# SENHOD: Scarce-Resources Wireless Sensor Network for Healthcare in Oil Derricks

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*Abstract:* - We present our experience with designing, developing, and deploying of a Scarce-resource Wireless Sensor Network (SWSN) for monitoring temperature and humidity high above oil derricks (drilling tower) in PEMEX (Parastatal Mexican Petroleum Company) drilling facilities. SENHOD system (scarce-resources wireless SEnsor Network for Healthcare in Oil Derricks) represents an information tool to reduce derrickmens' health risk due to high temperature and humidity exposure during a working day. For our deployment we meet the design requirements, in accordance to the scenario and its necessities. SENHOD has suitable operation characteristics configurable by users, such as: operation modes, physical parameter selection, sensing rate, and awake-sleep nodes.

*Key-Words:* - wireless sensor network, oil derrick, derrickmen, healthcare, temperature, humidity, sensor, exposure.

## 1 Introduction

A Scarce-resources Wireless Sensor Network (SWSN) is composed of nodes with capabilities to compute, communicate and sense the environment; the nodes intend to be physically small, mobile and inexpensive, thus they have limited resources in network bandwidth, energy, simple short-range wireless communication, and very limited memory and storage. However, we see this kind of networks as an opportunity to contribute to reduce health risk for derrickmen, specifically those who have to stay working for hours (sometimes four or more) at top oil derrick. In our case, derrickmen are exposed to high temperature and humidity of tropical areas. Our system consists of portable nodes with capabilities to sense environmental humidity and temperature. Each worker that has to climb an oil derrick and stays there for a long time is provided with a SWSN's node to monitor temperature and humidity from a base station situated on derrick's base. This helps to prevent faints and dizziness of workers due to long period of time working exposed to high temperatures and humidity. The SWSN's characteristics are convenient to help monitoring physics parameters that need to be controlled to prevent and avoid fatal accidents.

The rest of the paper is organized as follows. In the next section we describe our scenario and user's requirements. Next the system architecture is presented in section 3. In the following Section 4 we discuss our implementation and the results obtained during field trials in a PEMEX's oil derrick. In Section 5, we present some conclusions on the experience.

## 2 Healthcare in industrial facilities

Nowadays, wireless sensor networking in industrial facilities has been seen as an opportunity for industrial automation market as new technologies improve the functionality and economics of industrial monitoring and control systems. However we think that SWSN also represents an excellent opportunity for healthcare in industrial facilities. We have developed a new application that has a deep social impact with relative low costs. We have developed our application on the basis of the Mexican Official Standard for Worker's Health and Safety in High Thermal Conditions (NOM-015-STPS-2001) [1].

### 2.1 PEMEX Scenario

PEMEX is a petroleum company that has industrial facilities in Mexico's southeast where climate is humid warm. In that tropical zone their workers have to climb oil derricks to perform activities related with extraction hydrocarbons. During a job day, a worker that climbs an oil derrick has to stay making maneuvers at top derrick for a long time. That's a serious risk for his health because he's exposed for a long time to high humidity and temperature.

As environmental temperature and humidity is directly related to worker's temperature it is convenient to reinforce his security by monitoring the environmental parameters. In this way, the supervisor can determine when it is appropriate for a derrickman to down from oil derrick due to values of temperature and humidity and in accordance to the time that derrickman has been working on top of derrick.

Actually, derrickmens' health can be checked using conventional environmental thermometers; although they are effective, they are not portable and require a person to take values about temperature and humidity in a manual way. It implies a potential for error; also, wireless data transmission is not possible.

In some places, PEMEX has considered commercial wireless equipment but it requires a base station which it is of an expensive kind, so, this is a costly solution. Additionally, it's not scalable (few nodes) and it's not fail tolerant.

## 2.2 Apparent temperature (feeling heat)

Apparent temperature is the general term for the perceived outdoor temperature, caused by the combined effects of air temperature, relative humidity and wind speed. The heat index measures the effect of humidity on the perception of temperature. In humid conditions, the air feels hotter than it actually is, because of the reduction of perspiration.

Steadman [2] developed the feeling heat parameter as a combined effect of heat and humidity, it says, when humidity is high the feeling heat value exceeds air temperature value. Table 1 show it.

| Temperature (ºC) | Relative Humidity (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | *70* | *75* | *80* | *85* | *90* | *95* | *100* |
| *23* | 24 | 24 | 24 | 24 | 24 | 25 | 25 |
| *24* | 25 | 25 | 25 | 26 | 26 | 26 | 26 |
| *25* | 26 | 26 | 27 | 27 | 27 | 28 | 28 |
| *26* | 27 | 28 | 28 | 29 | 29 | 29 | 30 |
| *27* | 29 | 30 | 30 | 31 | 31 | 31 | 33 |
| *28* | 31 | 32 | 32 | 33 | 34 | 34 | 36 |
| *29* | 33 | 34 | 35 | 35 | 37 | 38 | 40 |
| *30* | 35 | 36 | 37 | 39 | 40 | 41 | 45 |
| *31* | 37 | 39 | 40 | 41 | 45 | 45 | 50 |
| *32* | 40 | 42 | 44 | 45 | 51 | 51 | 55 |
| *33* | 43 | 45 | 49 | 49 | 53 | 54 | 55 |
| *34* | 47 | 48 | 50 | 52 | 55 | | |
| *35* | 51 | 52 | 55 | | | | |
| *36* | 54 | 55 | | | | | |

Table 1. Table to calculate thermal sensation (feeling heat) [3].

In humid warm tropical zones, humidity is the element that elevates feeling heat. Tabasco is located in the tropic, this means sun's rays have little inclination and seasons are just a little differentiated. Annual media temperature is 26°C, but some days in April and May it reaches 45°C. Annual media relative humidity is 82%, having a maximum in winter of 86% and a maximum in spring of 76%. In general terms, annual media relative humidity is 70% [4].

PEMEX's facilities in Tabasco, Mexico are located in a plain at sea level, usually wind speed is between 10 and 20 km/h (normal weather conditions), so, having high thermal conditions these values don't decrease feeling heat.

In accordance to [1], we can appreciate in Table 2, times of exposure for workers in places like Tabasco.

| Maximum temperature ºC | | Percentage exposure and recovery times for each hour |
|---|---|---|
| Regimens work | | |
| Moderated | Heavy | |
| 26.7 | 25.0 | 100% exposure |
| 27.8 | 25.9 | 75% exposure<br>25% recovery |
| 29.4 | 27.8 | 50% exposure<br>50% recovery |
| 31.1 | 30.0 | 25% exposure<br>75% recovery |

Table 2. Maximum limits of exposure under high thermal conditions [1].

## 2.3 Users Design Requirements

Given the scenario, we have defined particular user requirements for the system, these are:

1. Mobility and portability: Derrickmen need to do movements and manoeuvres on top derricks, that's why sensor nodes should be mobile and easily portable.
2. Usability: It's related to aspects such as avoiding short-circuits, zero configuration effort for users, remote reset by software, lightweight devices, and portability.
3. Coverage capacity: It means to have enough coverage in accordance to the scenario of usage.
4. Ease of deployment and management: The users should be able deploy the system without any need for special configuration. Derrickmen don't need to realize any configuration which is very valuable when they are working on top derricks. Management topics are network reconfiguration and node's remaining battery power queries.
5. Suitable choice of operation mode: It means selecting alternatively between event oriented, on-demand (by request) or automatic periodical operation mode.

6. Configurable sensing rate: Supervisor on derrick's base needs to have the control to configure sensing rate in accordance to specific time requirements.
7. Configurable node's sleep time: As the last requirement, supervisor has to be able to configure node's sleep time periods in accordance to necessities. Supervisor can put node operation to sleep when monitoring is not necessary and continuous mode when derrickmen are working.
8. Configurable outputs: Users can select which physic parameter (humidity or temperature) they want to monitor. It means one or two parameters at same time. The monitoring results are saved in text files, this let us analyze them with datasheets or graphs.

# 3 System Architecture

SENHOD follows a simple conventional system layout. All sensor nodes send their sensor readings to the base station, and the base station serves those data to users via the network. See Fig.1 for a system architecture overview.

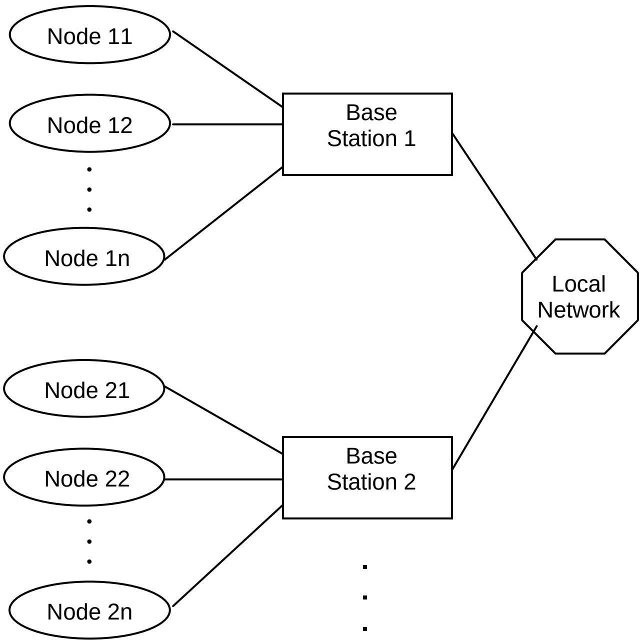


Fig. 1. SENHOD system overview

We have selected as sensor nodes Tmote Sky modules with sensing capacity. The Tmote Sky platform is a wireless sensor board from Moteiv [7]. It is an MSP430-based board with an 802.15.4-compatible CC2420 radio chip and one megabyte external serial flash memory. Humidity and temperature is measured using Sensirion's SHT11 [6] sensor. Nodes use two standard AA batteries.

Nodes' raw data reach the base station and we use TinyOS's[5] components to convert them to comprehensible information and storing them into a text file in the base station. Users can access those data by downloading that file from the base station and storing it in their computers, where they can analyze the data obtained.

Our sensor network provides three sensor readings: humidity, temperature, and internal voltage [8]. The internal voltage reading is used to know the remaining battery power on the mote.

The RF module has been certified for remote and base radio applications. Moteiv's modules use a radio frequency 2.4 GHz which is free. If the module will be used for portable applications, the device must undergo SAR (Specific Absorption Rate) testing. This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation.

For our expected values Moteiv's Relative Humidity sensor has an accuracy of ±2%RH and temperature sensor has an accuracy of 0.5ºC [7]. So, system reliability is ensured.

System is composed using as a base the TinyOS's component Oscilloscope [5]; it has been modified to meet user requirements. We have used MIG [5] tool to create a java message-object to pass configuration parameters to the system.

## 3.1 Design to fulfil users' requirements

Some design decisions have been taken to fulfil users' requirements:

A plastic protective case has been used to protect module in outdoor operation, this case has two functions: to protect the module for operations in exteriors and to let portability for workers.

Remote configuration is available and devices chosen are small and lightweight. Its radio technology is inoffensive and protected against interferences. User configuration efforts aren't required.

System was created specifically to be used in oil derricks. These kinds of towers have a maximum height of 90 feet (30 meters). SWSN have an outdoor theoretical coverage capacity up to 100 meters, then, single hop network architecture is enough to establish communication between nodes and a base station. Software's component used in sensor node is Oscilloscope, which is suitable for single-hop networks. We know that single-hop network architecture is an adequate choice due to distances between bottom and top derrick. In this case, it wasn't necessary to implement a multihop protocol.

System doesn't require any configuration by final user. Workers just have to carry nodes. Any change or configuration is realized by the operator in the base station. If any software or hardware component has an incorrect behaviour the supervisor can reset the system wirelessly.

System has a Java graphic interface that is used by the supervisor located in the tower base with a computer used as base station, supervisor can change operation mode at any time. Operation modes are: event oriented, on-demand or automatic periodical sensing. Event-oriented mode is used when user needs to be notified if an event occurs. On-demand operation is useful when sensing needs to be done only if user makes a query. Periodical sensing operation is used when user wants to monitor and to know in continuous mode the physical parameters.

Sensing rate can be assigned to system by the user at any time. It's provided in millisecond units. TinyOs components have been used to implement configurable node's sleep time. Its goal is to save battery energy. When sensing is not necessary nodes can be configured as sleep mode, otherwise, awake-mode is selected.

Sensing results are sorted by date, time and node id that has performed sensing operations. Files are plain text format; they are identified by name (humidity and temperature).

Table 2 summarizes the design of the system.

| Users' requirements | Design to fulfil user's requirements |
|---|---|
| Mobility and portability | Sensor nodes have a plastic protective case for this purpose |
| Usability | System has suitable usability. Remote configuration is available and devices are small and portable |
| Coverage capacity | Single hop network architecture is enough to establish communication between nodes and a base station |
| Ease of deployment and management | System doesn't require any configuration by final user. Network reconfiguration is considered |
| Suitable choice of operation mode | Operation modes are: event oriented, on-demand and automatic periodical sensing |
| Configurable sensing rate, node's sleep time | Sensing rate and sleep time can be assigned to system by user at any time |
| Convenient outputs | Outputs are plain text format which can be analyzed using datasheet |

Table 2. System Design Summary

An important feature of the system is its network reconfiguration facility. Against opinions that considers that gateway architecture is not a good choice because it represents a potential point of failure, our architecture has considered overlap node coverage to overcome this problem. We can appreciate it in Fig. 2. The following example illustrate its behaviour: if base station 1 (BS 1) fails, data from nodes N 11 and N 12 can be obtained through node N 13 and using BS 2. When the failure of BS 1 is detected, BS 2 replaces single-hop version system with a multihop version. Doing it, we can obtain data from nodes 11 and 12, until BS 1 is replaced or repaired.

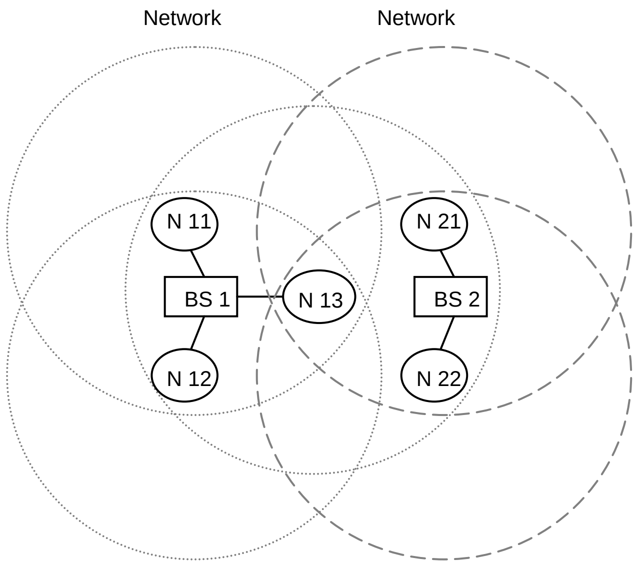


Fig. 2. Network reconfiguration scenario

Our network reconfiguration feature is possible because Moteiv's nodes have relay characteristic, therefore, our implementation with multi-hop communication is scalable and fail resilient.

## 4 Deployment and results

System has been deployed in Cunduacan, Tabasco, Mexico. A county were PEMEX has many facilities.

We were monitoring environmental temperature and relative humidity. As we can see in Fig. 3, Fig. 4, and Fig. 5 data obtained by SWSN are very similar to data obtained by specialized equipment in PEMEX.

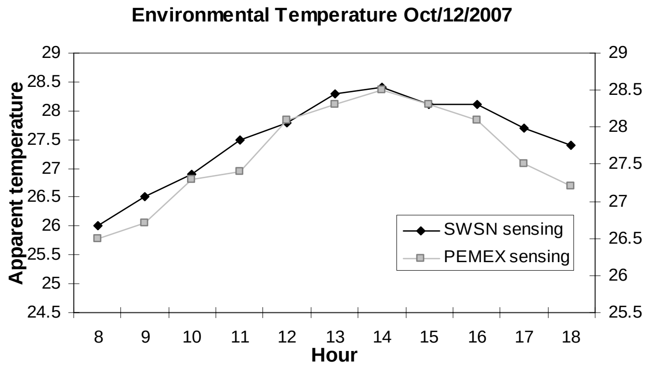


Fig. 3. Comparison between SWSN and PEMEX temperature sensing

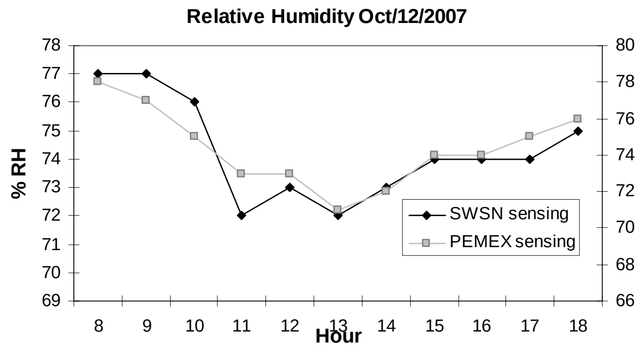


Fig. 4. Comparison between SWSN and PEMEX relative humidity sensing

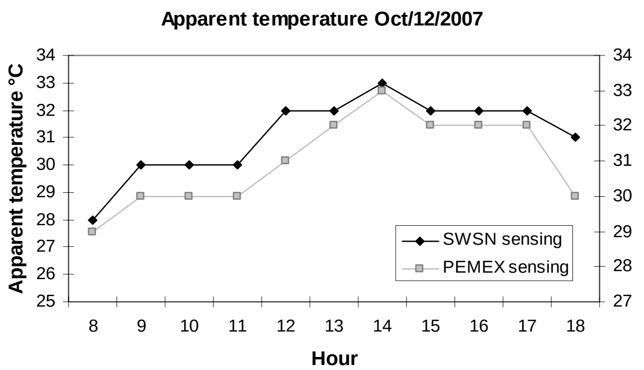


Fig. 5. Comparison between SWSN and PEMEX apparent temperature

Apparent temperature values are considered very important to determine when a worker has to go down oil derrick. In Fig. 6 we present data obtained in October 2007.

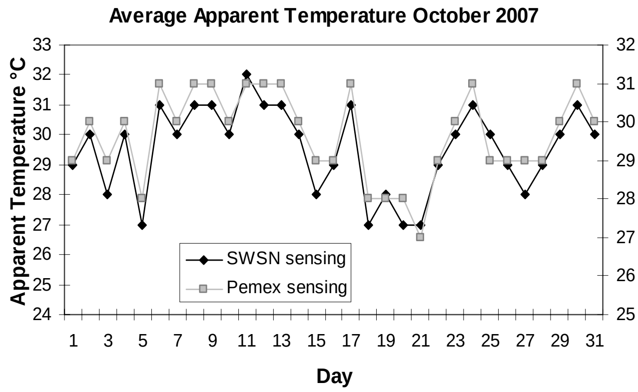


Fig. 6. Comparison between SWSN and PEMEX media apparent temperature

Having a null hypothesis shown in (1) and an alternative hypothesis shown in (2), where $\mu_1$ is PEMEX sensing and $\mu_2$ is SWSN sensing.

$$(1) \quad H_0 : \mu_1 = \mu_2$$

$$(2) \quad H_1 : \mu_1 \neq \mu_2$$

Secondly, we used student's t-test (3) to contrast hypothesis on average in populations with normal distribution.

$$(3) \quad t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

We applied student's t-test to temperature, relative humidity and apparent temperature data and we obtained that there is no evidence in data to say that PEMEX and SWSN sensing are different. This affirmation has a validation of 95% with an error margin of 5%. Then, null hypothesis is accepted and alternative hypothesis is rejected.

After statistical analysis from results we can infer that difference between SWSN's data and PEMEX's data is negligible. Table 3 shows differences average between PEMEX sensing and SWSN sensing and demonstrates it.

| PEMEX and SWSN sensing | Differences average |
|---|---|
| Temperature Oct/12/2007 | ± 0.2ºC |
| Relative humidity Oct/12/2007 | ± 0.63% |
| Apparent Temperature Oct/12/2007 | ± 0.27ºC |
| Apparent Temperature. Oct/ 2007 | ± 0.25ºC |

Table 3. Differences average between PEMEX sensing and SWSN sensing

## 5 Conclusion

We provide an efficient solution for monitoring worker's apparent temperature in oil derricks. This is in accordance to Mexican Official Standard for Worker's Health and Safety in High Thermal Conditions [1].

In this paper we reported our experience in the design, development and deployment of SENHOD. It enables monitoring feeling heat of derrickmen working on top oil derricks, it's a robust solution that meets all users' requirements and it's easy to manage. Also, devices used are appropriate for severe environments.

SENHOD does not require pre-configuration, turning on the sensor nodes and the base station is enough for deployment. A portable computer can be used as a base station, reducing the cost of SENHOD to just the cost of sensor nodes, which is about 180 USD each. With all these to its advantage, we hope that SENHOD can serve as a stepping-stone for worker's health and safety in high thermal conditions in accordance to standard.

Then, supervisors using SWSN's monitoring data can determine when workers should stop exposure in accordance to Mexican Official Standard for Worker's Health and Safety in High Thermal Conditions, so, SWSN represent a viable and more economic option. SENHOD has deep social, environmental and economic impacts.

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