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# The Networked Nitrous Node: A Low-Power Field-Deployable COTS-based N2O gas sensor platform

Ronaldo Leon
*Portland State University*

Wenyu Bi
*Portland State University*

Eyal Eynis
*Portland State University*

Travis Johnson
*Portland State University*

Wei Yan
*Portland State University*

*See next page for additional authors*



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## Authors
Ronaldo Leon, Wenyu Bi, Eyal Eynis, Travis Johnson, Wei Yan, David C. Burnett, and John M. Acken

Sensor Applications

# The Networked Nitrous Node: A low-power field-deployable COTS-based $N_2O$ gas sensor platform

Ronaldo Leon, Wenyu Bi, Eyal Eynis, Travis Johnson, Wei Yan, John Acken, David C. Burnett*
*Department of Electrical and Computer Engineering, Portland State University, Portland OR, USA*
**Senior Member, IEEE*

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Abstract—We present a wireless nitrous oxide ($N_2O$) gas sensor system consisting of a commercial high-current infrared $N_2O$ sensor wrapped in a "smart" sensor framework to make it suitable for battery-powered deployment. This framework consists of wireless mesh networking, data storage, additional environmental sensors, and a gas sensor power control circuit managed by a central microcontroller. The $N_2O$ sensor is the first order consumer of power and sampling $N_2O$ at approximately ten minute intervals yields an estimated system lifetime of 63 days when using four 18650 Li-ion batteries. The node stores data locally on SD card and wirelessly reports to a root PC that also stores data and displays to users in a simple graphical user interface. The system is composed of majority off-the-shelf components and any custom components were designed or programmed with open-source software. We expect these features will lead to this system being more easily understood, copied, and modified by engineers wishing to design similar sensor system frameworks and thereby allow even more power-prohibitive devices to be wirelessly deployed.

Index Terms—Internet of Things; gas sensors; mesh networking; wireless sensor systems

## I. INTRODUCTION

Gas sensors, optical or otherwise, can provide rich information about our local atmosphere that is of increasing criticality as climate change exacerbates ecological conditions on the planet. A wide variety of inexpensive gas sensors have been developed for use in applications where analysis with, e.g., mass spectrometry is infeasible due to accessibility, time delay, cost, or other reasons. A critical limitation to ubiquitous deployment of these inexpensive gas sensors is current consumption while active. Examples of peak active current draw for commercial gas sensors include 10 mA for $O_2$ [1], 85 mA for $N_2O$ [2], and 205 mA for $CO_2$ [3]. These sensors are fairly low cost, making them suitable for widespread fully wireless deployment when integrated with a datalogging system that can manage and selectively duty cycle these useful, but power-hungry, sensors.

We present such a battery-powered wireless data logging system capable of adding "smart" features and managing high-power gas sensors. It incorporates a nondispersive infrared (NDIR) nitrous oxide ($N_2O$) gas sensor and other majority-COTS electronics to form a node capable of taking data at ten-minute intervals for over two months before needing to be recharged. This project is in contrast to similar efforts to field gas sensors inside wireless sensor nodes but were limited to those electrochemical sensors requiring less than 1 $\mu A$ when operating [4] or depended on line power, foregoing fully wireless implementation [5]. Furthermore, this system is designed primarily from commercial components and evaluation boards using open-source tools that are easy to obtain, design with, program, and reconfigure. We believe this strategy is more advantageous than using many custom components to form a tightly-integrated atmospheric sensing device that does not lend itself to rapid iterations for new applications [6].

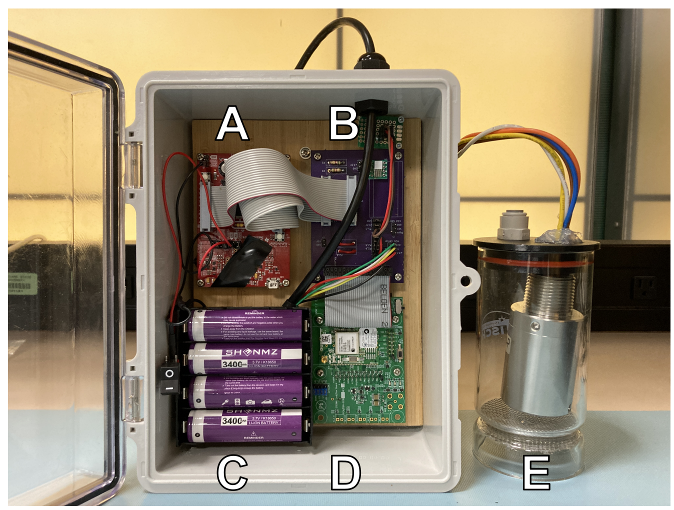


Fig. 1. Photo of a battery-powered sensor node assembled inside a weatherproof housing including (A) red microcontroller PCB with local logging to SD card, (B) purple junction PCB including temperature and humidity sensors, (C) Li-ion batteries, (D) wireless mesh network link to the root logging and dashboard display PC, and (E) $N_2O$ sensor with steel housing in glass gas test cylinder.

$N_2O$ was chosen as our target gas on account of its powerful greenhouse gas attributes and it being an agricultural runoff byproduct [7]. Despite the gas's significance, $N_2O$ sensors are rare and the only viable alternative to the sensor used in this work is approximately 10x the cost and consumes 5x more current [8]. Other greenhouse gases such as $CO_2$ are well represented in the market but atmospheric scientists and engineers wishing to monitor $N_2O$ have limited options,

Corresponding author: D. Burnett (e-mail: dburnett@ece.pdx.edu).
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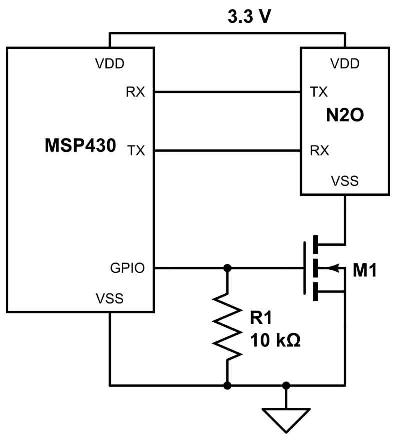


Fig. 2. Simple power control circuit used to cycle $N_2O$ sensor on/off. The fifth $N_2O$ sensor "output" pin, not labeled here, was ignored and left floating.

and thus could benefit most from a sensor platform such as this. In general, many gas sensor products focus on the core goal – sensitivity and selectivity – rather than "smart" features such as programmability and wireless communication. By integrating a sensor with fewer system-level features, we gain the flexibility to redesign using a wider assortment of sensors in the future.

## II. SYSTEM DESCRIPTION

The system is assembled inside a weatherproof box measuring 220 x 170 x 110 mm and powered from four 18650 Li-ion rechargeable lithium-ion cells. The gas sensor cable passes through the weatherproof box and is sealed with a cable gland. Electrical signals such as power, UART, and I2C are routed through a custom-made junction PCB designed in the open-source PCB design tool KiCad [9] which also hosts the temperature/humidity sensor and I2C pull-up resistors. The system contains two other PCBs: one each for the wireless mesh network controller and the central microcontroller. A photo of the system is shown in Fig. 1. Code, designs, and documentation are available online at https://web.cecs.pdx.edu/~dburnett/ojapn2o.

### A. Central Microcontroller and Local Logging

System operations are managed by the microcontroller on an MSP-EXP430RF5994 LaunchPad development board which includes an SD card slot [10]. Local storage on the SD card is used as a redundant local log file destination in case of wireless root node power failure and to allow standalone node deployment without a wireless connection. The default switched voltage source (the "EnergyTrace" source, 75 mA max) was bypassed in lieu of the LaunchPad's LDO (200 mA max) to accommodate the high current requirements of the $N_2O$ sensor: 75-85 mA, per its datasheet. Firmware development required modification of vendor-provided library files to enable a third UART for the $N_2O$ sensor.

### B. Wireless Mesh Network

The wireless mesh network is handled by the SmartMesh IP system from Analog Devices [11]. Out of the box, our DC9018B-B development boards accepted serial data packets formed by SmartMesh IP libraries written for the open-source Energia integrated development environment. This strategy allowed us to avoid developing code on the SmartMesh SoC, which requires expensive software tools. The wireless mesh system can support tens of thousands of nodes while ensuring highly reliable packet delivery rates, providing a path that supports growth as these nodes are refined, deployed at scale, and customized for future applications.

### C. Nitrous Oxide, Temperature, and Relative Humidity

Environmental sensing is accomplished using the Honeywell HIH6120 to obtain temperature and relative humidity and the Dynament MSH-P/N2OP to obtain $N_2O$ concentration up to 1000 ppm at 20 ppm resolution [?], [2]. The HIH6120 is a traditional I2C peripheral and responds to periodic commands to obtain temperature and/or humidity and is otherwise in low-current sleep mode. The current Energia development environment release contained flawed MSP430FR5994 I2C hardware libraries that required updating from the Energia GitHub repository.

The $N_2O$ sensor is a digital peripheral that communicates via UART. Communication involves the microcontroller sending a sequence to request a new set of data and the sensor returning gas concentration, temperature, and status flags. By our measurements the sensor burns 77 mA continuously while powered with small deviations every 0.5 s that presumably correspond to internal sampling operations. Our goals to design a long-lasting battery-powered sensor node while incorporating constant-current sensors such as this required us to find a way to let the central microcontroller to disconnect the sensor from power between samples. This simple circuit is illustrated in Fig. 2. This circuit was assembled on a small protoboard and is located adjacent to the junction PCB. Our first experiment disconnected VDD but, inexplicably, current consumed by the full system was only reduced to approximately 15 mA instead of the expected 1 mA. We assume a parasitic current path through the UART lines continued to partially power the sensor. Using an NMOS to disconnect VSS eliminated current through the $N_2O$ sensor altogether.

The sensor requires approximately one minute to warm up after power-on and will return a special invalid data value until ready. Environmental gas concentrations are not expected to change quickly so we power up the sensor for one minute and power it down for nine minutes to obtain samples with approximately 10 minute periodicity. In practice, with code execution time overhead the $N_2O$ sensor is powered for 61.8 s per sample and samples are taken on a 607 s period. The $N_2O$ sensor is the primary consumer of power so, if our application shows the environment changes more slowly, we can greatly extend the lifetime of the node by sampling the $N_2O$ sensor less frequently.

### D. Graphical User Interface

The wireless system writes to a set of text-based log files stored on the root PC to serve as a simple intermediate format between data arriving wirelessly and subsequent processing and display. A graphical user interface was written in Python based on the Tkinter framework [12] showing a list of connected wireless nodes organized by the last three bytes of each mote MAC address. When a node is clicked on, a table and plot of recent values is displayed. A screenshot of the program is shown in Fig. 3.

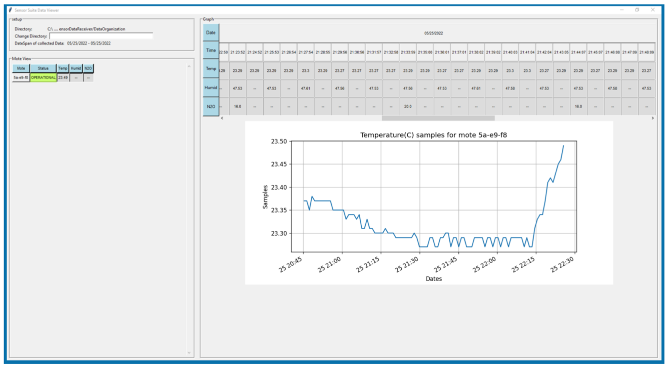


Fig. 3. Screenshot of the data visualization GUI running on the root PC.

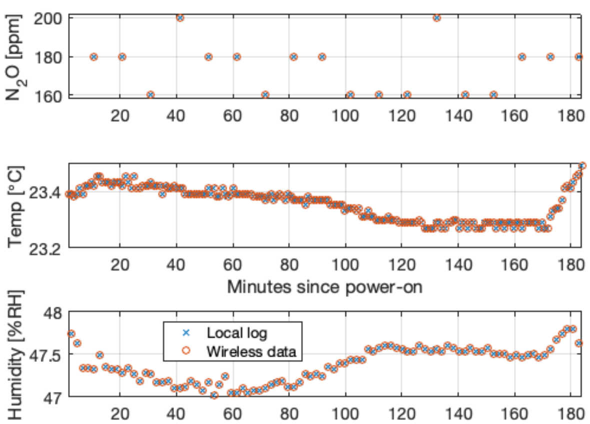


Fig. 4. Data collected by system in an ambient indoor lab setting showing excellent agreement between data logged by SD card and via wireless network as ambient conditions (temperature, humidity) or artificial noise signal ($N_2O$) varies during the three-hour test.

## III. SYSTEM RESULTS

The core microcontroller was programmed to request temperature data every minute, humidity data every two minutes, and $N_2O$ data every ten minutes. The $N_2O$ sensor requires approximately one minute of warm-up time so it is powered on via GPIO signal to the power control NMOS one minute prior to taking a reading. The sensor reports an invalid value if warm-up has not yet completed, so the system has closed-loop warm-up control. After a successful reading, the $N_2O$ sensor is powered off. The microcontroller is in deep sleep mode when not taking readings, warming up the $N_2O$ sensor, or handing data off to the wireless mesh network. Average power estimates were developed over long periods to capture repeated, brief, behaviors such as maintaining synchronization with the wireless network.

Data was taken continuously over a three-hour period. Data stored locally on SD card, and transmitted wirelessly, were time-aligned and plotted in Fig. 4 to verify data was being faithfully reproduced in both media. Time alignment was necessary owing to the SD card timestamp simply consisting of milliseconds since power-on. $N_2O$ readings are of an artificially-induced noise signal for testing purposes to allow reading nonzero values without the presence of $N_2O$.

TABLE 1. Current Consumption and Lifetime Breakdown

| Component | Average Current Draw |
|---|---|
| MSP430FR5994 (incl. SD card) | 0.87 mA |
| $N_2O$ Sensor | 7.84 mA (77 mA at 10.2% duty) |
| Wireless Mesh Module | 80 $\mu A$ |
| T/RH sensor | 0.8 $\mu A$ |
| TLV70033 3.3v LDO | 46 $\mu A$ when $N_2O$ idle<br>160 $\mu A$ when $N_2O$ active |
| Measured current from battery | 9.2 mA (sum of above: 8.8 mA) |
| Estimated lifetime from 4x 18650 Li-ion cells (3400 mAh per cell) | 63 days |
| Estimated battery lifetime if $N_2O$ sensor was used at 60 min intervals | 229 days |

### A. Power Consumption

Power consumed by major system components, and the full system in aggregate, were measured by the Joulescope instrument [13], tabulated in Table 1. Initial results lead us to expect a battery lifetime of approximately two months. We observe that the eZ-FET, EnergyTrace, etc. supporting management hardware integrated into the MSP430FR5994 LaunchPad board consumes approximately 18 mA continuously [10], [14]. If this background current was not identified and eliminated, estimated lifetime would have shrunk to only 21 days. This underscores the necessity of detailed power characterization of all components.

### B. Sensor Node Cost

Costs of each component in the sensor node are tabulated in Table 2. The standout cost is the DC9018B-B Eval Board evaluation board, which is effectively a breakout board for a LTP590x module [15]. At time of writing that module costs approximately $100 each through several popular electronics vendors; adding it to the junction PCB and eliminating the DC9018B-B would decrease per-node costs by 25%. Other opportunities for cost savings include adding a TLV70033 LDO ($1) to the junction PCB to eliminate its eval board ($24). Up to three batteries could be eliminated, saving $10 ea, depending on deployment goals; from results in Table I, using the $N_2O$ sensor hourly can extend battery lifetime by a factor of about 3.6. By those measurements we estimate a single battery could still power the system, when sampling $N_2O$ hourly, for about 57 days.

TABLE 2. Per-Node Component Cost

| Component | USD Cost to Nearest $1 |
|---|---|
| MSP430FR5994 Eval Board | 20 |
| SD card, 32 GB | 18 |
| $N_2O$ Sensor w/ Housing | 274 |
| DC9018B-B Mesh Network Eval Board | 360 |
| Junction PCB w/ T/RH sensor | 36 |
| TLV70033 LDO Eval Board | 24 |
| 4x 18650 Li-ion cells | 40 |
| IP67 Housing | 28 |
| Connectors, tubing, wires | 30 |
| Total | 830 |

## IV. CONCLUSION

The described sensor node was a success in its goals to transform a high-power, but valuable, gas sensor into a "smart" device incorporating power management, data storage, and wireless communication in a form factor capable of being deployed in the field for an extended period. Its rapid development was facilitated by the use of many commercial evaluation boards, lending a clear path to tighter integration as we strive to eliminate extraneous components to further reduce power and cost. Nitrous oxide is hardly the only important gas currently difficult to detect in part because of the power consumed by current sensing technology and we hope to use this low-cost and open-source framework to build new types of gas sensors in the future.

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