# Design and Implementation of a Wireless Automation Module for Diesel Engines

**Author(s):** Siemuri, Akpojoto; Glocker, Tobias; Mekkanen, Mike; Kauhaniemi, Kimmo; Mantere, Timo; Rösgren, Jonatan; Kuusisto , Jari; Elmusrati, Mohammed

**Title:** Design and Implementation of a Wireless Automation Module for Diesel Engines

**Year:** 2019

**Version:** Accepted manuscript



**Please cite the original version:**

Siemuri, A., Glocker, T., Mekkanen, M., Kauhaniemi, K., Mantere, T., Rösgren, J., Kuusisto, J. & Elmusrati, M. (2019). Design and Implementation of a Wireless Automation Module for Diesel Engines. In *2019 27th Telecommunications Forum (TELFOR),* 1-4. https://doi.org/10.1109/TELFOR48224.2019.8971093

# Design and Implementation of a Wireless Automation Module for Diesel Engines

Akpojoto Siemuri, *Student Member, IEEE*, Tobias Glocker, Mike Mekkanen, Kimmo Kauhaniemi, *Member, IEEE,* Timo Mantere, Jonatan Rösgren, Jari Kuusisto and Mohammed Elmusrati, *Senior Member, IEEE*

*Abstract* — **This paper describes the design of wireless CAN protocol with the aim to replace existing wired CAN protocol communication between the Smart NOx sensor on diesel engines and the Engine Control Unit (ECU). Wireless industrial automation becomes essential in modern industry with the emerge of 5G networks and the IoT. Besides the advantages of wireless nodes in automation systems, there are many real challenges. Several practical design challenges have been successfully addressed in this paper.**

*Keywords* — **CAN Protocol, Engine Control Module (ECM), Smart NOx sensor, Speedgoat, Wireless Communication, ZigBee.**

## I. Introduction

Modern industry has developed rapidly, fueled by an increasing growth in global economy. However, data collection, analysis, and integration has become an essential pillar for the new industrial structure. It is extremely important to have real-time information in automation systems on all levels. One of the first steps in wireless automation, is to decide the required wireless communication protocol for certain automation system. The decision should be based on the automation requirements such as: latency, data rate, coverage distance, reliability (in terms of outage and packet losses), costs, security, etc. Therefore, studying of some well-known wireless communication solutions is crucial in achieving reliable and flexible data transfer [1].

The research presented in this paper investigates the feasibility of implementing a reliable, secure and fault tolerant wireless communication between the Smart NOx sensor on diesel engines and the Speedgoat (real-time rapid prototyping tool) or Engine Control Module (ECM). The Smart NOx sensor is connected to the Engine Control Unit (ECU) with a wired CAN bus connection. Data is transmitted using SAE J1939 protocol which is built on top of CAN Networks. SAE J1939 is developed specifically for use in heavy duty environments, with an emphasize on achieving reliable and fault tolerant communication. The approach taken in this research, is based on a case study of Wärtsilä's Smart NOx sensor on a W4L20 diesel engine with the objective, to replace the wired CAN bus with wireless node. The design steps, implementation and performance analysis are discussed in next sections.

### A. Smart NOx sensor

The smart NOx is a sensor that measures the oxygen ($O_2$) percentage and nitrogen oxides (NOx) ppm in the exhaust of combustion engines. Oxygen is measured as a percentage, while the NOx concentration is measured in parts per million (ppm) [2].

Nitrogen Oxides (NOx) are a group of poisonous, highly reactive gases of which two occur naturally namely nitric oxide (NO) and nitrogen dioxide ($NO_2$). The combustion of fossil fuels is the most common source of NOx emissions. The amount of emission depends on the air-fuel mix ratio as well as the amount of nitrogen in the fuel. At high temperatures and conditions that encourage oxidation NOx formation in combustion is favored. $NO_2$ has adverse effects on human health and at high concentrations it can lead to the inflammation of the airways [3].

### B. Speedgoat and Engine Control Module (ECM)

The speedgoat applies Real-time systems with Simulink Real-Time™ from MathWorks to various applications across many industries, in the lab, field, classroom, or embedded in machinery. Speedgoat solutions and Simulink are seamlessly integrated and allows for fast test run of Simulink software designs with hardware [4].

The Engine Control Module (ECM), also called Engine Control Unit (ECU), is a kind of electronic control unit that manages the control of series of actuators on an internal combustion engine to ensure that the engine's performance is optimal. This is done by reading the values from all the sensors within the engine bay and interpreting the data using multidimensional performance maps (referred to as lookup tables) and adjusting the engine actuators accordingly [5]. The diesel engine used in this research is a medium speed W4L20 diesel engine. The engine produces approximately 1 MW of power and it is paired with ABB generator [6]. This combustion engine is in the Vaasa Energy Business Innovation Center (VEBIC) laboratory. VEBIC is a new research and innovation platform hosted by the University of Vaasa. The VEBIC environment has two laboratories namely, the internal combustion engine laboratory and a separate but related fuel development laboratory. It also has a program for energy and sustainable development research projects [7].

## II. CAN Protocol and the Wireless Module

In this section, the required wireless module is discussed. The selection is based on the automation requirements and the available wireless standards.

### A. Controller Area Network (CAN)

CAN is a solution for automation industries and the CAN protocol is used in systems that need to transmit and receive a small amount of data with real-time requirements. CAN bus was originally developed for the car industry to replace point to point connections in automotive systems. CAN protocol has been stipulated as international standard by 150 International Standard Organizations [8]. CAN transmits signals on the CAN network using two wires, CAN-High and CAN-Low. These two wires operate in differential mode carrying inverted voltages which decreases noise interference. The standard being used determines the voltage level and other characteristics of the physical layer. The two standards are the ISO11898 (CAN High Speed) standard and the ISO11519 (CAN Low Speed) standard [9].

### B. Wireless Communication Protocols

Wireless applications typically require burst transmission, reduced overhead, and they use a very small amount of data per node, therefore, the bandwidth is not the main requirement. Some applications require coverage of large areas; reliability, availability, bounded latency for real-time behavior and energy efficiency as some key performance indicators [10].

The XBee module used during implementation uses the ZigBee (IEEE 802.15.4) technology. ZigBee is a short-range wireless protocol which is a standard for personal-area networks developed by ZigBee Alliance aiming at providing a low cost, low power consumption, reliable and two-way wireless communication standard for short range applications. It allows the nodes to find new routes throughout the network when one route fails. Thus, Zigbee is a robust wireless solution [11].

The choice of using the ZigBee protocol was made from comparing four wireless solutions based on the analysis of experiment results. The wireless protocols compared were namely WiFi, LoRa, BLE and Zigbee. Performance analysis for these four wireless protocols was conducted based on key considerations that should influence the choice of wireless protocols for a specific application. The experiments and measurements were performed in Technobothnia laboratory. Technobothnia is a wide ranged advanced and modern laboratory unit that occupies 8000m$^2$ and which is within the campus of University of Vaasa [12]. Furthermore, the experiments related to the engine has been carried out in the Engine test room located in VEBIC.

From the experiments, the Xbee had a better RSSI values and security feature over the other wireless modules used. These features with some other factors like, good performance in the packet loss test; ability to enhance the battery life; better penetrating capability and range when compared to the BLE leads to the choice of implementing the ZigBee wireless protocol in designing the wireless-CAN protocol called the Xbee-CAN module.

## III. System Architecture

The system consists of a 24V power supply for the smart NOx sensor, which is connected to the CAN Bus of the wireless-CAN module (transmitter). Furthermore, the wireless-CAN modules (receiver) is connected to the speedgoat, the speedgoat device that contains a MATLAB Simulink model in order to calculate, monitor, and display the $O_2$ % and NOx ppm.

### A. The Xbee-CAN bridge Hardware

The setup (see in Fig. 1 and 2) provides a proof-of-concept that can be further developed from a prototype into a product.

At the transmitter side, a Multiprotocol Radio Shield is connected over the Arduino board and the CAN Bus module is placed in socket 0 of the Multiprotocol Radio Shield while the Xbee module is placed in socket 1. The CAN Bus module is used to interface the transmitter Xbee module with the smart NOx sensor using twisted pair cables (CAN High and CAN Low).

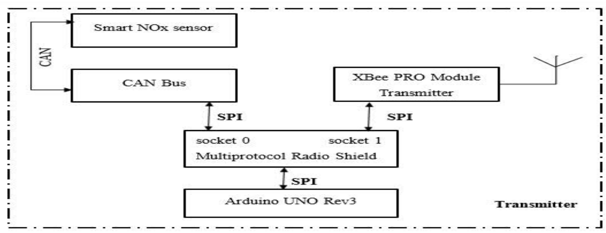


Fig. 1. Block diagram for the hardware setup of Xbee-CAN bridge Transmitter.

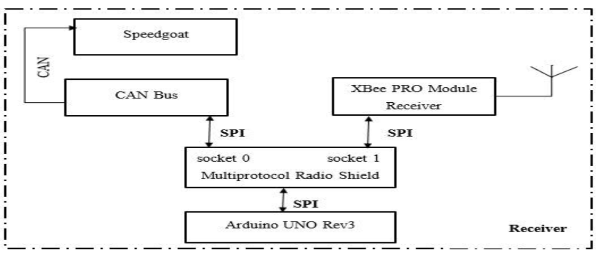


Fig. 2. Block diagram for the hardware setup of Xbee-CAN bridge Receiver.

At the receiver side, a Multiprotocol Radio Shield is connected over the Arduino board and the CAN Bus module is placed in socket 0 of the Multiprotocol Radio Shield while the Xbee module is placed in socket 1. The CAN Bus module is used to interface the receiver Xbee module with the speedgoat device using twisted pair cables (CAN High and CAN Low).

### B. The Xbee-CAN bridge Software

The programming of the hardware devices was done using the Arduino IDE environment.

At the transmitter side, the smart NOx sensor has a 29-bit CAN ID and the transmitter hardware is programmed to send an initialization heating signal “00000004h” (8 bytes hexadecimal) through the CAN Bus to this CAN ID to start heating and collecting the smart NOx data. The data is received through the CAN Bus and then transferred through SPI to the Xbee for wireless transmission. While at the receiver side, the hardware is programmed to receive the smart NOx sensor data and transfers the data through SPI to the CAN Bus of the receiver module. The CAN Bus is connected to the speedgoat using two twisted pair cable (CAN High and CAN Low) for analyzing the received data. The receiver module also performs packet loss and RSSI measurements.

The flowcharts for the programming of the transmitter and receiver modules are illustrated in Fig. 3 and 4 respectively.

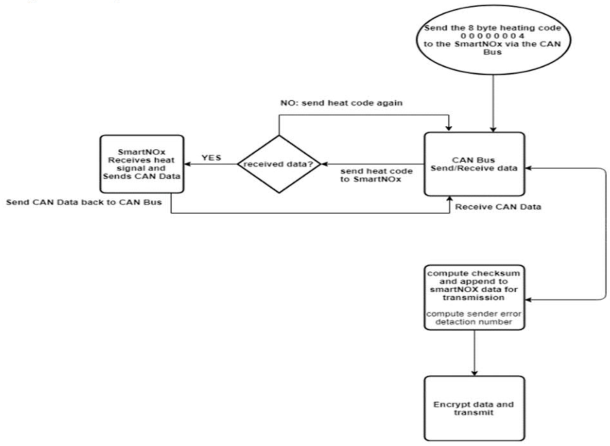


Fig. 3. Flowchart for the Xbee transmitter codes.

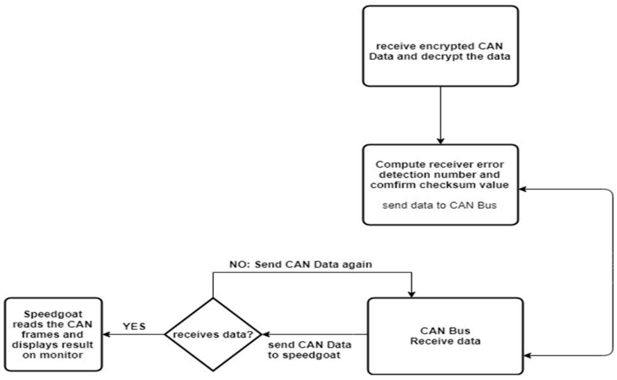


Fig. 4. Flowchart for the Xbee receiver codes.

### C. *Details of Transmitted Payload*

The transmitted payload is a 10-byte hexadecimal data comprising of 1-byte preamble, 8-byte smart NOx data and 1-byte checksum data as illustrated in Fig. 5.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| preamble | NOx0 | NOx1 | NOx2 | NOx3 | NOx4 | NOx5 | NOx6 | NOx7 | checksum |

Fig. 5. Transmitted Smart NOx Payload.

Equation (1) is the checksum and it is the sum of the 8-byte smart NOx data only.

$$NOx0 + NOx1 + NOx2 + \dots + NOx7 = checksum NOx0 + NOx1 + NOx2 + \dots + NOx7 = checksum \quad (1)$$

The preamble is computed as illustrated in Equation (2). The preamble is computed from the sum of the 8-byte smart NOx data plus the checksum value, that is, smartNOx[8] + checksum[1] = preamble[1].

$$NOx0 + NOx1 + NOx2 + \dots + NOx7 + checksum = preamble \quad (2)$$

Both, the checksum and preamble are used to verify data integrity, that ensures an error free data transmission and prevents the alteration of data.

## IV. Performance Test of the Designed Xbee-CAN Module on Wärtsilä's W4L20 Diesel Engine

The smart NOx sensor was installed on the Wärtsilä 4L20 Diesel Engine and the $O_2$% and NOx ppm values were measured and compared with the readings from the SICK|MCS100E. The MCS100E HW is an analyzer system used for extractive measurement of up to eight (8) active gas components from an engine [13]. Table 1 illustrates the comparison between the values from MCS100E and wireless Xbee-CAN prototype seen on the speedgoat device for the W4L20 diesel engine in different operation modes (engine is idle, running without load and running with load). It is the percentage error of the Xbee-CAN module prototype values when compared to the values from the MCS100E. The measurements from MCS100E and the Xbee-CAN module were performed at the same time. The difference between their readings in Table 1 comes from the fact that both had its own separate sensor (installed on different location on the exhaust of the same engine), therefore, their measurement time could not be properly synchronized. However, it was concluded from observation that the values obtained were close to what was expected from the engine test for the Xbee-CAN module and the MCS100E (as a reference).

Table 1: Comparison of the values from SICK|MCS 100E and the Xbee-Can module connected to a smart NOx sensor.

| Measurement Device | Engine Operation Modes | | | | | |
|---|---|---|---|---|---|---|
| | Engine is Idle | | Engine running without load | | Engine running with load | |
| | *NOx ppm* | *$O_2$ %* | *NOx ppm* | *$O_2$ %* | *NOx ppm* | *$O_2$ %* |
| **Xbee-CAN module percentage error (%)** | 0.0 | 0.0 | 3.09 | 7.22 | 3.83 | 2.06 |

In the present application (the engine test phase), the delay noticed in the wireless CAN (Xbee-CAN module) as compared to the wired CAN network, is still within the acceptable delay range.

For the Xbee-CAN module, Fig. 6 gives the sliding graph of the $O_2$% and NOx ppm values from the speedgoat monitoring tool.

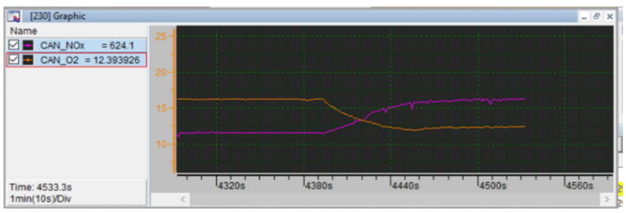


Fig. 6. Speedgoat sliding graph of the $O_2$% and NOx ppm values.

## V. Applying Additive Manufacturing to the Designed Prototype

Additive Manufacturing is applied in this project to design the protective casing for the designed Xbee-CAN Receiver/Transmitter. Two protective casings were designed, and 3D printed to encapsulate the receiver and transmitter XBee-CAN Modules prototypes. The installed Xbee-CAN Receiver/Transmitter in the 3D printed protective casings are illustrated in Fig. 7.

Fig. 7. Wireless Xbee-CAN prototype in 3D printed casing.

The Material used in printing the protective casings is PLA filament. The 3D printers used for the printing of the prototype casing are the PRUSA and MINIFactory. Both used the following settings during printing: printing temperature of 200°C for the extruder and 60°C for the bed plate and an infill of 20%.

## VI. Conclusion

Research on the feasibility of replacing the existing wired CAN bus connection between the smart NOx sensor and Speedgoat and possibly in the future the Engine Control Unit (ECU) with a wireless communication solution was performed. The devices have been designed to meet the required application in line with the performance expectation for communication in an industrial environment. The designed wireless Xbee-CAN prototype is currently installed and running on a W4L20 diesel engine in VEBIC. Possible future work involves integrating Field Programmable Gate Arrays (FPGAs) to the device. The most important motivation is to optimize the software to improve the battery life of the current prototype by optimizing all parameters related to data rates, power and energy consumption.

## Acknowledgment

Special thanks to Reino Virrankoski for the opportunity to work on this project and thanks to Rayko Toshev for granting access to the digital manufacturing laboratory in Technobothnia, University of Vaasa to achieve the 3D printing aspect of this project.

## References

[1] G. Xiang, D. Huang, Y. Chen, W. Jin and Y. Luo, "The Design of a Distributed Control System Based on CAN bus," in *Proceedings of 2013 IEEE, International Conference on Mechatonic and Automation, August 4 – 7*, Takamatsu, Japan., 2013.

[2] I. Senft and L. Bertrand, "Specification Smart NOx Sensor - Uninox24V," Wärtsilä Oyj Abp, 2010.

[3] "Nitrogen oxides (NOx) emissions," 2018. [Online]. Available: https://www.eea.europa.eu/data-and-maps/indicators/eea-32-nitrogen-oxides-nox-emissions-1.

[4] "Applications and Industries Overview," 2007-18. [Online]. Available: https://www.speedgoat.com/applications-industries.

[5] "Wikipedia - Electronic Diesel Control," 2018. [Online]. Available: https://en.wikipedia.org/wiki/Electronic_Diesel_Control.

[6] K. Antti, J. Marko, K. Teemu and F. Tero, "W4L20 VEBIC Genset dynamics—baseframe design," *Journal of Structural Mechanics,* vol. 50, p. 292, 2017.

[7] "VEBIC - Vaasa Energy Business Innovation Centre," 23 10 2018. [Online]. Available: https://www.univaasa.fi/fi/sites/vebic/.

[8] W. Xiao-feng, X. Yi-si and C. Li-xiang, "Application and Implementation of CAN Bus Technology in Industry Real-time Data Communication.," in *Proceedings of 2009 IEEE, International Conference on Industrial Mechatronics and Automation (ICIMA)*, 2009.

[9] S. Nilsson, "Controller Area Network - CAN Information.," 2018. [Online]. Available: http://hem.bredband.net/stafni/developer/CAN.htm.

[10] A. Khan and K. Turowski, "A survey of current challenges in manufacturing industry and preparation for industry 4.0," 2016. [Online]. Available: https://www.springer.com/cda/content/document/cda_downloaddocument/9783319336084-c2.pdf?SGWID=0-0-45-1564143-p179960859.

[11] "ZigBee – Technical documents," 2013. [Online]. Available: http://www.ti.com/wireless-connectivity/simplelink-solutions/zigbee/technical-documents.html.

[12] "Technobothnia," 2019. [Online]. Available: https://www.technobothnia.fi/.

[13] "CEMS solutions MCS100E HW," 2019. [Online]. Available: https://www.sick.com/fi/en/analyzer-solutions/cems-solutions/mcs100e-hw/c/g285463.