Building Efficient IoT Systems Using Multi Sensor Data Fusion

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Agenda

- Concept of IoT
- Wireless Sensor Networks(WSN)
- Challenges in WSN- IoT systems
- Artificial Intelligence for IoT
- Role of Multi Sensor Data Fusion in IoT
- Case study
- System Implementation
- Results & Discussions
- Conclusion & Future Research

Internet of Things

Internet of Things (**IoT**) is the network of physical objects—devices, vehicles, buildings and other items embedded with sensors, electronics, software and network connectivity, that enables these objects to collect and exchange data.

How Does IoT Work ?

Smart devices collect and exchange information machine to machine (M2M) and with us.

- Remote control and monitoring
- Operate automatically through software, cameras and sensors

Internet of Everything

People
Connecting People in More Relevant, Valuable Ways

Process
Delivering the Right Information to the Right Person (or Machine) at the Right Time

Data
Leveraging Data into More Useful Information for Decision Making

Things
Physical Devices and Objects Connected to the Internet and Each Other for Intelligent Decision Making

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Wireless Sensor Networks

- ➢WSN combines sensing, computation, and communication into single tiny device called sensor node.
- ➢Group of sensors linked by wireless media to perform distributed sensing task.

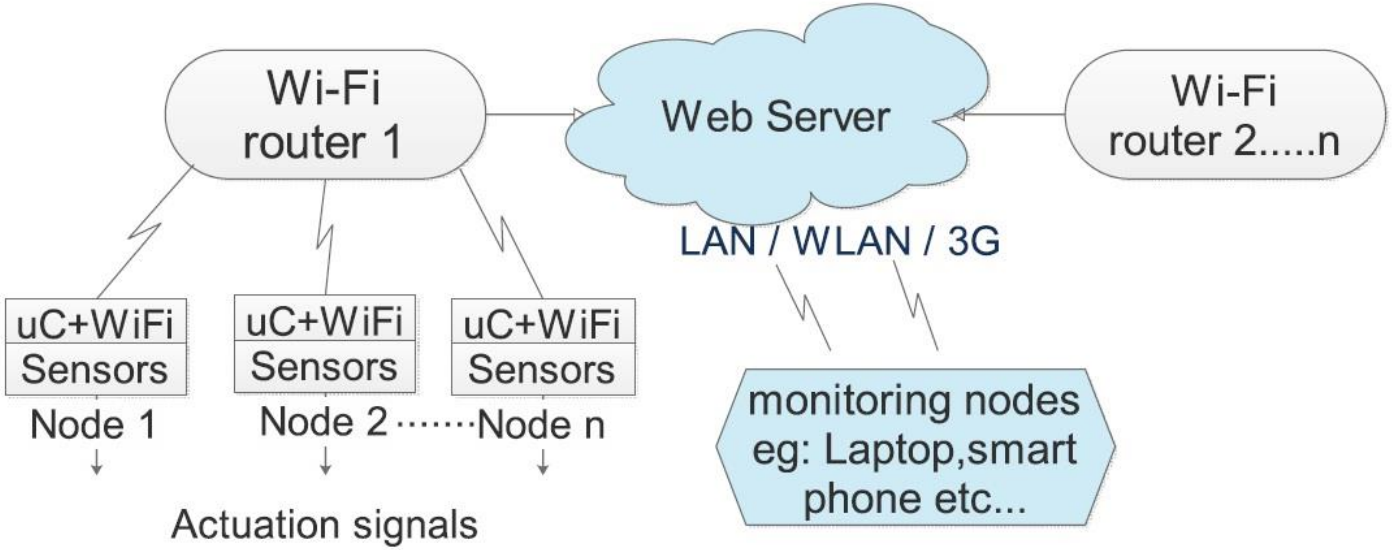
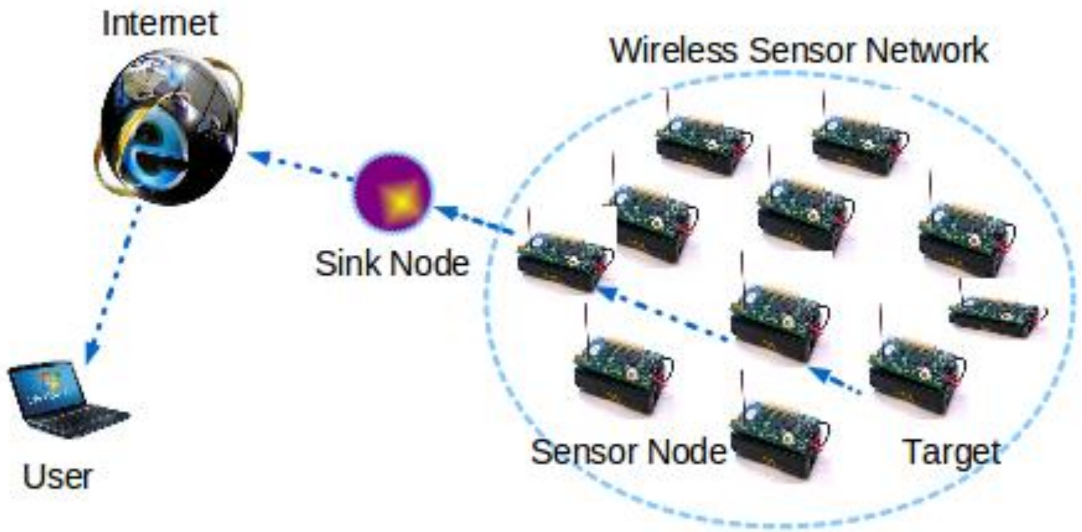


fig 1 : Overall system architecture

Sensor & Network Coordination

- In a distributed WSN, there will be one or more Routing Nodes, also known as Sink Nodes.

- Responsible for Sensor Coordination, Network Management, Data Sharing & Security.



Scenario of Laboratory Automation

- Features Real Time Monitoring, Analysis & Controlling of varying parameters.

- Such a system can improve
  - Work quality
  - Productivity
  - Human/machine healthcare
  - Energy management

System Overview

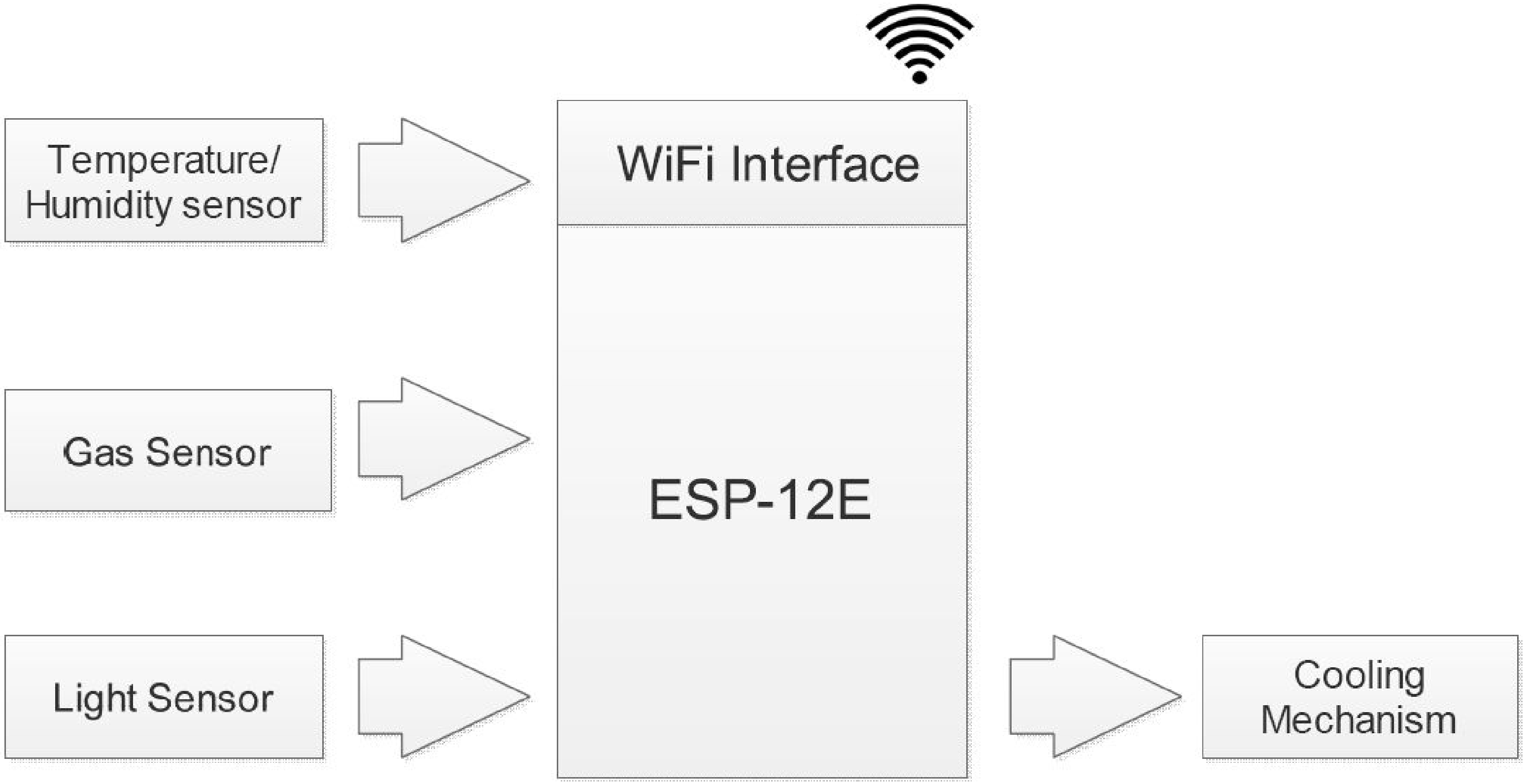
- A smart and Intelligent system, optimizing a complete set of functionalities & parameters inside the selected laboratories.

- A Real Time Monitoring System accessible to anywhere in the world, requiring just a trusted internet connectivity.

- A simple, power efficient and cost effective model.

- The system that exploits the latest trends- **Internet of Things (IoT) & Wireless Sensor Networks(WSN)**

Multi Sensor Data Acquisition

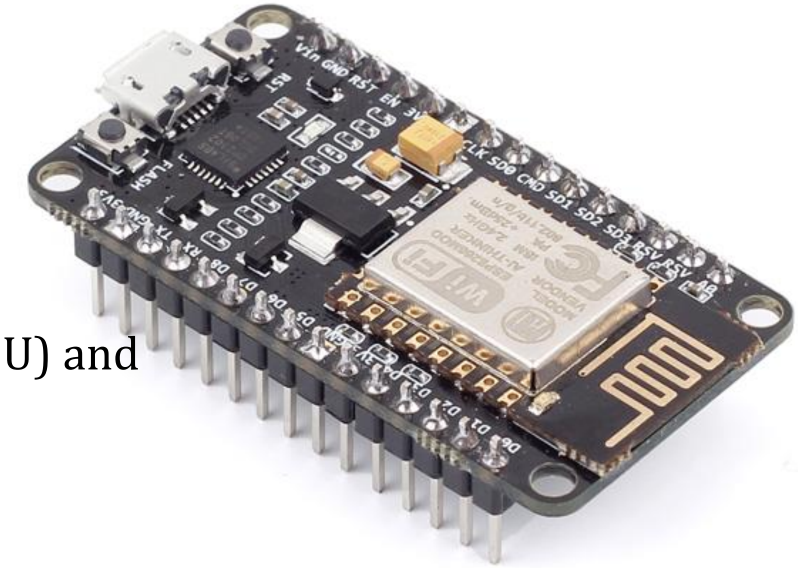


Sensor Node-MCU

- **Node MCU**(An Open source IoT platform) integrates
- ESP 8266-12E Wi-Fi module with I/O pins
- Programming platform : **Arduino IDE**

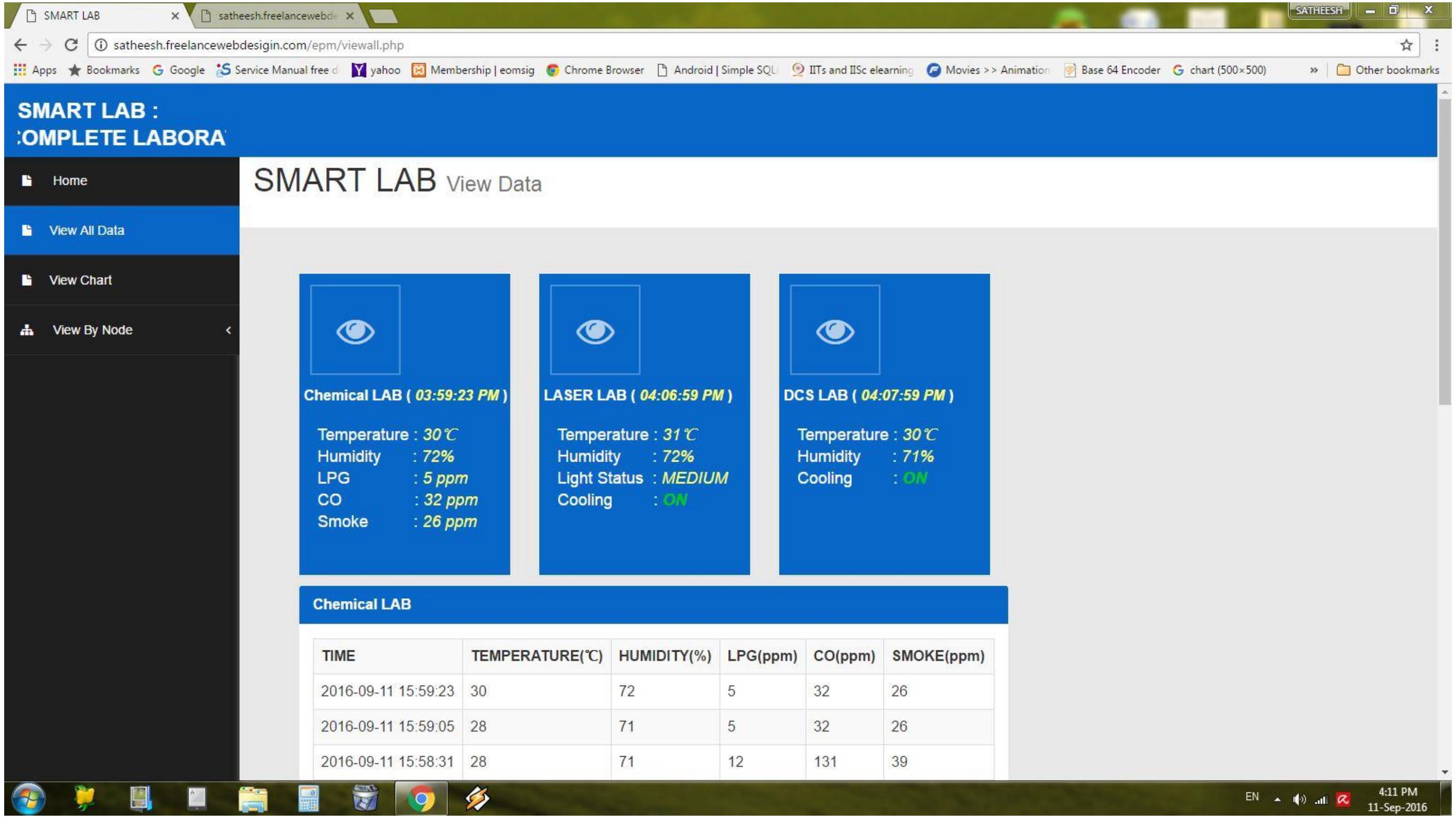
- **ESP 12E** module is
- Developed & Industrialized by *Ai Thinker* team.
- Embedded with Tensilica L106 32-bit micro controller (MCU) and an on-board antenna.

- **Tensilica L106** is,
- The smallest licensable 32-bit processor core based on an Industry Standard Architecture(ISA).
- An ultra low power MCU, smaller than the ARM7 or Cortex-M3 cores
- Delivers higher performance than the ARM9E cores.



Node MCU

Real Time Monitoring



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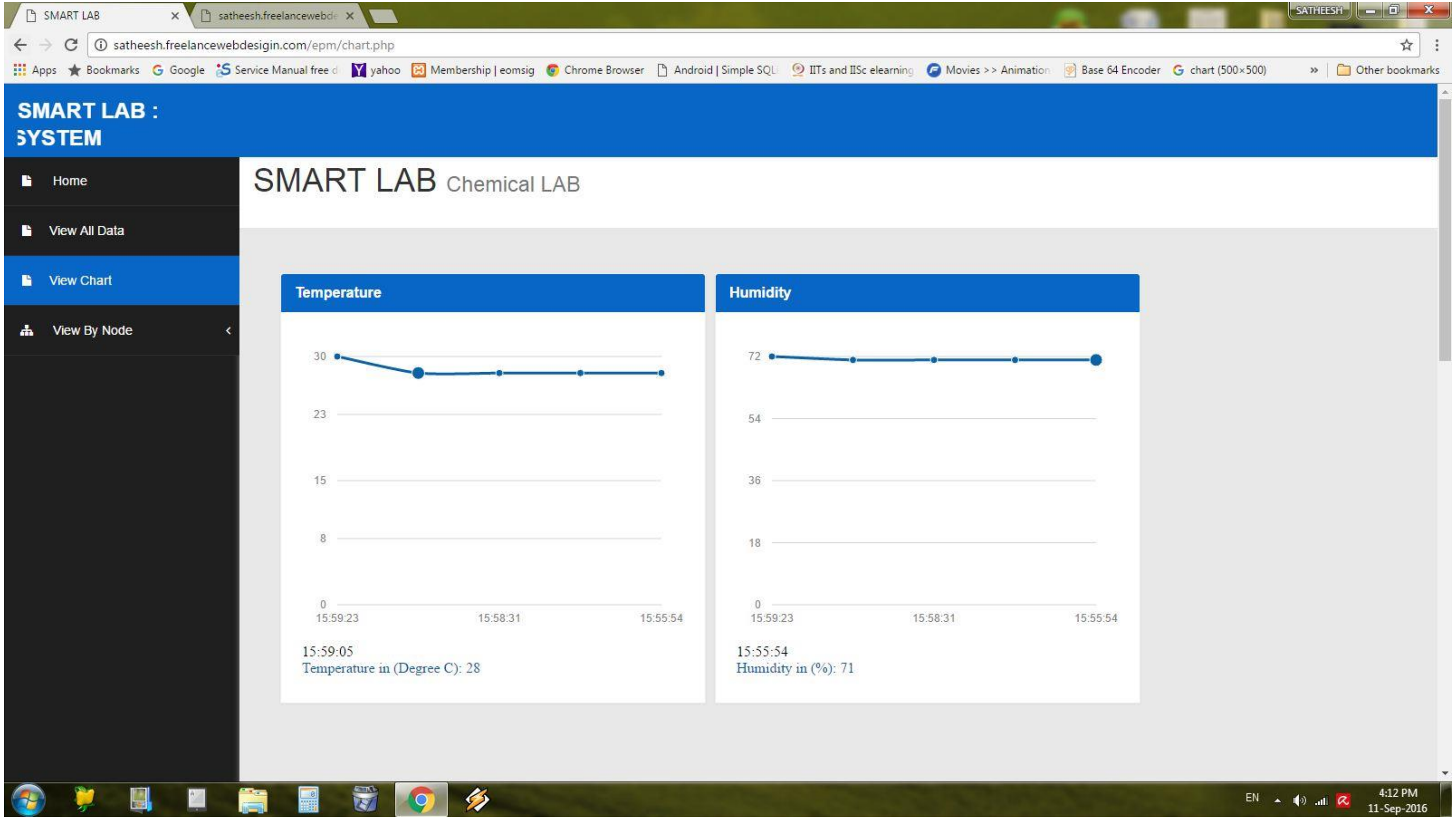
Graph Analysis



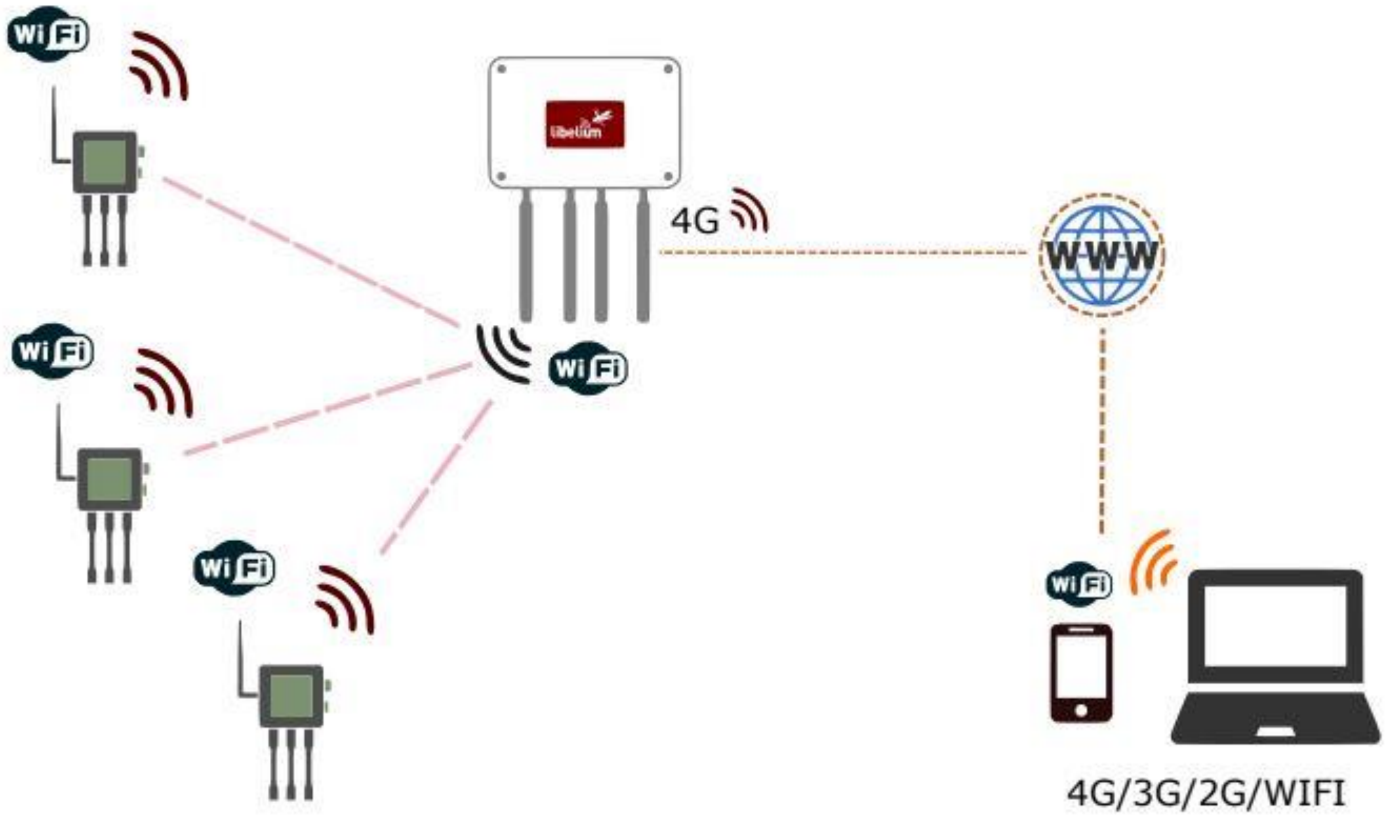
Libelium-WSN Components

Sensors

Plug & Sense Node

Meshlium Gateway

Libelium-WSN Architecture



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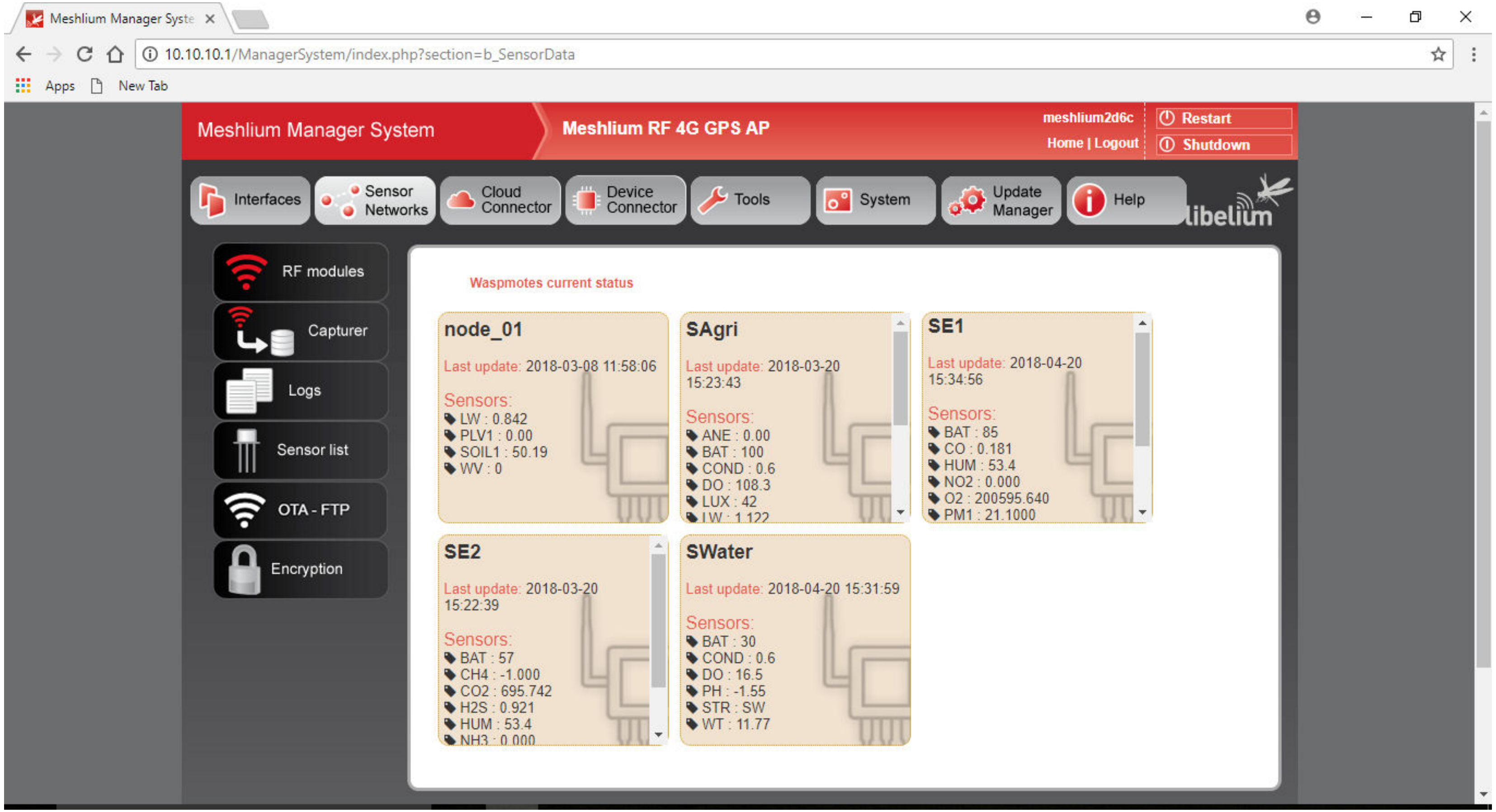
Real Time Dashboard Display



Intelligent Signal Processing

- Intelligent Signal Processing explores the area in which an automation system can perform like a HUMAN

- Means these systems can think…

- Probabilistic-Statistical Mathematics is the base of such system design

- Backbone of Artificial Intelligent(AI) systems

Popular AI Techniques

- Machine Learning
- Deep Learning
- Artificial Neural Networks
- Genetic Algorithm
- Fuzzy Logic
- Neuro-Fuzzy systems

Role of Sensor Data Fusion in IoT

- Sensing is the primary and important part of IoT systems

- There are lot of limitation with sensor Data Acquisition;
  - Sensors might not be linear
  - Single sensor data cannot provide clear idea about process
  - Increasing raw data increases power and data waste
  - Unable to deploy everywhere as we required
  - Higher presence of process and measurement noise

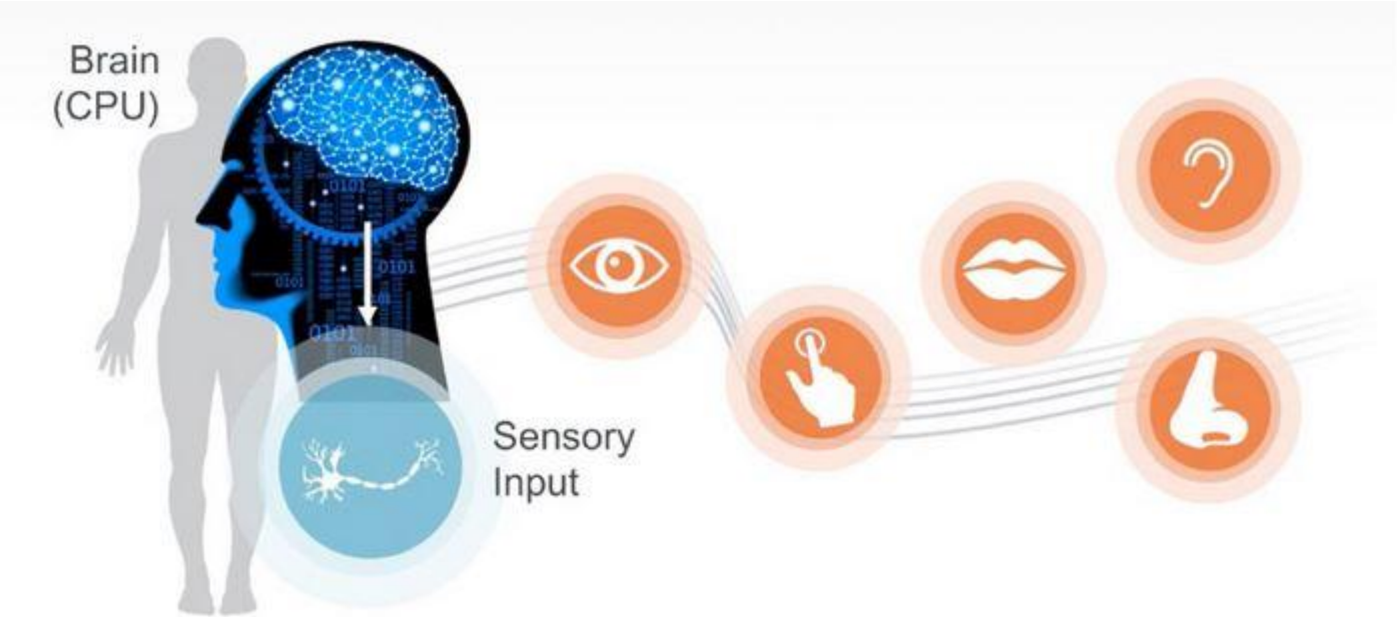
Multi Sensor Data Fusion

- Problem-solving techniques based on the idea of integrating many answers into a single; the **best answer**

- Process of combining data or information from various sensors to provide a robust and complete description of a process of interest

- Multilevel process dealing with automatic detection, association, correlation, estimation and combination of data or information from single or multiple sources

Brain: The Ultimate Fusion Example



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Levels of Data Fusion

- **Low level fusion:** The raw data are directly provided as an input to the data fusion process, which provide more accurate data (a lower signal-to-noise ratio) than the individual sources

- **Medium level fusion:** Characteristics or features (shape, texture, and position) are fused to obtain features that could be employed for other tasks. This level is also known as the feature or characteristic level

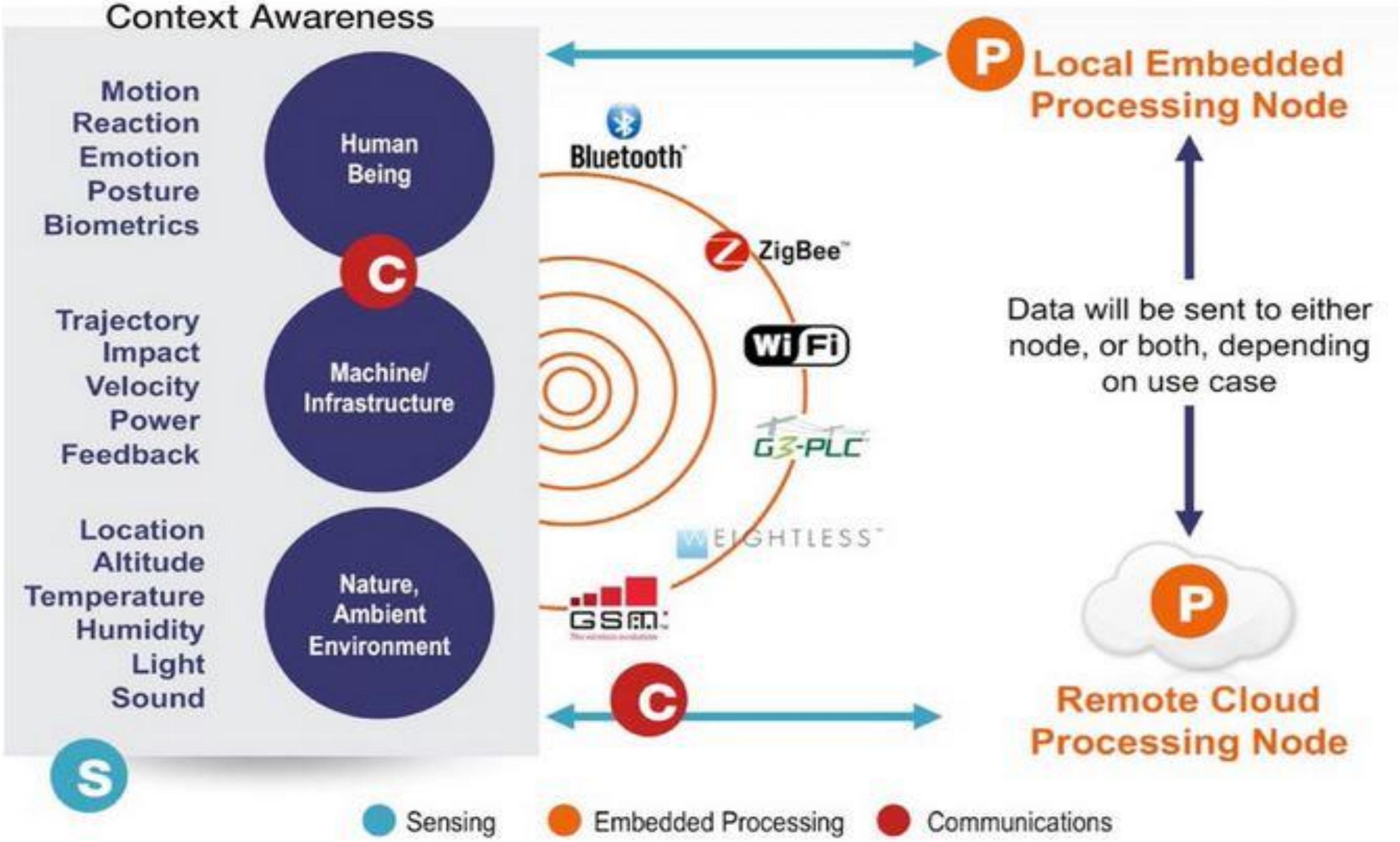
- **High level fusion:** This level, which is also known as decision fusion, takes symbolic representations as sources and combines them to obtain more accurate decision. Bayesian's methods are typically employed at this level

- **Multi-level fusion:** This level addresses data provided from different levels of abstraction (i.e., when a measurement is combined with a feature to obtain a decision)

What is context ?

- Circumstances or facts that form the setting for an event, statement, situation or idea
- Based on the environment, context may vary as biological sensing, climate systems, Industrial monitoring etc.
- Based on this definition, the four most important categories of information to formulate a context-aware action are:
  - Identity
  - Location
  - Time
  - Activity

Context Awareness



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State & Estimate

- *What's A State?*
  - The complete "solution" of the system is known, if all measurements are obtained. These quantities are the "state variables" of the system.

- *Why Estimate?*
  - Sensors aren't perfect
  - Sensors aren't everywhere
  - Very few or raw measurements

Kalman Filter

- Also known as **linear quadratic estimation** (**LQE**), The filter is named after **Rudolf E. Kálmán**, one of the primary developers of its theory.

- Estimation of state variables of a system from incomplete noisy measurements

- Fusion of data from noisy sensors to improve the estimation of the present value of state variables of a system

- Performs recursive operation with feedback and error correction mechanism to minimize the error percentage in the final value.

- The common applications are guidance, navigation and control of vehicles, particularly aircraft and spacecraft.

Kalman Filter Theory

State Estimation

$X_k = AX_{k-1} + Bu_{k-1} + w_k$ (1)

$z_k = HX_k + v_k$ (2)

Noise Covariance

$P(w) \sim N(0,Q)$ (3)

$P(v) \sim N(0,R)$ (4)

$P_k^- = P_{k-1} + Q$ (5)

State Updation

$K_k = P_k^- (P_k^- + R)^{-1}$ (6)

$X_k = X_k^- + K_k (z_k - X_k^-)$ (7)

$P_k = (1 - K_k) P_k^-$ (8)

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The Extended Kalman Filter (EKF)

- The Extended Kalman (EKF) is a sub-optimal extension of the original KF algorithm
- The EKF allows for estimation of non-linear processes or measurement relationships
- This is accomplished by *linearizing* the current mean and covariance estimates (similar to a first order Taylor series approximation)
- Suppose our process and measurement equations are the *non-linear* functions

$$\vec{x}_{k+1} = A\vec{x}_k + B\vec{u}_k + \vec{w}_k$$
$$\vec{z}_k = H\vec{x}_k + \vec{v}_k$$

Kalman Filter

$$\vec{x}_{k+1} = f(\vec{x}_k, \vec{u}_k, \vec{w}_k)$$
$$\vec{z}_k = h(\vec{x}_k, \vec{v}_k)$$

Extended Kalman Filter

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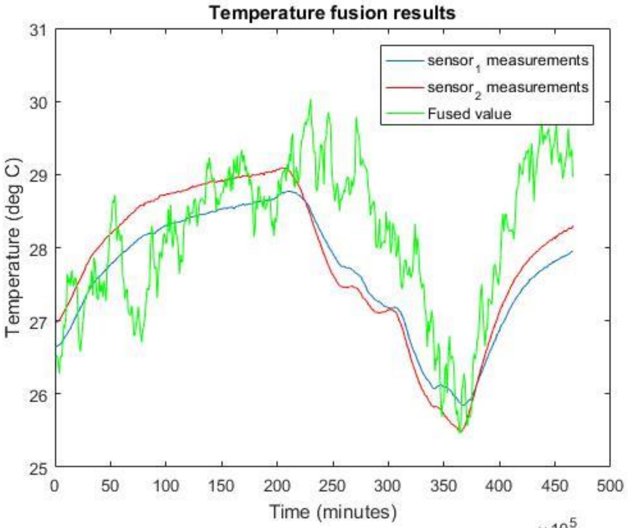
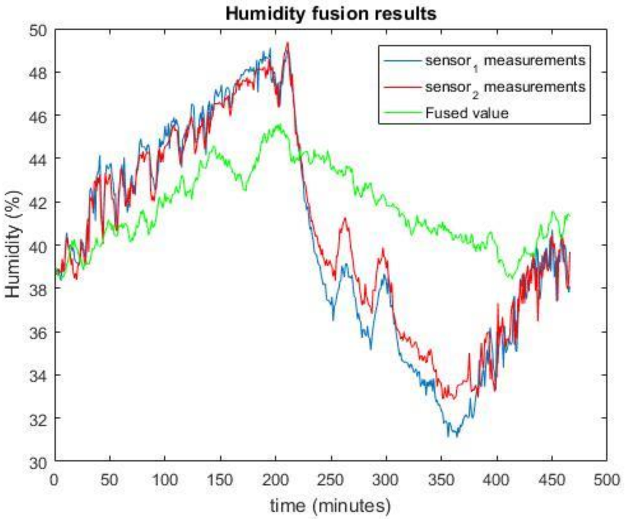
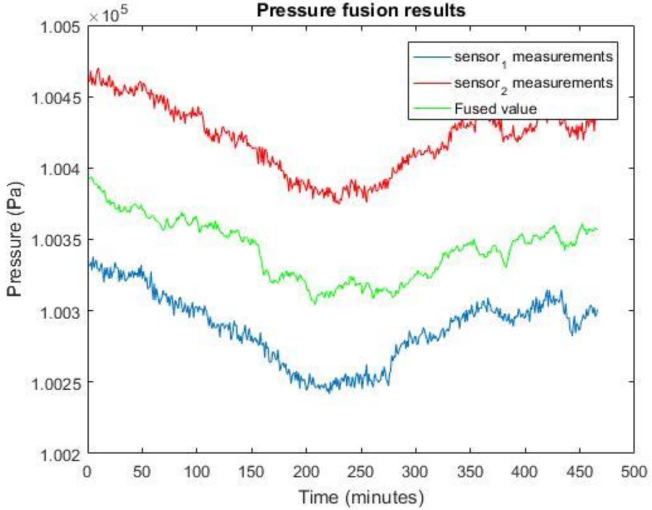
State Estimation & Fusion Results







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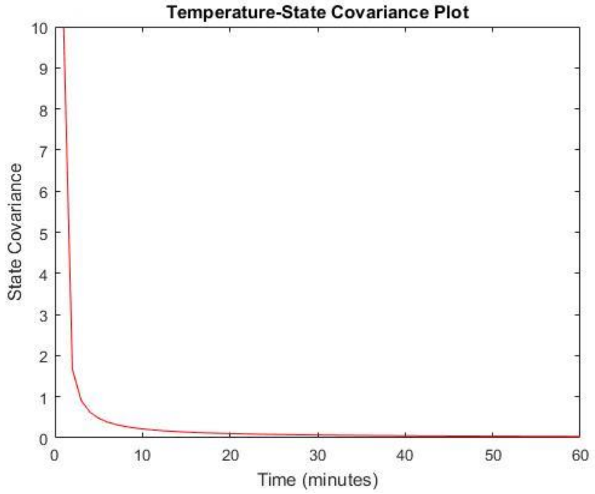
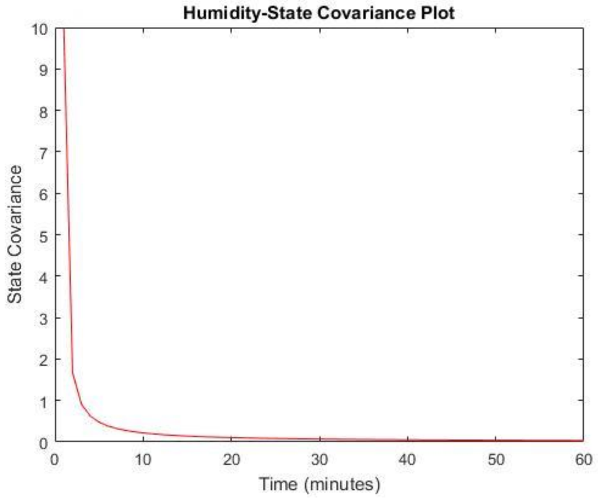
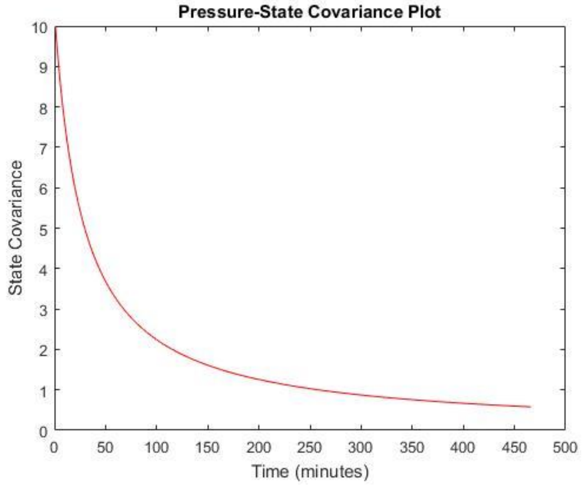
State Covariance Plot







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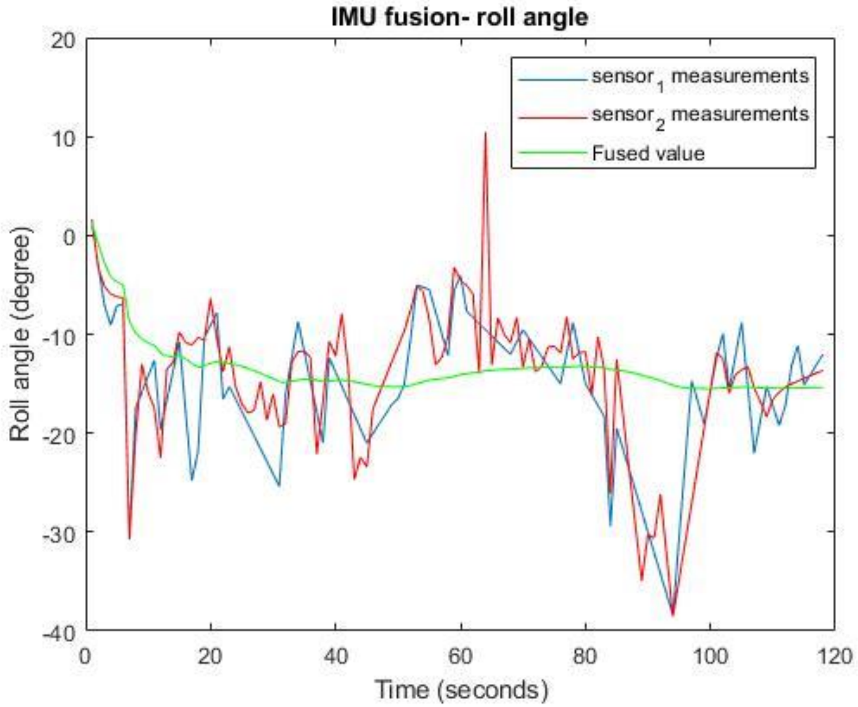
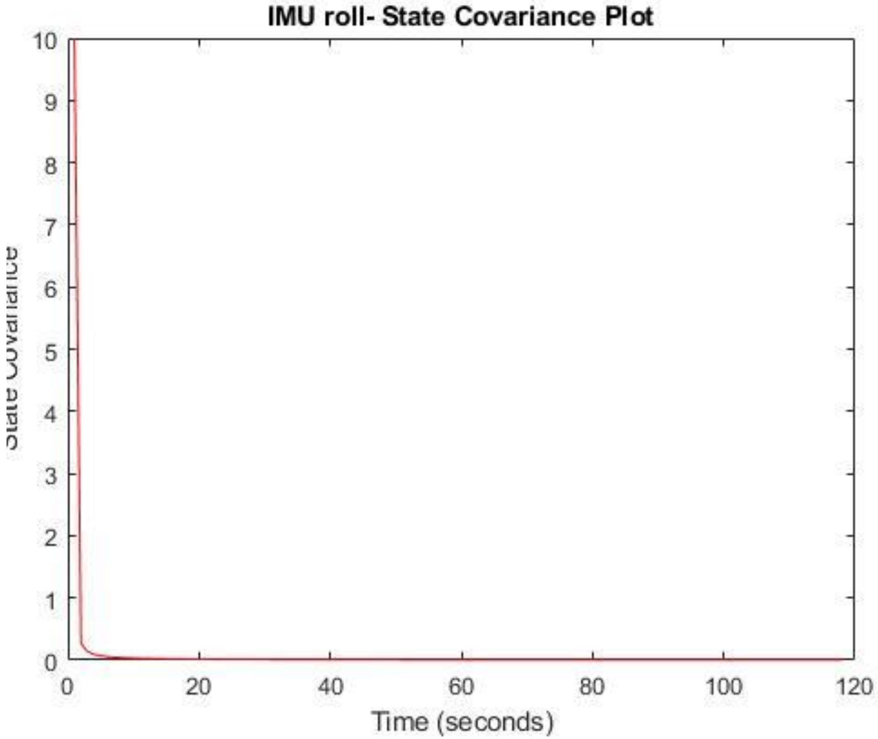
Extended Kalman Filter Fusion





Process Noise 1, Tailor function added for Measurement Noise

HIGHLIGHTS

- Provides Context awareness and detailed analysis of process by using data fusion technique.
- No communication distance limitations because the data communication medium is internet.
- Reliable, accurate and cost effective methods for data processing and data transmission.
- The intelligent sensing, monitoring and automated maintenance enhance a smarter living environment.

CONCLUSION & FUTURE RESEARCH

- The proposed analysis method is reliable for the monitoring and controlling of laboratory parameters.
- Sensor fusion approach can make the system capable of perform accurate and consistent analysis on the bulk and noisy measurements.
- In order to perform real-time monitoring and control, Extended Kalman filter will be used in future for non-linear measurements.
- It is planned to develop a centralized fusion architecture, making the cloud platform as fusion centre, instead of fusion at sensor nodes to improve the fusion compatibility and range.
- Planned to implement the decision level fusion, enabling an intelligent control as decided by the fusion centre, makes the system optimized.

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Thank You !