Experimentation with Inexpensive Internet of Things (IoT) Modules: A Thermometer Using LoRaWAN

by Timothy C Gregory

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Experimentation with Inexpensive Internet of Things (IoT) Modules: A Thermometer Using LoRaWAN

by Timothy C Gregory

Computational and Information Sciences Directorate, ARL

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<td>The US Army Research Laboratory’s Battlefield Information Processing Branch is experimenting with inexpensive Internet of Things (IoT) modules. This technical note describes the implementation of a wireless thermometer using such modules.</td>
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1. Introduction

The availability of commercial Internet of Things (IoT) modules has enabled the development of IoT for the battlefield.

This document describes a simple electronic thermometer that reports through the LoRaWAN infrastructure. The device will send temperature information and geographic position to the LoRaWAN gateway, which will distribute it via an Internet port.

2. Hardware

There are many development boards available for experimenting with IoT. The Pycom LoPy was chosen because of availability and low price.

2.1 Pycom LoPy

The Pycom LoPy module was selected as the foundation for the project. The LoPy is a MicroPython-enabled development board. The LoPy provides connectivity through WiFi, LoRa, Bluetooth, and Sigfox.

The specifications of the LoPy are shown in Fig. 1.

<table>
<thead>
<tr>
<th>Spec</th>
<th>Description</th>
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<tr>
<td>CPU</td>
<td>Xtensa® dual-core 32-bit LX6 microprocessor(s), up to 600 DMIPS</td>
</tr>
<tr>
<td></td>
<td>Hardware floating point acceleration</td>
</tr>
<tr>
<td></td>
<td>Python multi-threading</td>
</tr>
<tr>
<td></td>
<td>An extra ULP—coprocessor that can monitor GPIOs, the ADC channels, and control most of the internal peripherals during deep-sleep mode while only consuming ~25uA</td>
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<tr>
<td>Memory</td>
<td>RAM: 520KB + 4MB</td>
</tr>
<tr>
<td></td>
<td>External flash: 8MB</td>
</tr>
<tr>
<td>WiFi</td>
<td>802.11bg/n 16mbps</td>
</tr>
<tr>
<td></td>
<td>3.4 Bluetooth</td>
</tr>
<tr>
<td></td>
<td>Low energy and classic</td>
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<tr>
<td>LoRa</td>
<td>LoRaWAN 1.0.2 stack - Class A and C devices</td>
</tr>
<tr>
<td></td>
<td>Node range: Up to 40km</td>
</tr>
<tr>
<td></td>
<td>Nano-gateway: Up to 22km (Capacity up to 100 nodes)</td>
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Fig. 1   LoPy specifications

2.2 Temperature Sensor

The temperature data are provided by a prewired and waterproofed version of the DS18B20 temperature sensor. The DS18B20 interfaces with the LoPy board through a 1-Wire bus. The 1-Wire bus uses only one wire for data. There are MicroPython libraries available that provide support for the DS18B20.
2.3 Location Sensor

The Pycom Pytrack expansion board is used to provide the GPS data. The Pytrack board also provides a header for accessing some of the general purpose input/output pins on the Pycom board.

3. Programming Environment

3.1 MicroPython

The LoPy is programmed using the MicroPython programming language. MicroPython is an implementation of the Python 3 programming language that includes a small subset of the Python standard library and is optimized to run on microcontrollers and in constrained environments.

3.2 Libraries

There are MicroPython drivers and libraries to support various devices. They libraries are available through GitHub at https://github.com/micropython/micropython.

For this application, we use the OneWire class to enable using the 1-wire interface on the LoPy. We also use the DS18X20 class to operate the DS18X20 thermometer.

The source code for the OneWire and DS18X20 libraries are shown in Appendix A.

3.3 Development Environment

Running MicroPython code on the Pycom board can be done through the Read Evaluate Print Loop (REPL) interactive terminal. You can connect to the REPL terminal through a USB serial port. Once you have tested and debugged your code, you can install it in a file named “main.py” on the Pycom board. “main.py” is run each time the board boots up. Further information on connecting to and programming the module is located on the Pycom website (https://docs.pycom.io/gettingstarted/programming).

3.4 LoPy File System

The file system of the LoPy contains two MicroPython scripts: “boot.py” and “main.py”. These are executed when power is applied to the device or the device is rebooted. “main.py” is run at startup after “boot.py”. See the Pycom website (https://docs.pycom.io/product-info/development/lopy) for more information on the boot order and file system.
4. Connecting the Temperature Sensor

The connections between the DS18B20 temperature sensor and the Pytrack board are shown in Fig. 2. The wire colors may be different depending upon the source of the prewired DS18B20. Figures 3 and 4 show the relative positions of the header pins. Figure 5 details the functions of the header pins.

![Fig. 2 Temperature sensor wiring](image)

![Fig. 3 Pytrack board layout](image)
5. **MicroPython Source Code**

Appendix B details the MicroPython source code that reads sensor data and sends it to the LoRaWAN gateway.

6. **Summary**

The availability of inexpensive IoT modules has facilitated experimentation with the IoT technology. This experimentation should enable the evaluation of different ideas and components to determine their application to the Army.
#!/usr/bin/env python3

""
OneWire library for MicroPython
""

import time
import machine

class OneWire:
    CMD_SEARCHROM = const(0xf0)
    CMD_READROM = const(0x33)
    CMD_MATCHROM = const(0x55)
    CMD_SKIPROM = const(0xcc)

    def __init__(self, pin):
        self.pin = pin
        self.pin.init(pin.OPEN_DRAIN, pin.PULL_UP)

    def reset(self):
        ""
        Perform the onewire reset function.
        Returns True if a device asserted a presence pulse, False otherwise.
        """
        sleep_us = time.sleep_us
        disable_irq = machine.disable_irq
        enable_irq = machine.enable_irq
        pin = self.pin

        pin(0)
        sleep_us(480)
        i = disable_irq()
        pin(1)
        sleep_us(60)
        status = not pin()
        enable_irq(i)
        sleep_us(420)
        return status

    def read_bit(self):
        sleep_us = time.sleep_us
        enable_irq = machine.enable_irq
        pin = self.pin

        pin(1) # half of the devices don't match CRC without this line
        i = machine.disable_irq()
        pin(0)
        sleep_us(1)
        pin(1)
        sleep_us(1)
        value = pin()
        enable_irq(i)
        sleep_us(40)
        return value

    def read_byte(self):
        value = 0
        for i in range(8):
            value |= self.read_bit() << i
        return value

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def read_bytes(self, count):
    buf = bytearray(count)
    for i in range(count):
        buf[i] = self.read_byte()
    return buf

def write_bit(self, value):
    sleep_us = time.sleep_us
    pin = self.pin
    i = machine.disable_irq()
    pin(0)
    sleep_us(1)
    pin(value)
    sleep_us(60)
    pin(1)
    sleep_us(1)
    machine.enable_irq(i)

def write_byte(self, value):
    for i in range(8):
        self.write_bit(value & 1)
        value >>= 1

def write_bytes(self, buf):
    for b in buf:
        self.write_byte(b)

def select_rom(self, rom):
    ""
    Select a specific device to talk to. Pass in rom as a bytearray
    (8 bytes).
    ""
    self.reset()
    self.write_byte(CMD_MATCHROM)
    self.write_bytes(rom)

def crc8(self, data):
    ""
    Compute CRC
    ""
    crc = 0
    for i in range(len(data)):
        byte = data[i]
        for b in range(8):
            fb_bit = (crc ^ byte) & 0x01
            if fb_bit == 0x01:
                crc = crc ^ 0x18
            crc = (crc >> 1) & 0x7f
            if fb_bit == 0x01:
                crc = crc | 0x80
        byte = byte >> 1
        return crc

def scan(self):
    ""
    Return a list of ROMs for all attached devices.
    Each ROM is returned as a bytes object of 8 bytes.
    ""
    devices = []
    diff = 65
    rom = False
    for i in range(0xff):
rom, diff = self._search_rom(rom, diff)
if rom:
    devices += [rom]
if diff == 0:
    break
return devices

def _search_rom(self, l_rom, diff):
    if not self.reset():
        return None, 0
    self.write_byte(CMD_SEARCHROM)
    if not l_rom:
        l_rom = bytearray(8)
    rom = bytearray(8)
    next_diff = 0
    i = 64
    for byte in range(8):
        r_b = 0
        for bit in range(8):
            b = self.read_bit()
            if self.read_bit():
                if b: # there are no devices or there is an error on
                    return None, 0
                else:
                    if not b: # collision, two devices with different bit
                        meaning
                        if diff > i or ((l_rom[byte] & (1 << bit)) and
                        diff != i):
                            b = 1
                            next_diff = i
                            self.write_bit(b)
                            if b:
                                r_b |= 1 << bit
                                i -= 1
                            rom[byte] = r_b
                            return rom, next_diff

class DS18X20(object):
    def __init__(self, onewire):
        self.ow = onewire
        self.roms = [rom for rom in self.ow.scan() if rom[0] == 0x10 or rom[0] == 0x28]
        self.fp = True
        try:
            1/1
        except TypeError:
            self.fp = False # floatingpoint not supported
    def isbusy(self):
        """
        Checks whether one of the DS18x20 devices on the bus is busy
        performing a temperature conversion
        """
        return not self.ow.read_bit()
    def start_conversion(self, rom=None):
        """
        Start the temp conversion on one DS18x20 device. Pass the 8-byte
        bytes object
        with the ROM of the specific device you want to read.
        If only one DS18x20 device is attached to the bus you may
omit the rom parameter.

```python
if (rom==None) and (len(self.roms)>0):
    rom=self.roms[0]
if rom!=None:
    rom = rom or self.roms[0]

ow = self.ow
ow.reset()
ow.select_rom(rom)
own.write_byte(0x44)  # Convert Temp

def read_temp_async(self, rom=None):
    """
    Read the temperature of one DS18x20 device if the conversion is complete,
    otherwise return None.
    """
    if self.isbusy():
        return None
    if (rom==None) and (len(self.roms)>0):
        rom=self.roms[0]
    if rom==None:
        return None
    else:
        ow = self.ow
        ow.reset()
        ow.select_rom(rom)
        ow.write_byte(0xbe)  # Read scratch
        data = ow.read_bytes(9)
        return self.convert_temp(rom[0], data)

def convert_temp(self, rom0, data):
    """
    Convert the raw temperature data into degrees celsius and return as a fixed
    point with 2 decimal places.
    """
    temp_lsb = data[0]
    temp_msb = data[1]
    if rom0 == 0x10:
        if temp_msb != 0:
            # convert negative number
            temp_read = temp_lsb >> 1 | 0x80  # truncate bit 0 by shifting, fill \

            # high bit with 1.
            temp_read = -((-temp_read + 1) & 0xff) # now convert from two's \n            # complement
        else:
            temp_read = temp_lsb >> 1  # truncate bit 0 by shifting
        count_remain = data[6]
        count_per_c = data[7]
        if self.fp:
            return temp_read - 25 + (count_per_c - count_remain) / count_per_c
        else:
            return 100 * temp_read - 25 +\
            (count_per_c - count_remain) // count_per_c
    elif rom0 == 0x28:
        temp = None
        if self.fp:
            temp = (temp_msb << 8 | temp_lsb) / 16
        else:
```

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9
temp = (temp_msb << 8 | temp_lsb) * 100 // 16
if (temp_msb & 0xf8) == 0xf8:  # for negative temperature
    temp -= 0x1000
return temp
else:
    assert False
Appendix B. MicroPython Source Code

This appendix appears in its original form, without editorial change.

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import time
import utils
import pycom
from machine import Timer
from machine import Pin

import network
from network import WLAN
from network import LoRa
import socket
import binascii
import pycom
import struct
from onewire import DS18X20
from onewire import OneWire

print('GPS/DS18X20 Test')

ow = OneWire(Pin('P10'))
temp = DS18X20(ow)

# activate the Thread used by GPS 'M6N' or 'G76-L'
utils.GPSstart('G76-L')

########################

def select_subband(lora, subband):
    if (type(subband) is int):
        if ((subband<1) or (subband>8)):
            raise ValueError("subband out of range (1-8)")
        else:
            raise TypeError("subband must be 1-8")

    for channel in range(0, 72):
        lora.remove_channel(channel)

    for channel in range((subband-1)*8, ((subband-1)*8)+8):
        lora.add_channel(channel, frequency=902300000+channel*200000,
                         dr_min=0, dr_max=4)

# Initialize LoRa in LORAWAN mode.
lora = LoRa(mode=LoRa.LORAWAN)

# create an OTAA authentication parameters
# The values specified below for app_eui and app_key are placeholders.
# You will need to specify the correct "app_eui" and "app_key" for your
# network.
# These can be found in the configuration of your LoRa Network Server.
# app_eui is the LoRa Network ID.
# app_key is the LoRa Network Key
app_eui = binascii.unhexlify('00:00:00:00:00:00:00:00'.replace(':', ''))
app_key = binascii.unhexlify('00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00'.replace(':', ''))

print("Network ID: ",binascii.hexlify(app_eui))
print("Network Key: ",binascii.hexlify(app_key))
print("Frequency: ",lora.frequency())

pycom.heartbeat(False)

# join the LoRa network using OTAA (Over the Air Activation)
for i in range(20):
try:
    print('Connecting to LoRaWAN')
    stime = time.time()
    lora.join(activation=LoRa.OTAA, auth=(app_eui, app_key),
              timeout=20000)
    etime = time.time()
    print("Connection established in ", etime-stime," seconds")
    break
except:
    pycom.rgbled(0x7f7f00)
    print("LoRaWAN connection timed out...retrying")
    i = 1

# wait until the module has joined the LoRa network
if lora.has_joined() != True:
    print("NO LORAWAN CONNECTION ESTABLISHED...EXITING!")
    pycom.rgbled(0x007f00)
    sys.exit(-1)
    pycom.rgbled(0x007f00)
    s = socket.socket(socket.AF_LORA, socket.SOCK_RAW)
    s.setblocking(True)

GPS_Locked_Flag=False

while GPS_Locked_Flag==False:
    if utils.GPS_Is_Fixed==True:
        GPS_Locked_Flag=True
        print("GPS coordinates:")
        print(utils.GPSlat)
        print(utils.GPSlon)
    else:
        print ('No Sat')
        time.sleep(0.5)

msgCount=0
temp.start_conversion()
time.sleep(1)

while True:
    temperature = temp.read_temp_async()
    print("Temperature: "+str(temperature))
    if (temperature == None):
        temperature=0.0
        tempbytes = list(struct.pack("!f",temperature))
    print("Temperature: "+str(temperature))
    print("Latitude: " + str(utils.GPSlat))
    print("Longitude: " + str(utils.GPSlon))
    print("Time: " + str(utils.GPSDatetime))
    msgCount=msgCount+1
    msgCountBytes=msgCount.to_bytes(2,"little") #has to be fixed
    lat = float(utils.GPSlat[0]+(utils.GPSlat[1]/60.0))
    if utils.GPSlat[2]=='S':
        lat=-lat
    latBytes=list(struct.pack("!f", lat))
    lon = float(utils.GPSlon[0]+(utils.GPSlon[1]/60.0))
    if utils.GPSlon[2]=='W':
        lon=-lon
    lonBytes=list(struct.pack("!f", lon))

    print("Lat:")
    print(lat)
print("Long:")
print (lon)

# build the array of data.
DataPack=bytes([33, msgcountBytes[1],
                 msgcountBytes[0],
                 latBytes[3],
                 latBytes[2],
                 latBytes[1],
                 latBytes[0],
                 lonBytes[3],
                 lonBytes[2],
                 lonBytes[1],
                 lonBytes[0],
                 tempbytes[3],
                 tempbytes[2],
                 tempbytes[1],
                 tempbytes[0]])
print("Sent: ",list(DataPack))
s.send(DataPack)
temp.start_conversion()
time.sleep(5)
## List of Symbols, Abbreviations, and Acronyms

<table>
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<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>GPS</td>
<td>global positioning system</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>REPL</td>
<td>Read Evaluate Print Loop</td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
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