New wearable body sensor for continuous diagnosis of internal tissue bleeding

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Background

Many applicable medical conditions such as Trauma accidents, internal bleeding after childbirth, post-surgery conditions and stroke lead to bleeding or ischemia.

A diagnostic device that can monitor abdominal bleeding continuously, under normal physiological conditions, and in any environment, is essential for assessment of medical condition and treatment.

Bleeding usually cannot be detected by vital signs (e.g. pulse rate)

Magnetic resonance imaging (MRI) and Computer Tomography (CT) are expensive and not portable.

Electrical Impedance Tomography (EIT) requires galvanic coupling between the electrode and the tissue under measurement.

Magnetic Induction Tomography (MIT) is the preferred solution for bleeding sensor: Portable, low cost, does not require galvanic coupling and has sufficient performance

Sensor data analysis and bleeding diagnosis

Analysis criteria

The criteria for finding the optimal weight vector W of the problem in Minimum Square Error (MSE) sense is given by:

$$\hat{W} = \arg\min_{W} E\left(AW^{T}\Delta P_{I} - \Delta C\right)^{2}$$

$$s.t. \qquad \|W\| = 1$$

A is scaling factor, $\|W\|$ is the norm, ΔP_I is phase shift difference vector from a basal phase reference, ΔC is the blood content change

Bleeding Approximation algorithms

MSE linear optimal weights:

$$\hat{W}_L = R^{-1}_{\Delta P_I, \Delta P_I} R^{T}_{\Delta P_I, \Delta C}$$

Where:

$R_{\Delta P_I, \Delta P_I}$ is phase autocorrelation matrix.

$R_{\Delta P_I, \Delta C}$ is the cross correlation vector.

It is difficult to derive these correlation matrices analytically as it does not depend linearly on the frequency, the geometrical properties and the configuration.

Maximum Ratio Combining (MRC) weights :

$$W_{MRC} = \rho_{\Delta P}\theta_{\Delta P}$$

$\theta_{\Delta P}$ is magnitude vector.

$\rho_{\Delta P}$ is the polarity (-1 or +1) vector.

- MRC is Simple intuitive suboptimal solution to the optimal MSE solution.
- Both magnitude and polarity can be obtained from the correlation matrices.
- The MRC method is less sensitive to low statistics, require less calculations with fewer parameters and has sufficient performance for general raw data.

Sensor Calibration

We suggest obtaining the correlation matrices needed for solution, in particular the cross correlation matrix, through a set of calibration processes.

- For MRC, the calibration process uses only two scalars.
- The auto correlation matrix and MRC amplitude vector be obtained directly from the raw data.

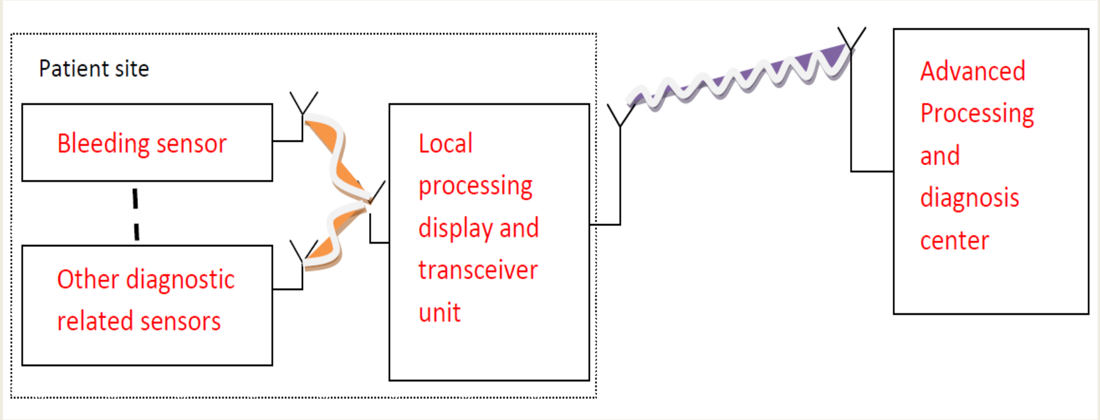
There are two main way of calibration processes :

1. **Centralized data base calibration process**
   - Requires many offline calibration experiments performed on many patients.
2. **Local calibration process**
   - Performed locally before activating the sensor.
   - Requires to add and remove known fluid quantities from known locations.

System

A typical continuous monitoring medical system is composed of three main units.

1. **Set of body sensors** that are attached to or implanted in a specific patient.
2. **A local processing unit** (computer, cell phone) near the patient that collects, processes and displays the sensor.
3. **A central processing utility**. Needed in case of limited computation resources at the patient site, or when there is a need to consult an expert physician, or to access a patient personal database.



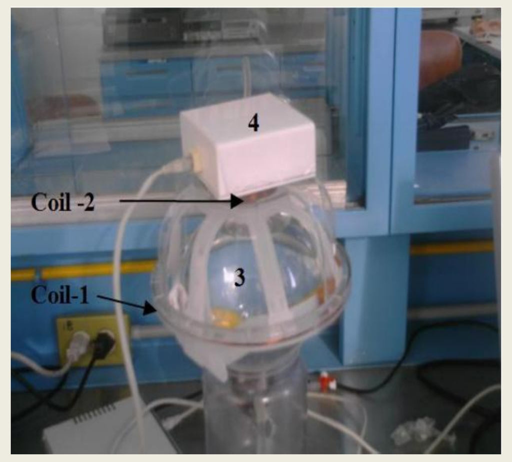
Experimental design

We simulated head injury bleeding for first order proof of the feasibility of the system.

We used a sensor prototype and a head model.

We supplied a cosine signal of approximately 10mA at five frequencies of 10, 40, 110, 160 MHz and 1GHz

Fluid volumes of physiological saline in 20ml decrement and increments were injected or removed to simulate different hypoperfusion or hyperperfusion levels respectively.



Experiment stages:

1. **Initial Calibration**.
   - Injecting and removing 10 known diverse volumes of fluid.
   - The experiments were performed in Mexico City and the data on the volumes and measured data on the phase shift were transferred through the Nokia N75 cellular phone (3G) to a central processing unit in Jerusalem.
2. **Bleeding monitoring**
   - The volumes of saline were changed in Mexico city in a way that was not known in Jerusalem.
   - Only the raw data regarding phase shift measurements was transferred to Jerusalem, through the cellular phone continuously every 5 minutes with different saline volumes.
   - This data was analyzed in Jerusalem and the diagnostic returned to Mexico City through the cellular phone, in real time, for confirmation.

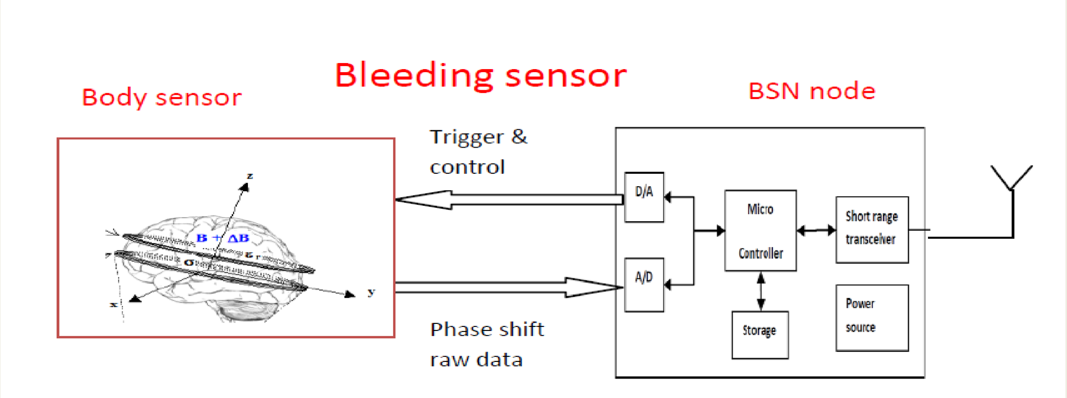
Sensor description

The bleeding sensor is a non-invasive data acquisition device (DAD) worn around patient's tissue of interest.

It consists of two subunits:

1. **Multi-frequency electromagnetic inductive body sensor** to detect continuously tissue bleeding or ischemia. Consists of three modules: Sensor Transceiver (coils), Sinus wave generator, Phase detector

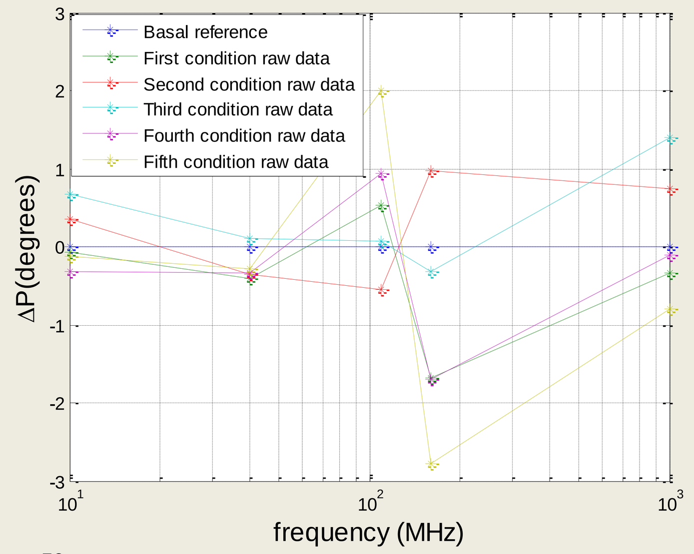
2. **A conventional BSN node unit** for initial processing of raw data, short range communication with the processing unit and controlling the body sensor.



Results

A plot of the phase shift difference for the data sets sent at different times.

No simple direct observation can give a simple diagnosis.



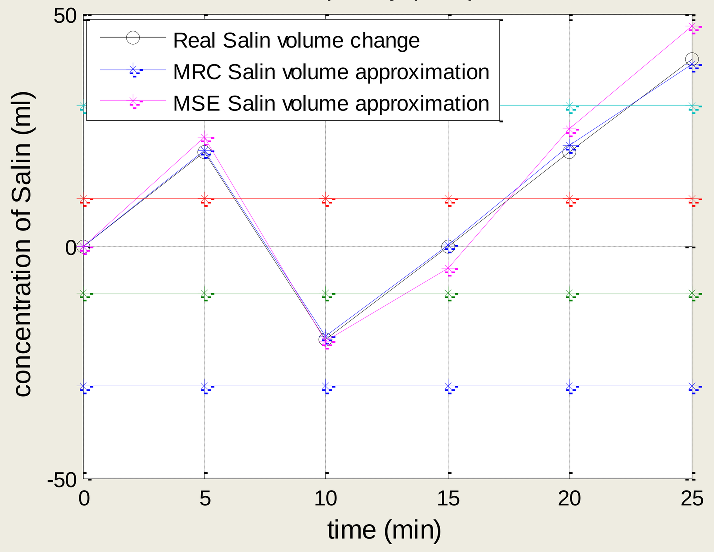
We used the linear optimal MSE and MRC methods to approximate blood content change relative to initial blood content reference.

In all the cases the methods predicted correctly whether the situation involves bleeding or ischemia.

MSE std = 0.89ml, MRC std = 4.8 ml.

The results indicate a trade-off between size of database and accuracy of results.

The accuracy of the method could be further improved with a larger database and more measured frequencies.



Monitoring graph as was displayed in the cell phone (local processing unit) in Mexico after being derived by MRC method and sent in real time from in Jerusalem (central diagnosis center)