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# Comment on soil-2021-72

Anonymous Referee #1

Referee comment on "An underground, wireless, open-source, low-cost system for monitoring oxygen, temperature, and soil moisture" by Elad Levintal et al., SOIL Discuss., https://doi.org/10.5194/soil-2021-72-RC1, 2021

## General comments

The authors present the design of an inexpensive underground soil sensor device that communicates wirelessly with an above-ground data logger, and that can be used to set up a network of wireless soil sensors.  The strength of the study is that sensor device and datalogger are built with off-the-shelf components costing no more than 150 USD (without the soil sensors), and can be assembled by people with minimal electronics knowledge and without the need to design and construct a printed circuit board.  All information needed to build it is given in the manuscript and the microprocessor scripts are made available on Github. In addition, the authors present results of a 5 months field testing during which the voltage of the battery of below-ground sensor device was monitored to assess how long such a device could operate without having to dig it up to recharge or replace the battery.

The very practical orientation of the manuscript is a strength, but at the same time a weakness in the sense that too little information is provided on power consumption as a function of measurement frequency, and about which performance can be expected in other soils that may have more radio signal attenuation hampering the wireless communication between the below-ground sensor device and the above-ground datalogger.  The authors also did not measure power consumption, they only monitored battery voltage, and do not present information on the voltage -charge relationship for the battery they used.  And some claims made about the autonomy of the device (up to 2-3 years with larger battery) and the possibility to scale it up to several sensor devices are not well founded.

The field test results they presented no doubt provided the authors with the necessary information to set up a wireless sensor network on their field site.  But to make their work useful for colleagues who want to deploy it in different conditions, important information is missing.  And that the above-ground datalogger is not capable of sending the data in real time to a server is a missed opportunity.  Anybody who sets up a network of wireless soil sensors will also want to monitor the data in real time, and also that can be done with off-the-shelf components.

The manuscript is written in clear language. It can be published in Soil and is relevant for the readership of Soil provided the authors provide extra information and justification for their claims, as explained in the specific comments below.

**Specific comments**

P1 L10: ‘Wireless sensors pose the least disturbance to soil structure’ needs to be formulated differently. The installation of a wireless sensor, i.e. the digging to install it, causes as much soil disturbance as for a wired sensor. The difference is that a wireless sensor that is installed below the tillage depth can stay in place for several years, while a wired sensor needs in many cases to be removed and installed again to allow field operations, in particular tillage, thus causing much more soil disturbance. That is the main selling point of wireless underground sensor devices, and that has to be made clear in the abstract, as well as in the first paragraph of the introduction.

P5 L129-136: two methods for reducing the power consumption of the below-ground sensor device are presented. But I guess the two methods (putting the Lora-Feather microprocessor in sleep mode and powering off the sensors) are complementary and were used simultaneously. That needs to be clarified.

P5 L131: power consumption of the LoRa-Feather during active mode and during sleep is given, and it is correctly explained that the fact the calculation that in sleep mode (35µA power consumption) the 2200 mAh battery can last 7 years is theoretical because most power is consumed when the module is doing and transmitting a measurement, and there is also the self-discharge by the battery. As power consumption is critical for an application where the sensor device needs an autonomy of several years (otherwise the advantage of an underground wireless device is largely lost), the authors need to report also the power consumption (in mAh, and best also duration of the active mode and its average power consumption in mA) during one measurement. That is essential to allow readers to assess what measurement frequency is possible for a given battery capacity.

P8 L 169-171: An important aspect given the radio signal attenuation in soils is the power emitted by the antennas of the above-ground and below-ground devices. The authors report they used 5 and 23 dBm transmission power. The dipole antenna they used may have a gain of 2 dBi or so, so emitted power was probably +7 and +25 dBm. That is within the limits in the USA, Australia, India (+30 dBm), but too high for regulations in Europe (max is +14 dBm) or China (max is +12.15 dBm.) The authors need to point to the fact that there are such limits and discuss whether their system can still work in regions with such limits.

P15 L249-252: The authors calculate that the battery of their below-ground sensor device would last 333 days. But this calculation is only approximate as the relation between voltage and battery capacity is not linear. For the same reason, it is also dangerous to compare the slopes of the different scenario's in Fig. 4 to draw conclusions on discharge rates. The authors need to discuss this non-linearity at least.

P15 L260: The authors explain that by simply increasing the capacity of their lithium-ion battery to 6000 mAh, they can increase the battery's life to 2-3 years. But that depends on how much the battery's self-discharge rate is. If that self-discharge rate is 5% per month, then that battery will not last 3 years, no matter how large the capacity. If it is only 2% per month, they can probably last 3 years. Unfortunately, LiPo battery manufacturers do not report self-discharge rates, and that rate is moreover dependent on temperature (it probably doubles for each temperature increase by 10K). So by 'extrapolating' from the 5-month field test that by increasing the battery capacity, it can work for 2-3 years is quite uncertain. At least, the authors should discuss this aspect and point to the fact that non-rechargeable lithium-thionyl batteries exist which have a much lower self-discharge rate (1% per *year*) and are suited for IoT applications that need an autonomy of several years.

P17 L231-234: The authors claim that additional underground nodes can be added at different locations, and that it only requires simple software modification. I doubt that this is true: if sensor devices are sending their payload at the same time (which undoubtedly will happen), how can the datalogger LoRa device handle that? This is normally solved in LoRa communication by using multichannel gateways. But the LoRa-Feather that the authors use for their above-ground datalogger node cannot work as a multichannel gateway. So the authors need to explain why they are sure that more nodes can simply be added (which is what you want to do to get a wireless sensor network). Also, what is then the practical distance between sensor nodes and data logger that is possible (the maximum distance)?

In their discussion, the authors also need to explain to what extent their system is also going to work in other soil types. What if the dielectric permittivity of the soil is larger (higher water content) or the bulk electrical conductivity is higher (both conditions are likely in clay soils)? They may base this discussion on e.g. the paper by Bogena et al. (2009) that looked into these aspects (the paper is already cited in the manuscript under review)

**Technical comments**

P2 L40: remove 'Zhang et al.,' from between the brackets of the reference.

P2 L48: 'Out of these,' instead of 'Out of which,'

Fig. 4: Y-axis title should read ‘Battery voltage (V)’

P11 L196: ‘March’