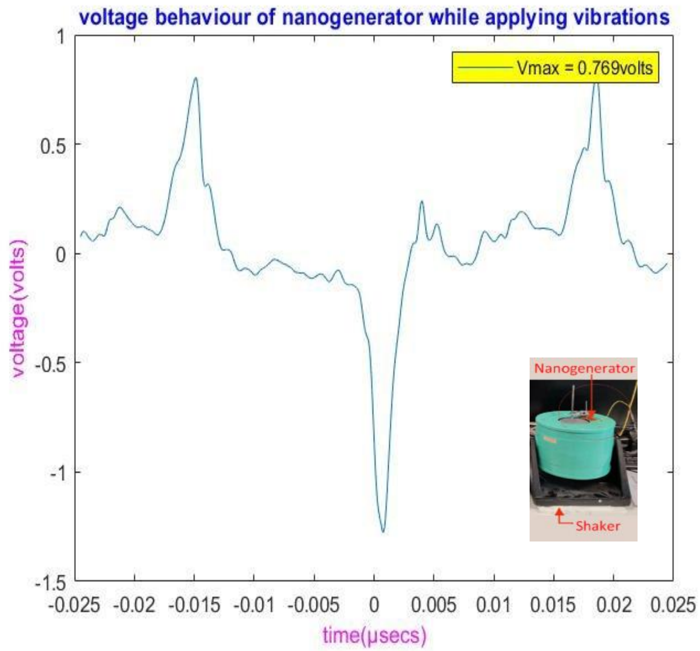


Fig 5 :- Voltage behaviour while applying vibrations

Measurement Conditions :-
Input from voltage generator:
Voltage =10V

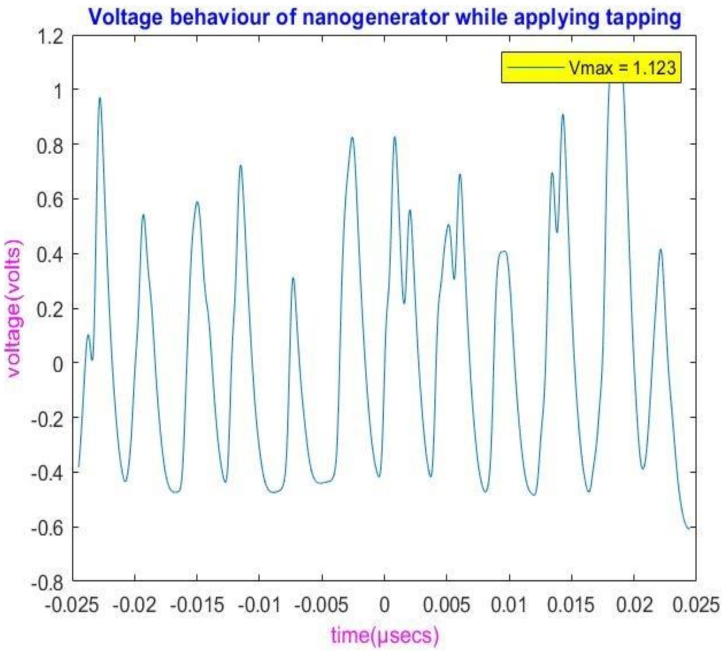


Fig 6 :- Voltage behaviour while applying tapping

Efficient Energy Management Circuit for Energy Harvesting

	How is energy harvested under low electromechanically regime?	How is load Independence?	How low voltage Harvesting?	Implementation complexity	Efficiency	References
STANDARD	poor	poor	poor	none	low	[10]
SERIES SSHI(DIODELESS)	good	poor	good	low	medium	[10]
PARALLELSSHI	good	poor	good	low	medium	[10]
HYBRID SSHI	good	good	good	low	high	[10]
SSDCI	good	good	good	low	high	[10]
SECE	good	poor	good	medium	high	[10]
DSSH/ESSH	very good	good	good	medium	high	[10]
LTC3588	very good	good	good	low	very high	[07]

Table 3 :- Selecting an Efficient Circuit

- As the generated electrical energy from nanogenerator is in the form of Alternating Ccurrent and also due to the presence of piezoelectric effect in the PENG component there is huge power loss, while extracting from it.

Efficient Energy Management Circuit for Energy Harvesting

LTC 3588:-

Working Principle:-

- An integrated low-loss full-wave bridge rectifier.
- Higher efficiency Dc-Dc converter is present.
- An ultralow quiescent current under voltage lockout (UVLO) mode allows charge to accumulate on an input capacitor.
- The buck converter turns on and off as needed to maintain regulation.

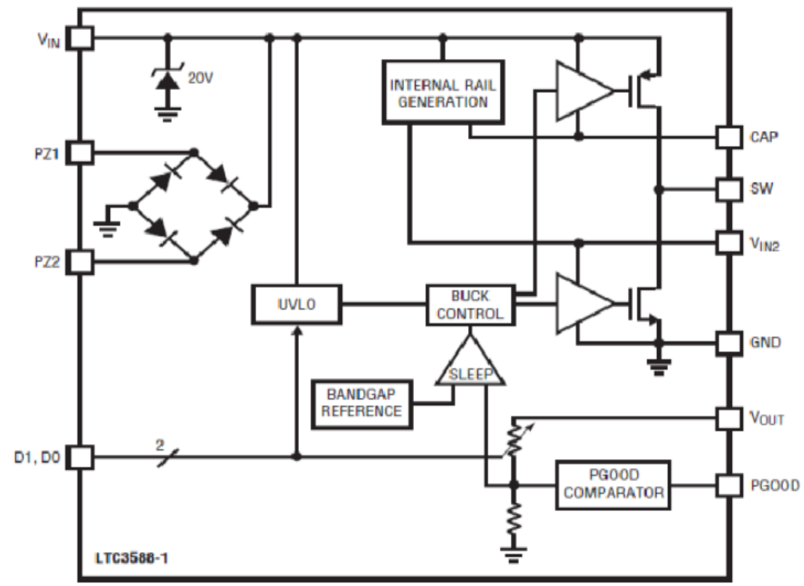


Fig 7 :- Circuit Diagram of LTC3588

The proposed self-powered wireless strain sensor for Structural Health Monitoring

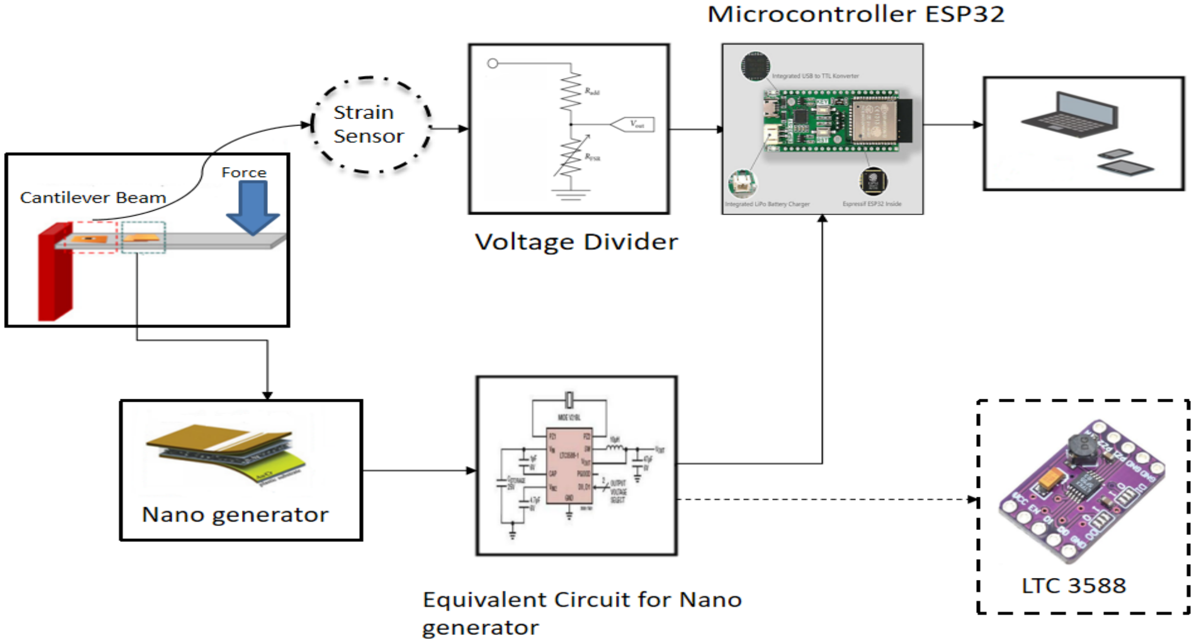
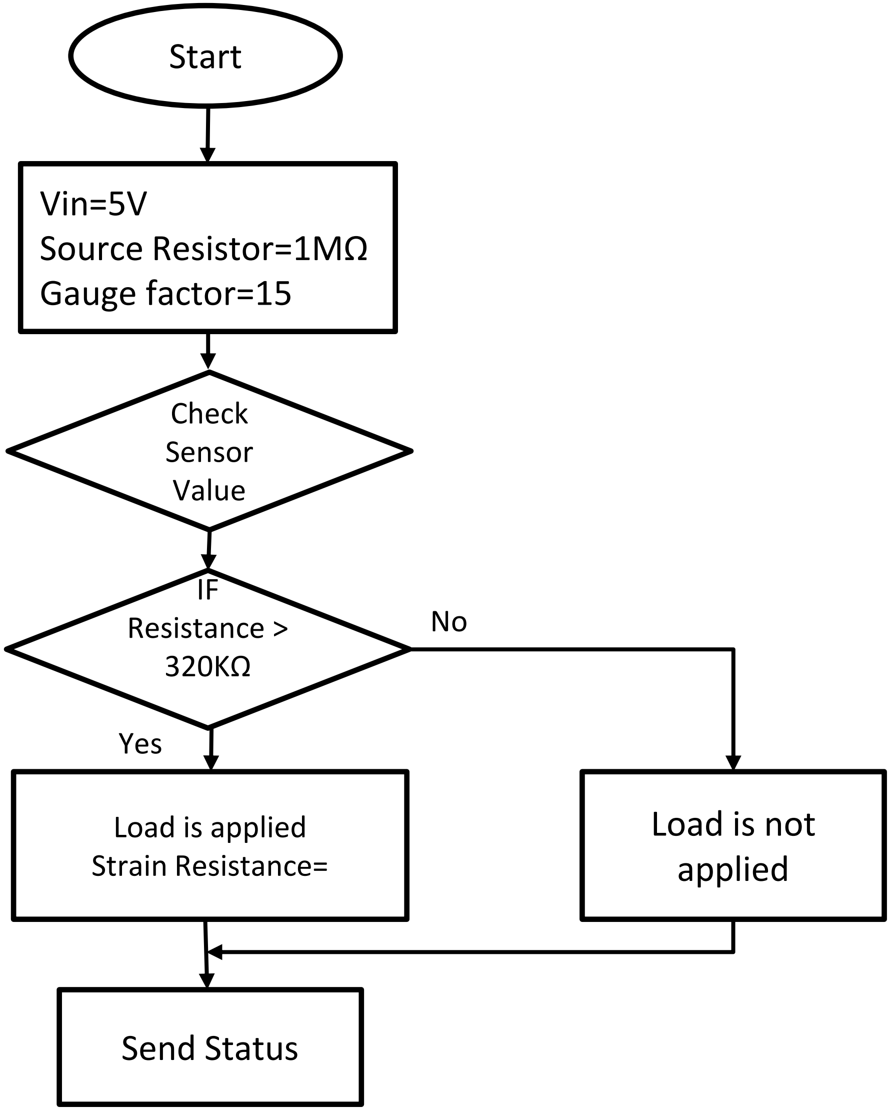


Fig 8:- Block Diagram of self-powered wireless strain sensor for Structural Health Monitoring

- Nanocomposite Strain Sensor
- Nano generator
- Microcontroller ESP32
- LTC3588

Flowchart


Start
Vin=5V
Source Resistor=1MΩ
Gauge factor=15
Check
Sensor
Value
IF
Resistance >
320KΩ
No
Yes
Load is applied
Strain Resistance=
Load is not
applied
Send Status

Experimental Setup

- The experimental setup for the project is as shown in the figure below. The sensor is placed on the cantilever beam. ESP32 is integrated with the nanocomposite strain sensor in order to monitor the resistance value with the increasing load.

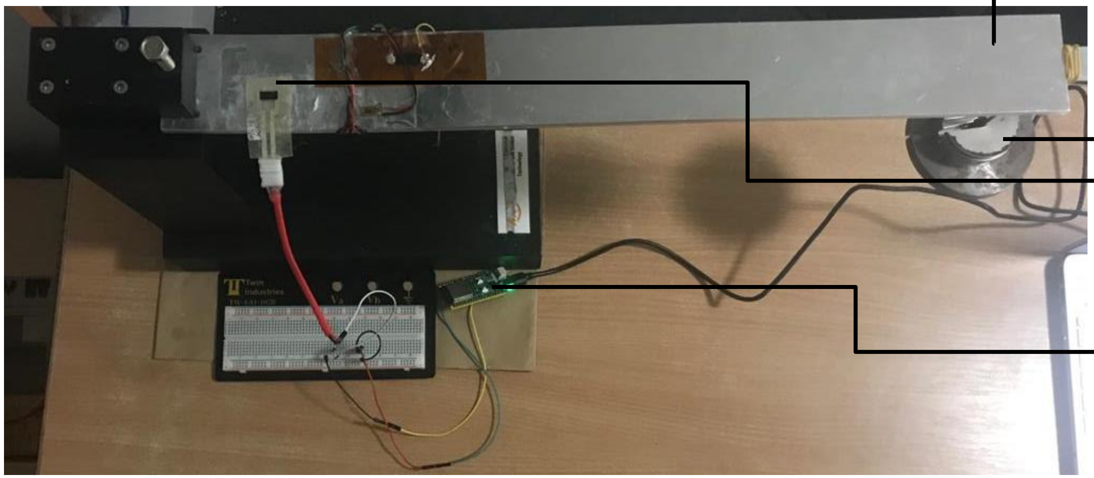
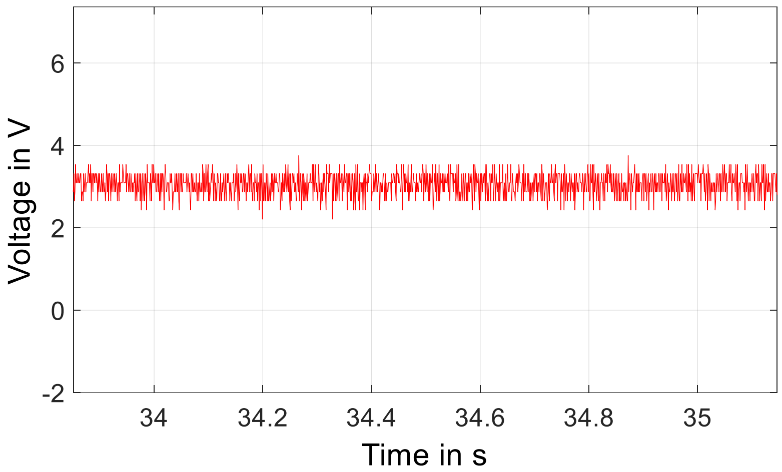


Fig 9 :- Experimental Setup

Results

- Below graph shows the output voltage from the LTC3588, when the input is 2.7 volts from the function generator with frequency of 150Hz.

- Where we can observe that voltage is fluctuating between 2.7 volts to 3.3 volts over a period of time, which is enough to feed the ESPWROOM 32 to be in operation.



Results

- Observing resistance value on serial monitor, when no load is applied

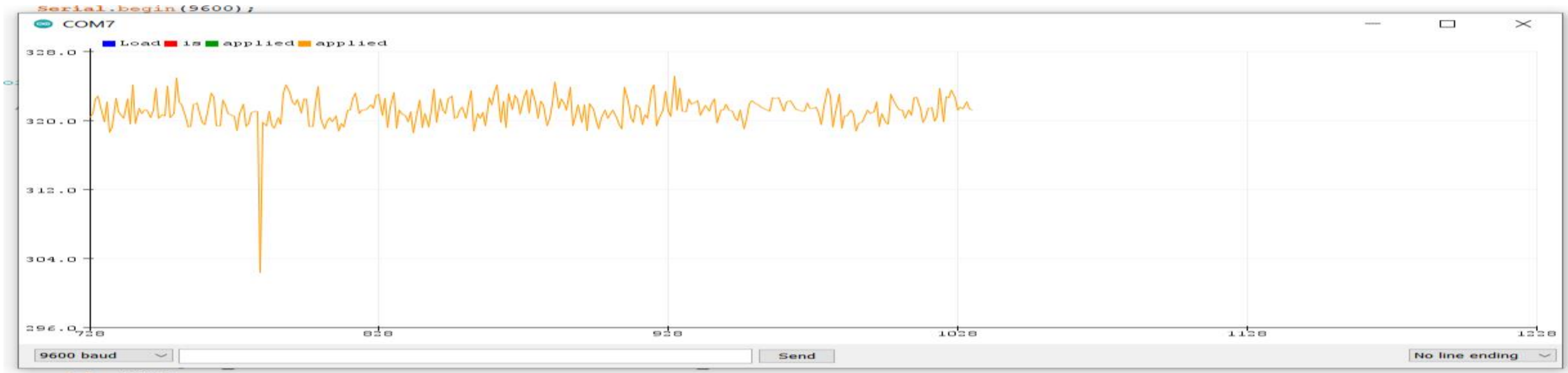
```
COM7
Send
Welcome toDevelopment of self powered wirless strain sensor for Structural Health Monitoring
resistance in(KΩ)   : 320KΩ
load is not applied
strain is 0.0 %
resistance in(KΩ)   : 319KΩ
strain is 0.0 %
load is not applied
```

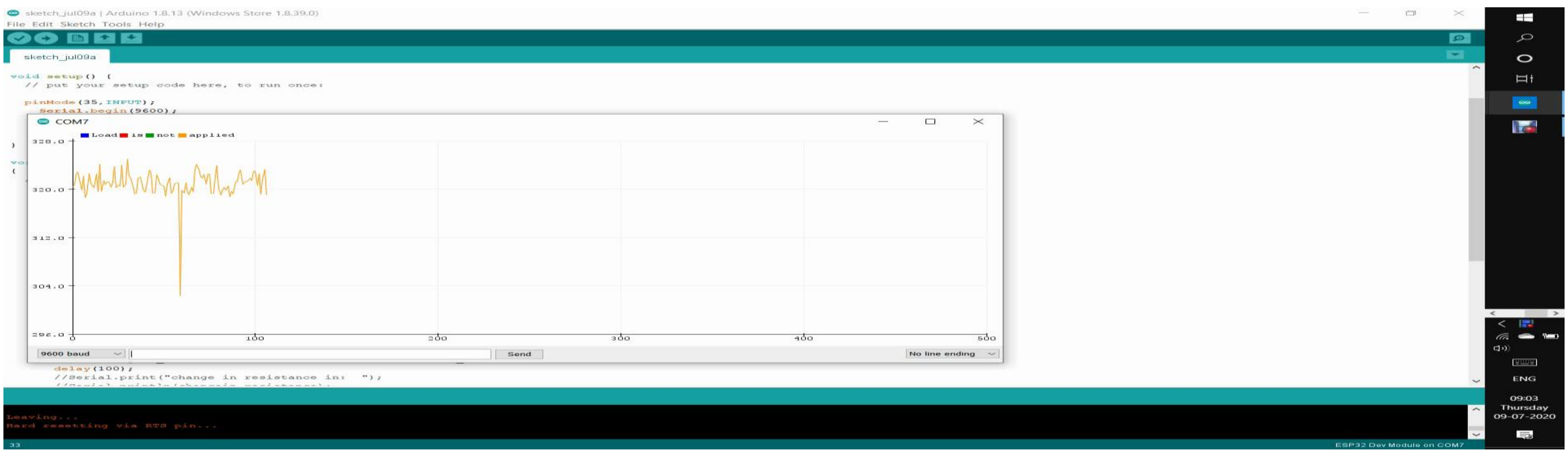
- Observing resistance value on serial monitor, when load is applied

```
COM7
Send
Welcome toDevelopment of self powered wirless strain sensor for Structural Health Monitoring
resistance in(KΩ)   : 320.00KΩ
load is not applied
strain is 0.0 %
resistance in(KΩ)   : 321.00KΩ
strain is 0.021 %
load is applied
resistance in(KΩ)   : 322.20KΩ
strain is 0.045 %
load is applied
resistance in(KΩ)   : 323.10KΩ
strain is 0.06 %
load is applied
resistance in(KΩ)   : 320.00KΩ
load is not applied
strain is 0.0 %
```

Results

- When load is applied on beam, output from the serial plotter.





Conclusion

- Successful design of self-powered wireless strain sensor
- A highly sensitive strain sensor was chosen based on polymer/CNTs nanocomposite with a gauge factor 15 which is 7 times higher than conventional strain sensor.
- A low power embedded wireless solution is chosen with effective energy harvesting solution.
- The chosen nanogenerator gives more energy by tapping than vibrational stress around 1.24V.
- The chosen circuit was efficient to rectify the electrical signal

Future Scope:

- Needs to be implemented in a wireless sensor network with mobile nodes.
- Implementation of the energy harvester with the developed wireless strain sensor

Reference

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[3]https://www.eeeguide.com/types-of-strain-gauge-transducer/

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Zhao, K., Wang, Y., Han, L. et al. Nanogenerator-Based Self-Charging Energy Storage Devices. Nano-Micro Lett. 11, 19 (2019). https://doi.org/10.1007/s40820-019-0251-7

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