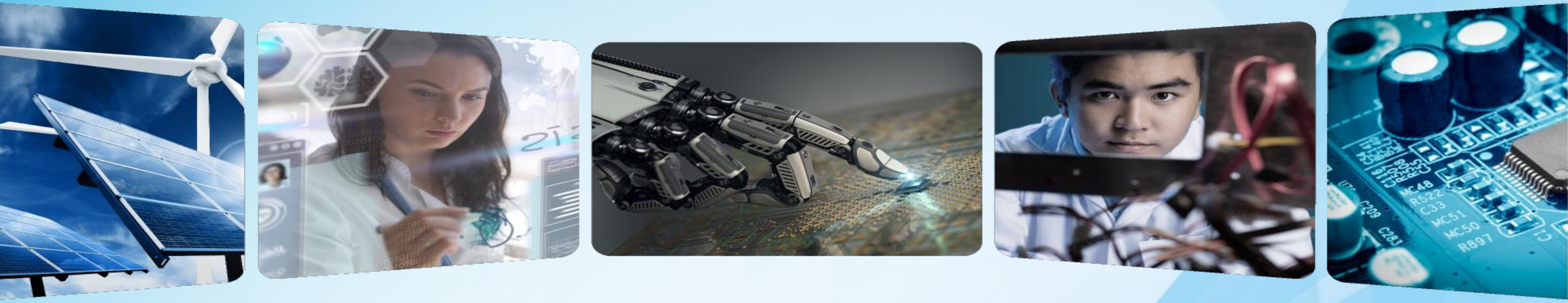

Towards a Photonic Sensor based Brain-Computer Interface (BCI)

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Introduction

- Smart Healthcare is one of the subsets that make up a Smart City.
- One aspect of Smart Healthcare that is gaining tremendous attention in recent time is the Brain-Computer Interface (BCI).

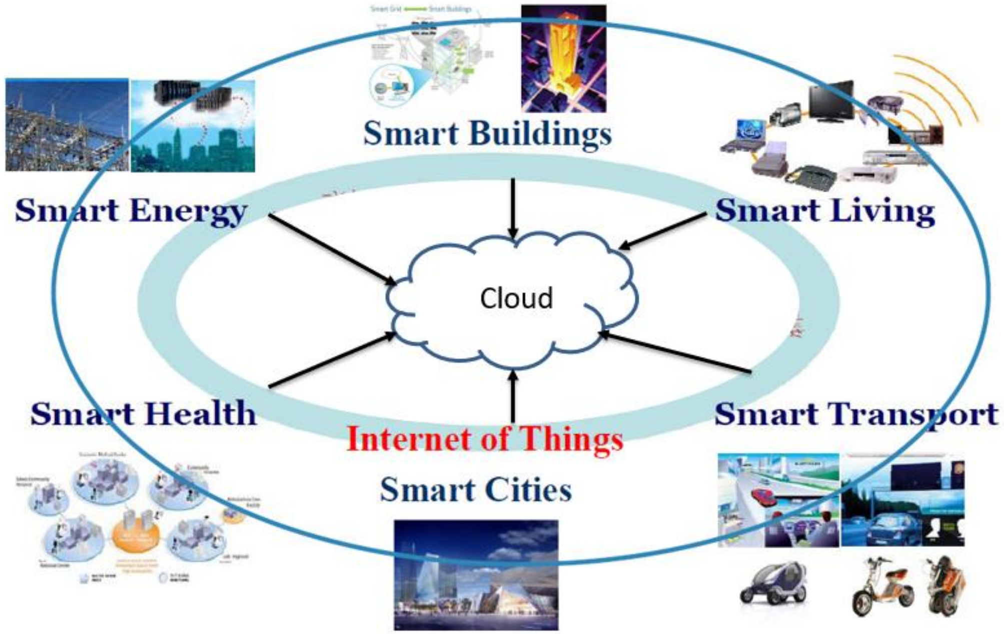

Fig.1: Some components and technologies in a smart city.

What is BCI?

- BCI is a system in which signals or commands retrieved from the brain are communicated directly to a computer for further analysis on the state of the brain or used to control devices or systems that are external to the body .
- Richard Caton (1842 - 1926) was the first to measure electrical impulses in an animal brain using a galvanometer [2]. His method was invasive.
- Nowadays, it is done through a process called Electroencephalography (EEG) by attaching metal electrodes to the scalp.

Why Photonics?

- The traditional EEG adds weight to the head, can cause skin irritation and prone to scalp injury due to the use of metal electrodes.
- It can also be messy because of the use of gels in certain instances.
- Photonic materials are very light in weight and also skin-friendly.
- Another very important case for photonics is that light travels faster than electricity.

Photonic Sensing

- Functional Near Infrared Spectroscopy (fNIRS) is a form of photonic sensing that gives insight to the functioning of the brain by measuring the concentration of the oxygenated haemoglobin in the brain.
- A near infrared light is sent to a part of the brain. The absorption or scattering of the light is used to estimate oxyhaemoglobin and brain activity.

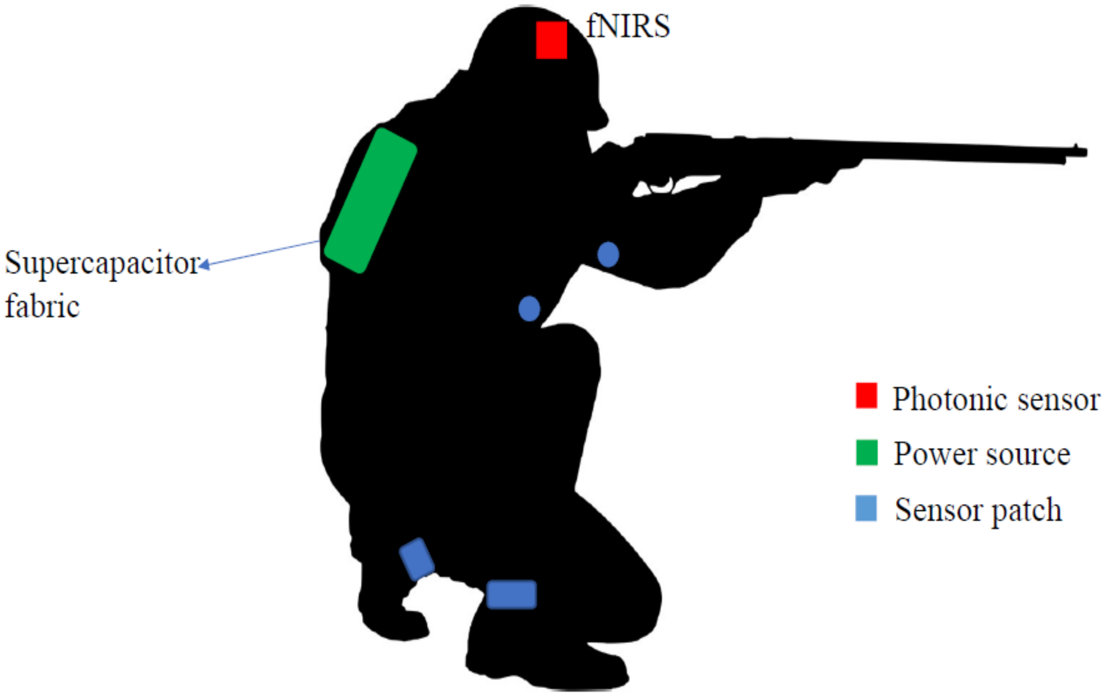

Fig.2: Photonic neurological sensing in a military application

Types of Photonic Sensing

- **fNIRS**: While functional Near Infrared Spectroscopy has been tested for BCI, its effectiveness is only reliable when used as a hybrid with EEG.
- **Sensing with micro-structured optical fiber**: This takes advantage of the air holes in the transverse refractive index profile along the length of an optical fiber. It is more suited in applications relating to fluids such as gas sensing or concentration of pollutants in a gas. It has therefore not been used for a BCI application.
- **Sensing with a polymeric micro-resonator**: This promises to be an ideal candidate for BCI sensing because of its capacity to establish a linear relationship between signals from the brain and the morphology of the micro-resonator.

Photonic Sensing for BCI

- The modeled photonic sensor makes use of a dome-shaped microscale laser as a sensing element and its operation relies on the principle of morphology-dependent resonance (MDR) in which the wavelength at resonance is shifted based on the morphology of the micro-scale laser as affected by its physical environment.

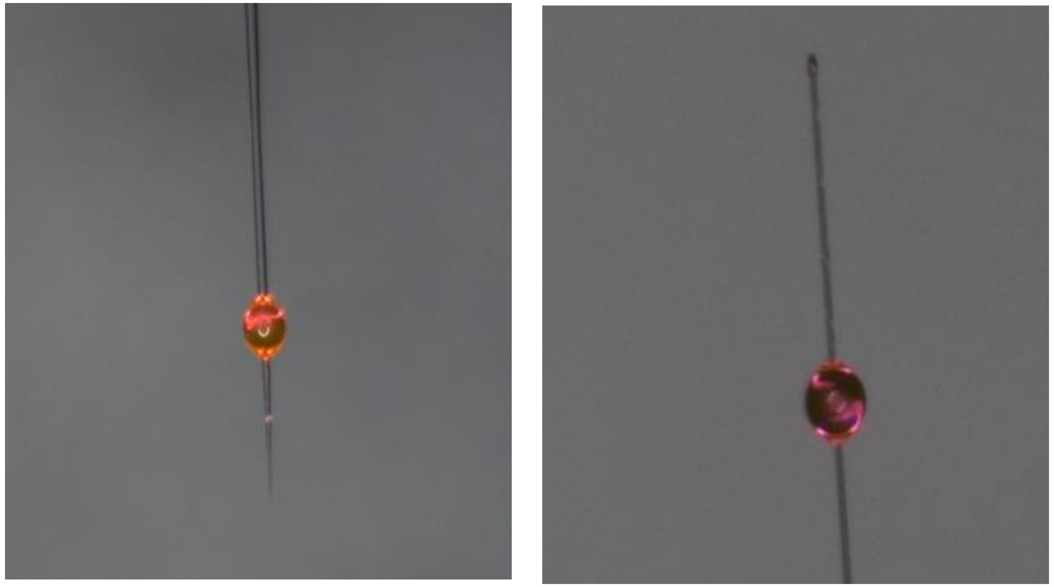

Fig.3: Photonic microresonators captured under the microscope.

Operating Principle

- When the photonic polymeric structure is subjected to certain strains such as pressure or electric field, they respond with some deformation which is interpreted as the MDR shift or the Whispering Gallery Mode (WGM) shift.
- The photonic substance that is used as a sensing element in this paper is a dome-shaped micro-scale laser that is obtained from chemical combination of glycol and trimethylopropan at a predetermined ratio.

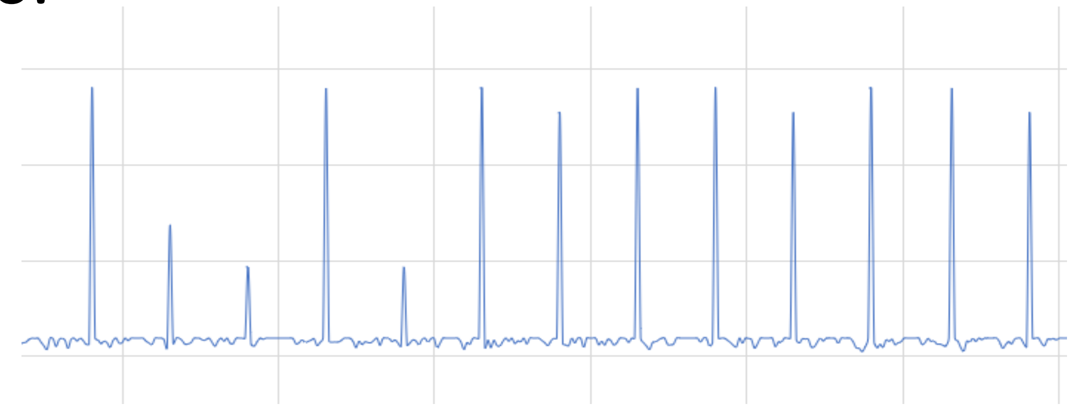

Fig.4: Sample emission spectra

Operating Principle (contd.)

$$\Psi = f(n,r) = \frac{\delta\lambda}{\lambda}, \qquad (1)$$

$$\frac{\delta\lambda}{\lambda} = \frac{\delta n}{n} + \frac{\delta r}{r}. \qquad (2)$$

$$\frac{\delta\lambda}{\lambda} = k\delta P + c\delta P = (k+c)\delta P, \qquad (3)$$

$$\delta P = \frac{\Psi}{\rho}. \qquad (4)$$

$$\Psi = \frac{\delta\lambda}{\lambda} = \rho\delta P + \epsilon. \qquad (5)$$

where Ψ = MDR shift, n = refractive index of the sphere and r = radius of the sphere, λ is the wavelength of the incident radiation and $\delta\lambda$ is the shift due to MDR. P is pressure, while k, c and ρ are proportionality constants.

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Photonic BCI

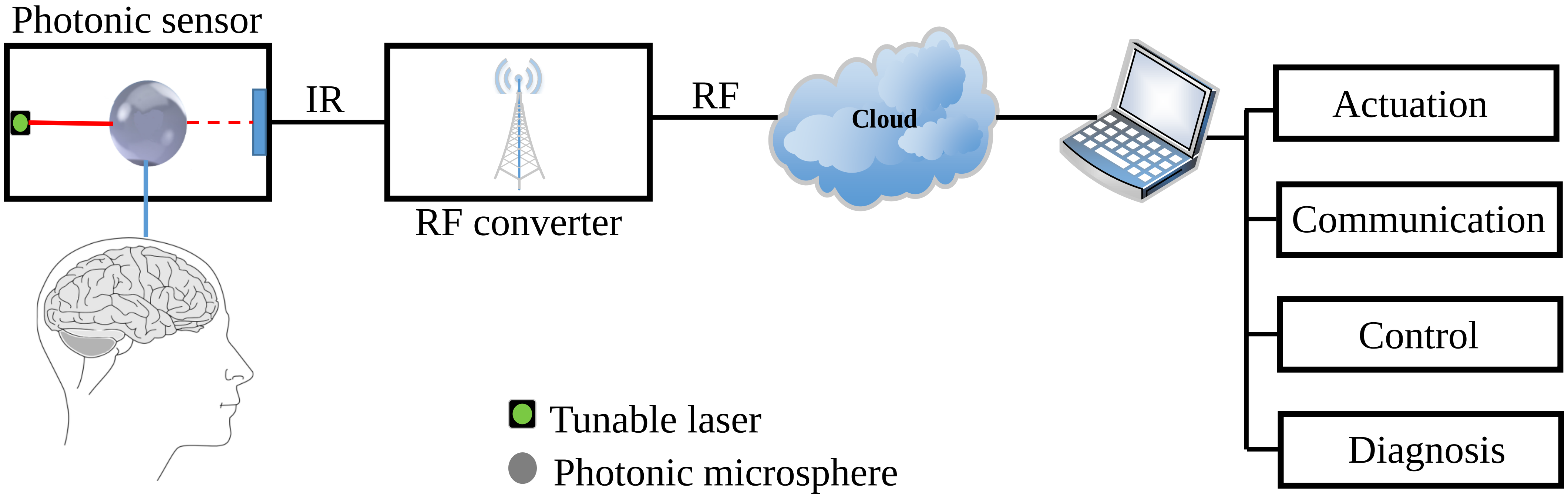

Fig.5: A conceptual BCI system based on photonic sensing.

Photonic Sensor Modeling

- The linear relationship between the applied pressure and the MDR shift is what is exploited in the development of the Simulink model and it also tips the photonic sensor to have some really fancied application in smart healthcare.
- The physical Photonic sensor has a sensitivity of 4 x 10^{-4} nm/Pa. This is used as the value in the gain block of the Simulink model.
- Two architectures were proposed. The two architectures are similar with some minor differences in their implementation.

Photonic Sensor Modeling (contd.)

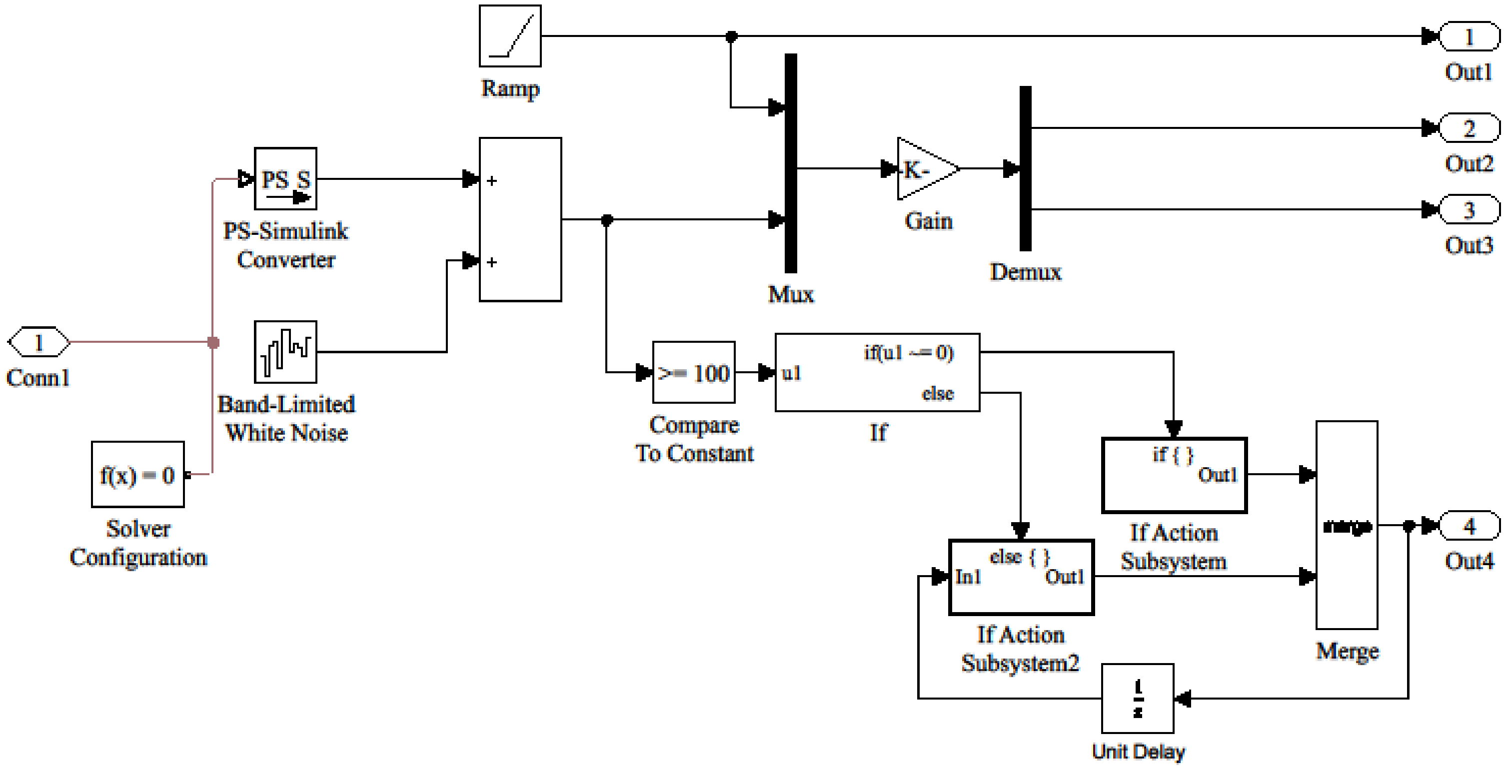

Fig.6: Functional block of the photonic sensor model 1.

Photonic Sensor Modeling (contd.)

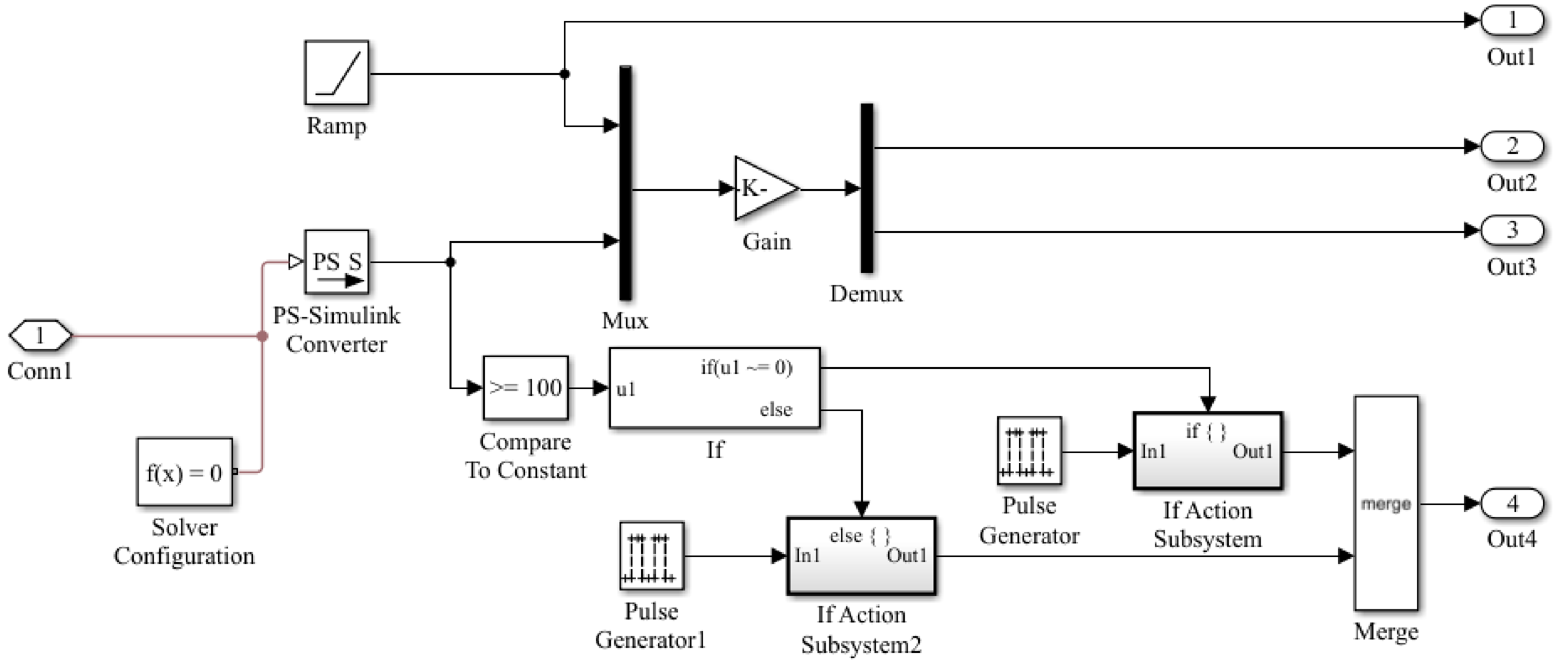

Fig.7: Functional block of the photonic sensor model 2.

Photonic Sensor Characterization

- The physical photonic sensor has the following characterization shown in the table below:

Metrics	Values
Sensitivity	4×10^{-4}nm/Pa
Resolution	50Pa
Dynamic range	5.5
Linearity	Linear

Table 1: Characterization of the physical photonic sensor.

Simulation Results

- The table below compares the morphology dependent resonance (MDR) shift of the physical sensor to that of the modeled photonic sensor when subjected to the same pressure.

Pressure	Modelled Sensor MDR Shift	Physical Sensor MDR Shift
50 Pa	0.01993 nm	0.02000 nm
100 Pa	0.03950 nm	0.04000 nm
150 Pa	0.05950 nm	0.06000 nm
200 Pa	0.07953 nm	0.08000 nm
250 Pa	0.09993 nm	0.10000 nm

Table 2: Characterization of the photonic sensor model against the physical photonic sensor.

Simulation Results (contd.)

- An experimental simulation was performed using the modeled photonic sensor by feeding in different pressure inputs. The effect of the resulting MDR shift against the input pressure values is shown below.

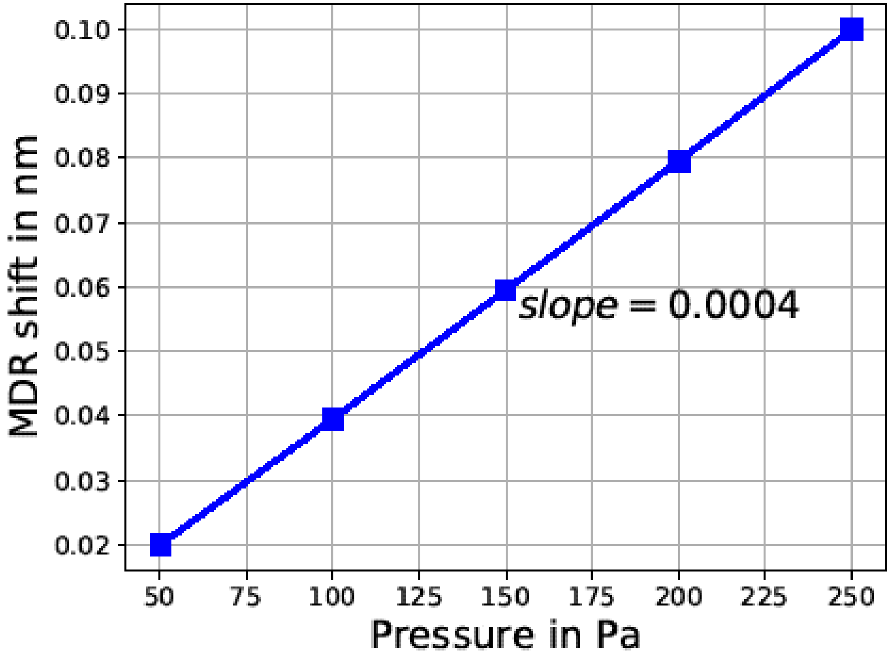

Fig.8: Simulation of the modeled photonic sensor.

Conclusion

- This paper explores the merits of photonic sensing and its prospects for BCI applications as a first step towards designing a complete system.
- A specific photonic sensor was modeled so as to facilitate further studies of the field of photonics in relation to brain signal measurement for BCI systems development.
- This is only a preliminary effort on the relevance of photonics in BCI.

Future Work

- Further research will be performed by using the modeled photonic sensor and a real photonic sensor on a BCI system while comparing their performance with existing methods of collecting electrical impulses from the brain.
- We are also working towards the actual design of the conceptualized system in figure 5.

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