HAUTE ÉCOLE
D'INGÉNIERIE ET DE GESTION
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Département TIC

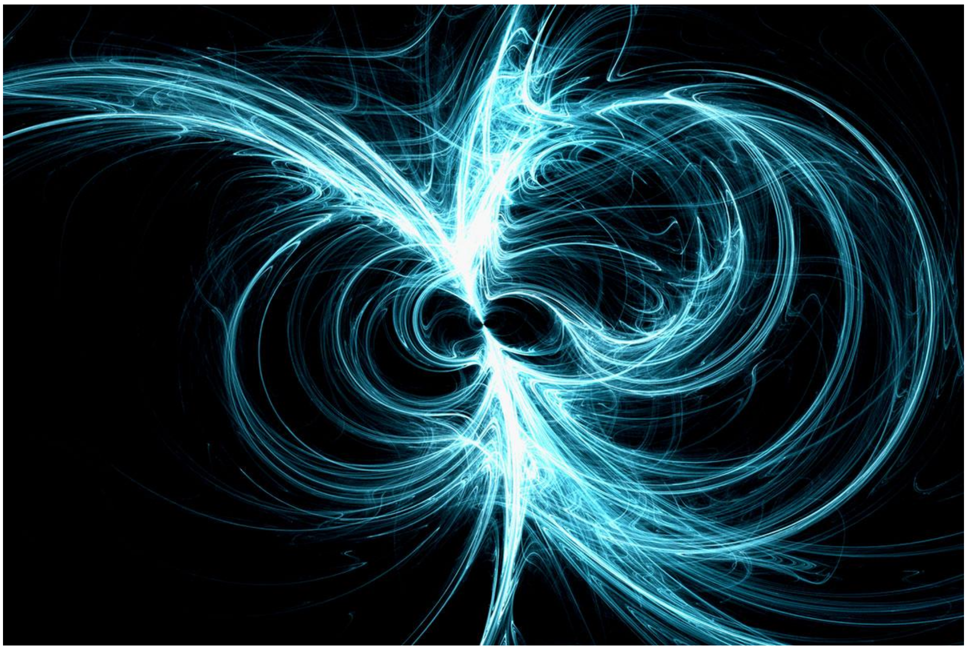
Filière Informatique

Orientation Informatique embarquée

Travail de Bachelor

Conception d'un système embarqué sur un drone pour la mesure de champs électromagnétiques

Non confidentiel



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Yverdon-les-Bains, le 7 mars 2022

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HEIG-VD

Résumé publiable

La protection contre la foudre et les connaissances de ce phénomène se basent essentiellement sur des mesures de courant et des champs électromagnétiques faites au niveau du sol. Dans ce projet, un système de mesure du champ électrique/magnétique sera embarqué sur un drone et les données récoltées seront transmises vers un système de stockage au sol. Le système sera testé dans des conditions réelles.

Étudiant :	Date et lieu :	Signature :
Werkle Johann	Yverdon, le 07.03.22	……………………………………
Enseignant responsable :	Date et lieu :	Signature :
Rubinstein Marcos	……………………………………	……………………………………
Nom de l'entreprise/institution :	Date et lieu :	Signature :
HEIG-VD	……………………………………	……………………………………

Préambule

Ce travail de Bachelor (ci-après TB) est réalisé en fin de cursus d'études, en vue de l'obtention du titre de Bachelor of Science HES-SO en Ingénierie / Economie d'entreprise.

En tant que travail académique, son contenu, sans préjuger de sa valeur, n'engage ni la responsabilité de l'auteur, ni celles du jury du travail de Bachelor et de l'Ecole.

Toute utilisation, même partielle, de ce TB doit être faite dans le respect du droit d'auteur.

HEIG-VD

Le Chef du Département

Yverdon-les-Bains, le 7 mars 2022

Authentification

Le soussigné, Johann Werkle, atteste par la présente avoir réalisé seul ce travail et n'avoir utilisé aucune autre source que celles expressément mentionnées.

Yverdon, le 7 mars 2022

Johann Werkle

Table des matières

1 Introduction

Description of the project

The objective of this bachelor thesis is the creation of an embedded system to be mounted on a drone to make geo-localized, time-stamped measurements of the atmospheric electric field.

Lightning protection and knowledge of this phenomenon are based mainly on measurements of current and atmospheric electric field at ground level. In this project, an embedded electric field measurement system will be developed to be mounted on a drone for the collection and storage of data for later analysis.

This work is related to a research project funded by the Swiss National Science Foundation on the study of the initiation and characteristics of upward lightning discharges. The embedded system will be developed and tested in Yverdon-les-Bains and Lausanne. Tests at the Säntis experimental facility in the canton of Appenzell are also foreseen depending on the availability and development status of the embedded system and the drone.

Statement of work for the project

Deliverables

1. A report
2. A prototype of the embedded system

Report content

- Block and functional diagram of the system
- A description of the system:
    - Drone
        - Autonomy on batteries
        - Flight altitude
        - Payload capacity
    - Embedded platform
        - Type of platform (Raspberry Pi, Arduino, other), version, operating system
        - Digitization speed (achievable with the platform and actually used)
        - Storage space on the platform (available, description of requirements)
        - Energy consumption (utilized source such as drone batteries, independent batteries, other?)
    - E-field Sensor
        - Specifications: passive/active? Digital or analogical output, gain
        - Electric field datasheet in the appendices.
        - Any comments on the special care, connection to the platform, utilization.
    - Positioning sensor (GPS, other? Description of the operation and requirements)
        - Timing (GPS, onboard clock, other? Description of operation and requirements)
    - Other sensors (discussion on the possibility of adding them on the same embedded system):
        - Thermometer
        - Hygrometer
        - Barometer
    - Explanation on the functionalities of the system
        - Time stamping
        - Information on the 3D Geopositioning.

- Synchronization of time and location data
- Rationale for the choice of platform and other hardware, for instance geolocalization if applicable.
- Rationale for the choice of software if applicable (this could include the operating system or systems, any software to control de measurements, etc.)
- Software developed during the project including commented source code
- Description of tests in the laboratory

Structure of the document

The structure of this document will mostly follow the statement of work requirements but with some more documentation as necessary.

Methodology

The methodology of work lies mostly on priorities of the requirements, step by step experimentations and subdividing of the problematics as smaller problematics when it's required:

- At first, the priority is to be able to make and monitor electric fields measurement on a time basis
- The second priority is to monitor the localization and to add it to the electric field measurements
- The third priority is to make this system autonomous and to find a drone capable of transporting it
- Finally, the rest of the project will be about tests and potential enhancements.

2 Planning and organization

Gantt Diagram

The project has been planned as follow:

				Dependency	Estimated time [h]	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Counted time [h]
1.0	**Analyze**				**8**																																	**0**
1.1	EFM-113B				**8**																																	**0**
1.1.1		Reading datasheet			**8**							2	2	2	2																							**8**
1.2	RTK				**24**																																	**0**
1.2.1		Reading about material and implementation			**16**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1																**16**
1.2.2		Reading about other projects			**4**																2	2																**4**
1.2.3		Choosing equipment		1.2.1, 1.2.2	**4**																				2	2												**4**
1.3	Other sensors																																					**0**
1.3.1		Thermometer																																				**0**
1.3.1.1			Reading about material and implementation		**2**																												2					**2**
1.3.1.2			Choosing equipment	1.3.1.1	**2**																												2					**2**
1.3.2		Hygrometer																																				**0**
1.3.2.1			Reading about material and implementation		**2**																												2					**2**
1.3.2.2			Choosing equipment	1.3.2.1	**2**																													2				**2**
1.3.3		Barometer																																				**0**
1.3.3.1			Reading about material and implementation		**2**																													2				**2**
1.3.3.2			Choosing equipment	1.3.3.1	**2**																													2				**2**
2.0	**EFM-113B**				**32**																																	**0**
2.1	Making circuit				**32**																																	**0**
2.1.1		Design		1.1	**8**																		6	2														**8**
2.1.2		Software implementation		2.1.1	**8**																		4	4														**8**
2.1.3		Tests & Verification		2.1.1, 2.1.2	**16**																			4	12													**16**
3.0	**RTK**				**160**																																	**0**
3.1	Implementation				**160**																																	**0**
3.1.1		Software implementation		1.2.3	**80**																					16	16	16	16	16								**80**
3.1.2		Tests & Verification		3.1.1	**80**																					8	8	8	8	8	16	16	8					**80**
4.0	**Drone**				**16**																																	**0**
4.1	Battery selection			2.1.3, 3.1.2	**4**																										4							**4**
4.2	System protection			4.1	**8**																											8						**8**
4.3	Model selection			4.2	**4**																											4						**4**
5.0	**Other sensors**				**24**																																	**0**
5.1	Thermometer				**8**																																	**0**
5.1.1		Software implementation		1.3.1	**4**																													4				**4**
5.1.2		Tests & Verification		5.1.1	**4**																													4				**4**
5.2	Hygrometer				**8**																																	**0**
5.2.1		Software implementation		1.3.2	**4**																														4			**4**
5.2.2		Tests & Verification		5.2.1	**4**																														4			**4**
5.3	Barometer				**8**																																	**0**
5.3.1		Software implementation		1.3.3	**4**																															4		**4**
5.3.2		Tests & Verification		5.3.1	**4**																															4		**4**
5.0	**Organization**				**202**																																	**0**
5.1	Report				**120**				4	4													12	12	12						4	4	4	8	16	20	20	**120**
5.2	Guides and graphs				**32**																			4	4						2	2	6	2	4	4	4	**32**
5.3	Meetings				**38**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**38**
5.4	Planning				**12**		2	4											1	1			2	2														**12**
	TOTAL				**478**	1	4	6	6	6	2	4	4	4	4	2	2	2	3	3	4	4	25	29	31	27	25	25	25	25	27	35	25	25	29	33	25	**478**
			Days (8 hours)		**59.75**	0.125	0.5	0.75	0.75	0.75	0.25	0.5	0.5	0.5	0.5	0.25	0.25	0.25	0.375	0.375	0.5	0.5	3.125	3.625	3.875	3.375	3.125	3.125	3.125	3.125	3.375	4.375	3.125	3.125	3.625	4.125	3.125	**58.75**

3 Analysis and conception

Choices of technology

Raspberry Pi

Justification

We choose to use a Raspberry Pi as the board of the project for numerous reasons:

- It has a lot of existing sensors at a relatively cheap price
- It is easy to replace in case of malfunction thanks to a high availability
- It is easy to maintain code on it since it can host a Linux and have access to a lot of compatible drivers with different interfaces through USB, GPIO, etc. (like SPI, I2C, UART)
- A lot of projects already use Raspberry Pi (including inside the HEIG-VD) and offer some well documented features and implementations
- It is lightweight (about 60 grams)
- It can be power through USB or through its GPIO

Model and specifications

Since the COVID-19, Raspberry Pi have been hard to find. But luckily, I was lent a Raspberry Pi 4 8GB Model B which is the most powerful one on the market for the moment. However, I had some problems with the AD Hat and had to finally use my own Raspberry Pi 3b.

To work with the Raspberry Pi, I installed an image of the last 32bits version of Raspberry Pi OS by using the Raspberry Pi Imager program, as the AD Hat was compatible with. I choose the latest release not only by convenience but also because it is important to keep the OS updated as it offers a larger number of features, a wider compatibility with new devices, a better security and a more stable system. The version of the OS is the 32bits 22-04-04.

Methodology

The early methodology of development of the software tools used to retrieve and process data was to use Python, since it's a versatile and very compatible programming language. The version used is the 3.10.4.

However, Python is a high-level language and might not be ideal for optimization when we will need to get data at more precise intervals. During the progress of the project, a migration towards the C language will be necessary to obtain more precise tools and close to the devices. But the post treatment of data will still be in Python, because it offers a wide variety of functions and features and takes less time and efforts to implement.

EFM-113B

As already stated, the first priority of this project is to monitor atmospheric electric field measurements in order to help the study of the initiation and characteristics of upward lightning discharges. Since it is a peculiar phenomenon, the EFM-113B, the device used for the monitoring, has been imposed by the research team.

Figure 1 - EFM113B Precise Field Strength Sensor

This sensor is analog, active, compact and light (120 x Ø 36 mm and app. 180g). It has been designed for the measurement of DC fields, static charges and electric and electrostatic highly resistive voltage supply. The head has a little golden fan necessary to retrieve low frequency electric field measures. It has a 5 pins connector assigned as follow:

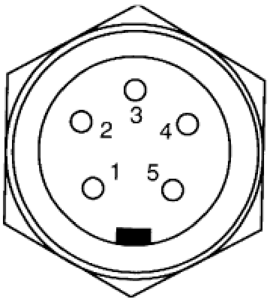


Figure 2 - EFM113B Pinning

Pin	Color	Function
1	White	Range select B
2	Brown	Power supply (+9-15[V] DC)
3	Black	Ground (GND)
4	Blue	Range select A
5	Grey	Output current (+- 1[mA])

The range selectors have two states each:

- High (H) = open
- Low (L) = connected to ground

Their configuration changes as follow:

Pin 1(B)	Pin 4(A)	Range
L	L	5 kV/m
L	H	20 kV/m
H	L	50 kV/m
H	H	200 kV/m

Figure 3 - Range selection

We can calculate the field strength by multiplying the configurated range by the output-current of the fifth pin:

$$E = Ra * I$$

E being the field-strength in [V/m], *Ra* the Range in [V/m] and *I* the current in amps.

The manual of this sensor specifies that the cable length shouldn't exceed 50 meters and is very sensitive to electrostatic dischargement. It also specifies that it shouldn't be exposed to explosive-areas, its usage in power installation in not allowed, it can't be used to measure alternated fields higher than 1[Hz] and it has to be adjusted to 0 at every use through inserting a pin in his back-side hole.

Analog to digital converter

Since the sensor is analog, we must convert the output signal to digital so we can work with it. As suggested by Antonio Sunjerga, we choose to use a specific analog to digital converter: the High-Precision AD HAT ADS1263 from Waveshare.

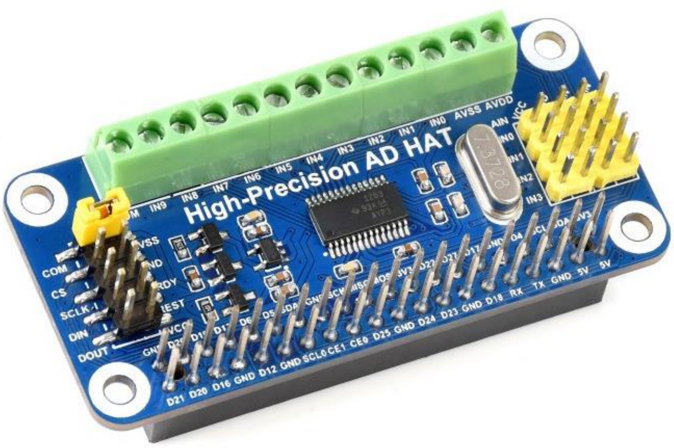


Figure 4 - High-Precision AD HAT For Raspberry Pi, ADS1263 10-Ch 32-Bit ADC

This hat for the Raspberry Pi is ideal since it has a 32 bits resolution, a 38kSPS sample rate and 10 input channels which provide a great precision at high frequency (26.315 [MHz]) and can host other analog sensors if needed. His hat condition and SPI communication makes it compatible with other Raspberry Pi addons if we need to add some.

The input voltage range that the device can measure is between ±2.5[V].

GNSS-RTK

GNSS-RTK is a positioning technology using satellite navigation and real-time correcting through a position-defined base-station. It is currently the most accessible, in terms of cost, availability and configuration, outside sub-meter localization technology.

At this state of the project, no solution has been chosen yet. An interesting solution would have been to use the SparkFun GPS-RTK2 Board - ZED-F9P, a centimetre accurate GNSS-RTK module, since it can be use both as standalone base station and on the embedded system and because it can be connected to the Pi through several communication ports including USB, UART, SPI and I²C which would have been a versatile solution. However, Sebastien Guillaume, professor in the INSIT institute in HEIG-VD, offered a collaboration by lending ready to use RTK solutions and a drone, which still need to be discussed. This solution might change the course of the project.

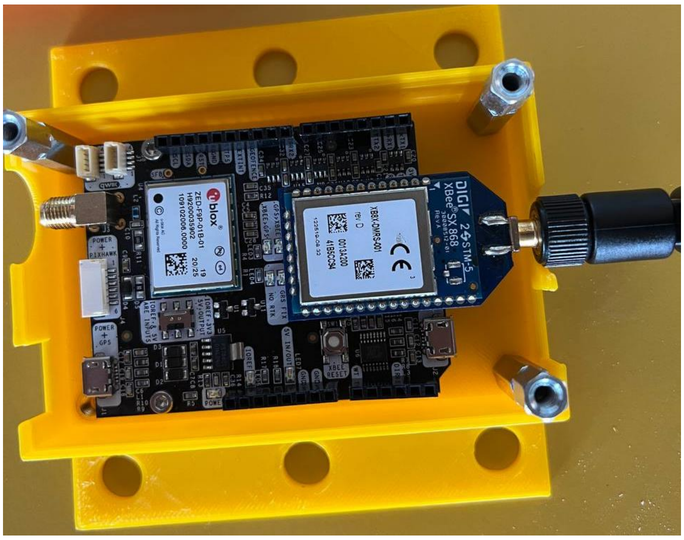
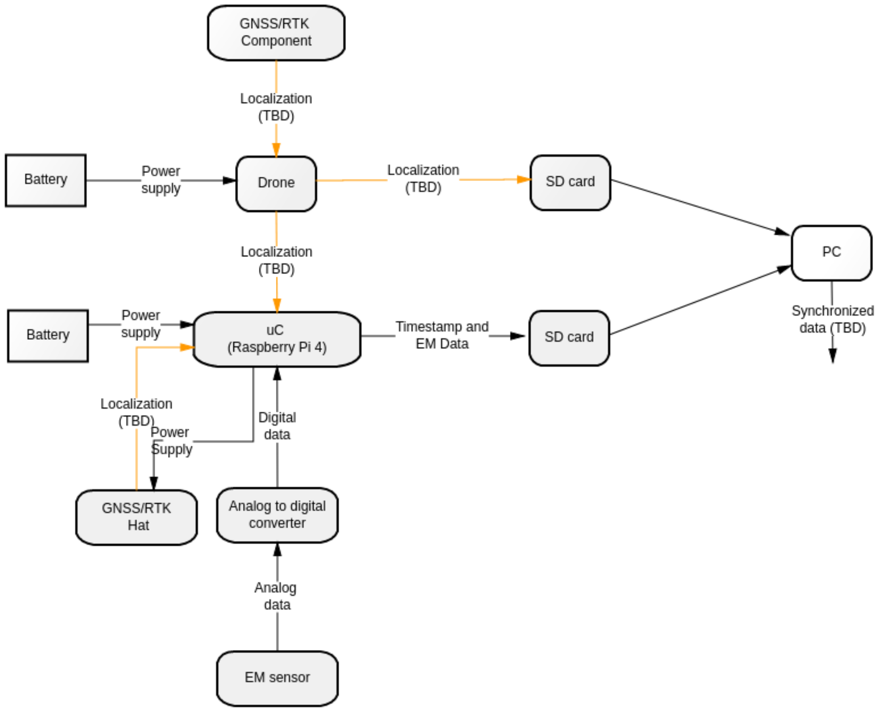


Figure 5 - A GNSS-RTK module with XBee communication presented by Professor Sebastien Guillaume

Bloc diagram

At early stage of the project, this is the full system diagram as we figured it:



We didn't directly decide where to retrieve and stock the localization's data at first since we also considered to use a drone with RTK embedded like the Phantom 4 RTK from Dji or an autonomous RTK solution to merge the data after the monitoring. But since we're already retrieving electric fields data, it seemed easier and more practical to use a RTK module directly on the Raspberry. It is important to keep in mind that this diagram could still change, as RTK solution is not definitive yet.

Drone and other sensors

Since we still have to define which technology and power-supply solution we will use, no drone has been selected as for the other eventual sensors. An eventual solution would be a Dji Inspire 2 drone that can carry a payload of 800 grams, as proposed by Professor Sebastien Guillaume, but the needs still have to be defined before choosing such a solution.

Other sensors required for the project are a thermometer, a barometer and a hygrometer. The list might expand more with, for example, an accelerometer.

4 Electric field measurement

Analog to digital conversion

After installing the hat to the Raspberry Pi by clipping it on the GPIO of the board, instructions are given to install the software needed to retrieve voltage through the input channels. Once the installation is complete, 2 example methods are given to get the voltage values. One use python and the other use C program. C program has a far more precise frequency of gathering but Python is easier to handle so I first used Python to gather the data but a C program with command-line configuration will be implemented for the final solution, once RTK is available on the board.

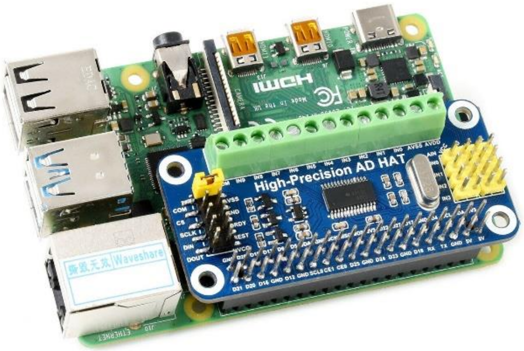


Figure 6- Example picture of the AD Hat on the Raspberry Pi 4

EFM-113B

The output of the EFM-113B is given in the form of a current of ± 1[mA]. Since our analog to digital converter monitors voltage, we used a 2.2[kΩ] serial resistor between the output and the ground and to measure the difference of voltage before and after the resistor. We selected a 2.2[kΩ] resistor because of the max voltage that the AD Hat can receive. The output current varies between ± 1[mA], so with Ohm's law, we found that the delta of voltage varies between

$$U = R * I = 2.2[\mathrm{k\Omega}] * (\pm 1[\mathrm{mA}]) = \pm 2.2[\mathrm{V}]$$

Which is perfectly in the range of the analog to digital converter.

With the voltage measured, the known value of the resistor and the range selected at 5[kV/m], it is possible to retrieve the field strength with the following formula given by the manufacturer:

$$E = Ra * I$$

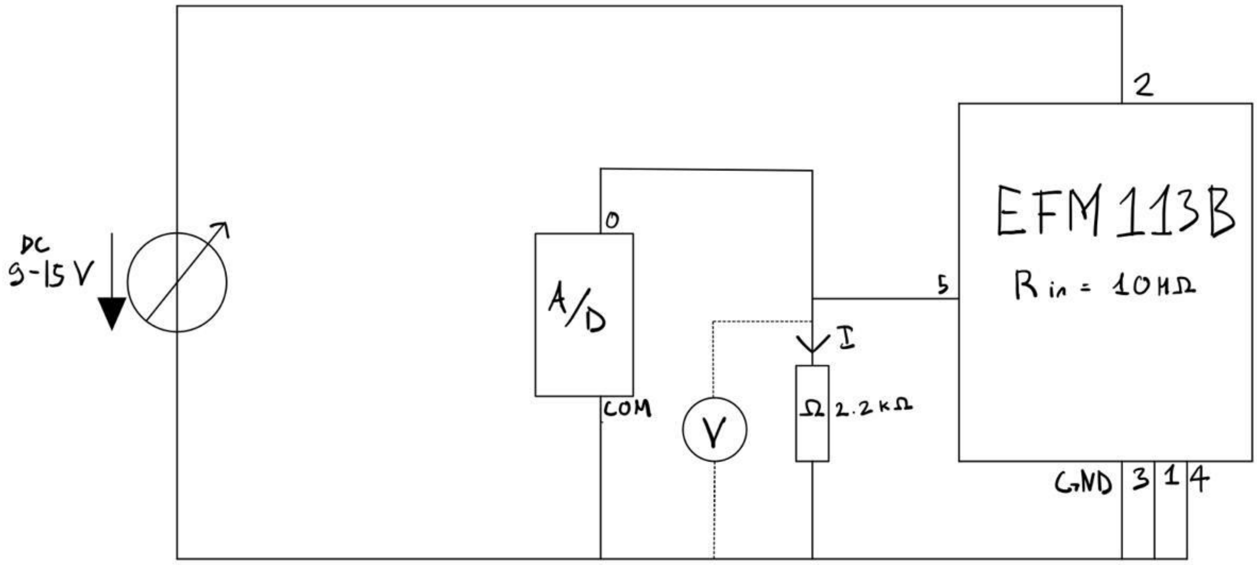
Which becomes:

$$E\left[\frac{kV}{m}\right] = 5\left[\frac{kV}{m}\right] * \left(\frac{U}{2.2[\mathrm{k\Omega}]}\right)$$

As U is comprised between ±2.2V, the expected field strength will be comprised between ± 11 [kV/m].

Circuit Diagram

The circuit has been assembled as follow:



As requested by Antonio Sunjerga, the range of the circuit is set on 5[kV/m] by connecting pin to the ground of the power supply. However, it has to be possible to disconnect the first and four pins of the sensor to keep the connection open in order to set another range. The input 0 of the AD Hat is connected to the fifth pin of the sensor (its current output) and the ground pin of the AD Hat is connected to the ground of the power supply.

Installation

The installation process has been done on a breadboard without soldering with the idea of been able to change everything while the obtained results haven't been validated. The process follows strictly the circuit diagram shown above. Originally, a 2[kV] resistor was used but since the AD Hat can tolerate a voltage of ± 2.5[V], I used a 2.2[kΩ] resistor to have a bit wider range of results.

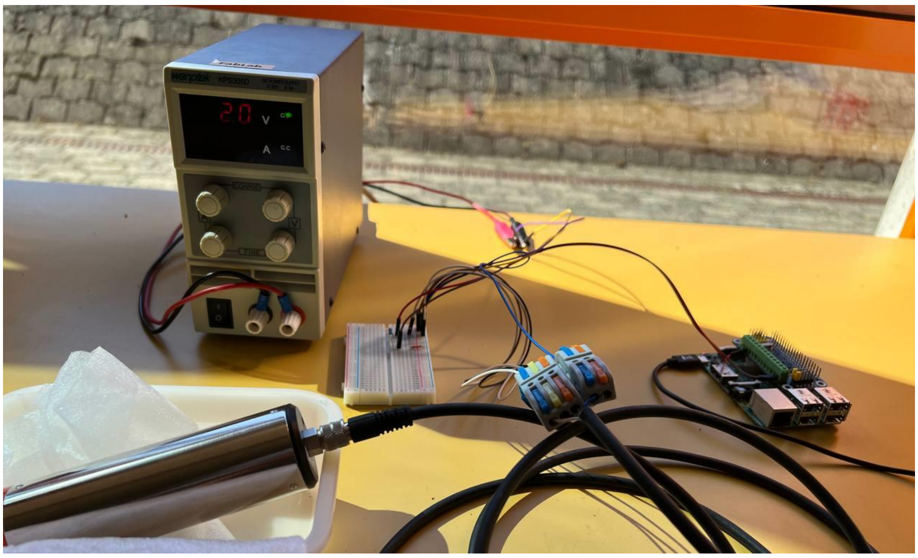


Figure 7 - General picture of the circuit

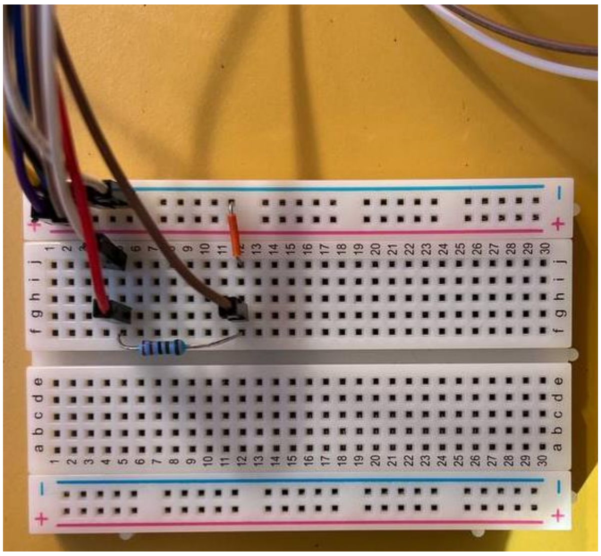


Figure 8 - Montage on the breadboard

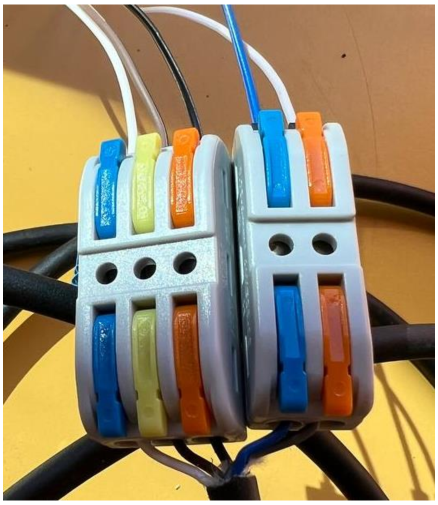


Figure 9 - Extension of the connector of the EFM-113B

Power consumption

All the measures done showed that, with a fixed input voltage of 12.0[V], the input current was 0.03[A]. So, without the Raspberry Pi own power consumption, the circuit power would be 0.36[W].

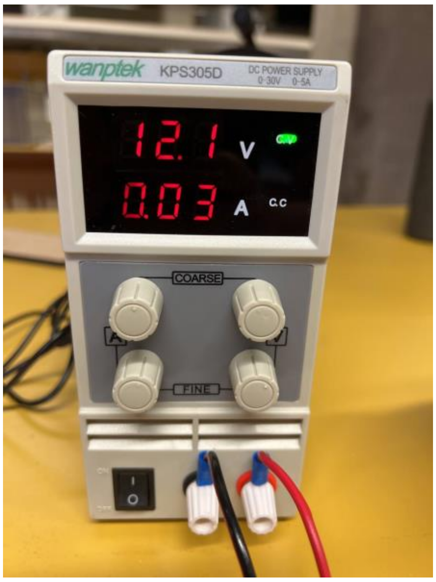


Figure 10 - Power supply turned on and connected to the circuit

I choose to fix the input voltage to 12V because it's a standard input voltage very frequently used for batteries. The system will have to be portable once finished so it is a convenient value for input voltage.

I didn't measure the Raspberry Pi power consumption yet since we still must add some sensors and the GNSS-RTK localization system, but the Raspberry Pi power consumption is maximum 6.0W[1]. This still needs to be verified with the AD Hat on and with the entire circuit.

5 Localization

As stated above, a localization's solution still have to be determined.

6 Drone

As stated above, the project still needs to be completed to get total weight of the solution. Since we don't have total weight, there is no good reason to already choose a drone for the project.

7 Other sensors

As stated above, the priority of the project is to have a perfectly working electric field measurement's solution and localization's solution before adding other sensors to it.

8 Tests and results

Electric field measurements

Several tests were made by executing a python code at about 20 Hz to gather data. The conditions were in the HEIG-VD, inside or next to the B07 classroom. All the measures were done with the sensor up (except for the tinfoil dataset), in hand, the base rolled in a thin plastic material used to pack and protect the sensor initially in a way not to meet the skin and the frontside free. The five datasets were taken:

1. Inside the classroom, with the power-supply off, to check normal behavior of the AD and the Raspberry Pi
2. Inside the classroom, with the power-supply on, with the orange cap on the sensor on to check the 0 adjusted state of the sensor
3. Inside the classroom, with the power-supply on, with the orange cap off the sensor to check the inside results and compare them to the outside results
4. Inside the classroom, in a tinfoil handmade box, to check the behavior of the sensor in a neutral electromagnetic context (like a faraday cage)
5. Outside of the classroom, with the power-supply on, with the orange cap off the sensor to obtain results in a context similar to that for which the system is intended.

Here is a plot done in python with matplotlib about obtained results comparing all five conditions followed by details and explanations about each one:

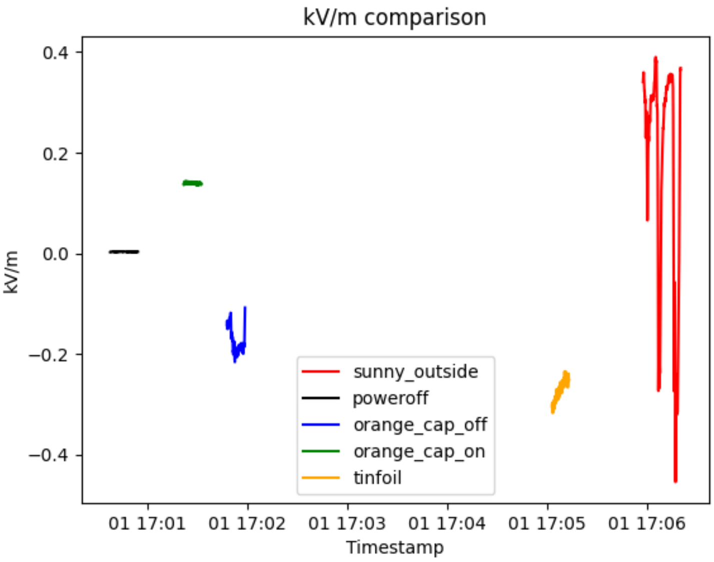


Figure 11 - Comparison of kV/m values of the different measurements

1. Power supply off

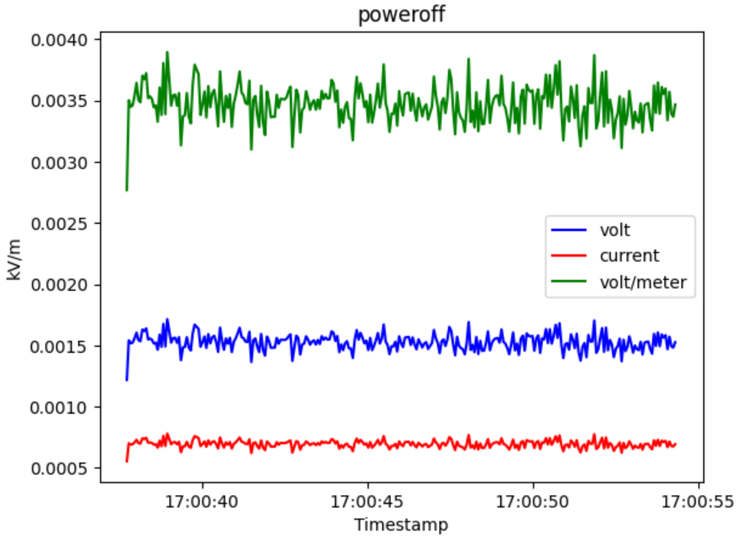


Figure 12 - Measure with the power supply off

With the power supply off, the AD Hat detect no voltage difference. The results are very next to null.

2. Orange cap on

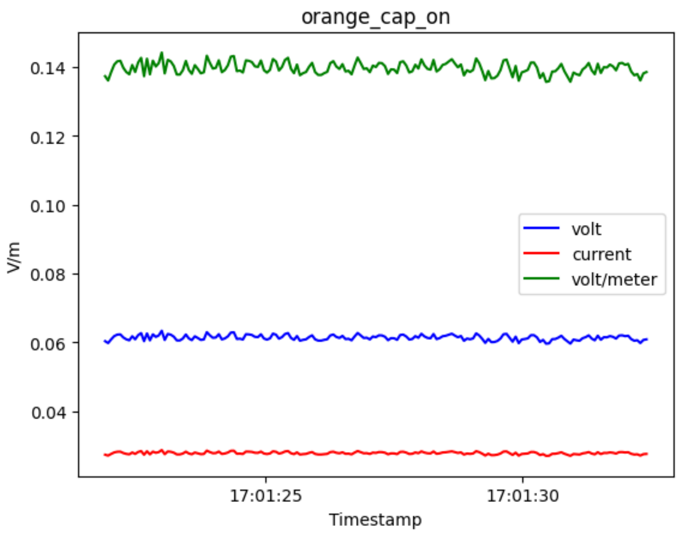


Figure 13 - Measure with the orange cap on the sensor

The orange cap on the sensor has 2 utilities: protect the sensor and isolate it. Even if the measures are more important than when the power supply is off, it is still very close to null.

3. Inside the classroom

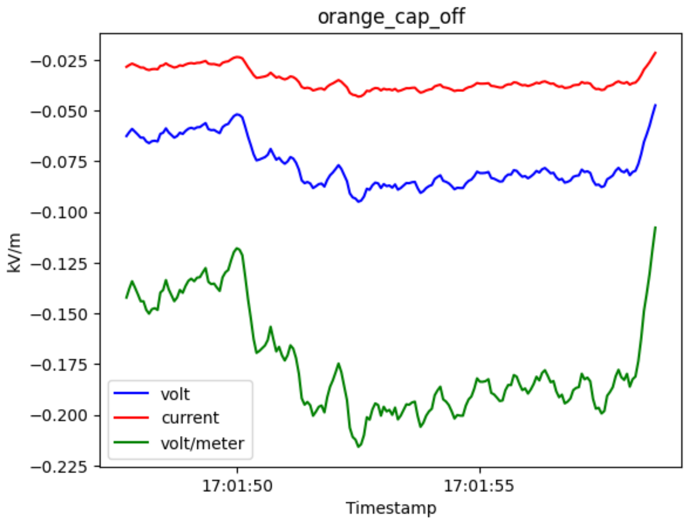


Figure 14 - Measure inside the classroom with the orange cap off

Once we remove the orange cap, the measures are changing. It is interesting to observe that the values inside are always negative.

4. In tinfoil

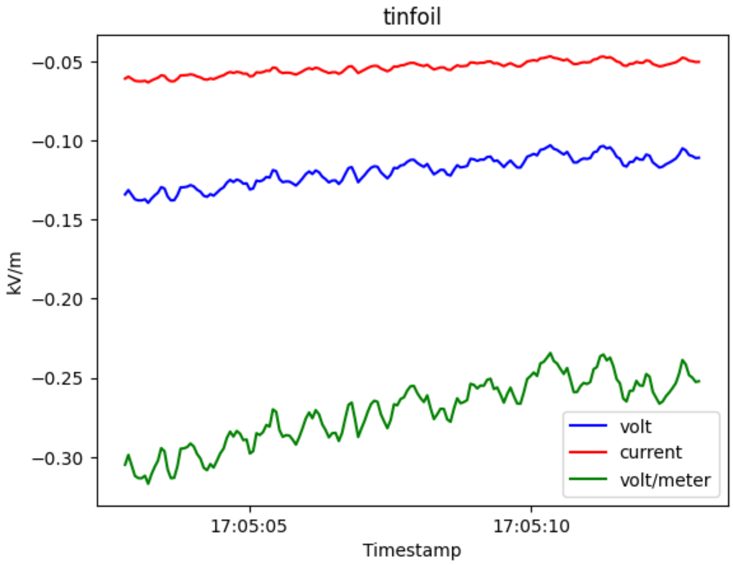


Figure 15 - measures in a home-made faraday cage

The behavior of the sensor inside the tinfoil seems to be really similar to the measures without inside, which might be probably because the sensor wasn't deep enough in the tinfoil to be affected by it. Some other data sets showed another behavior with results looking like the orange cap is on. Some better datasets, comparisons and results will be available for the next iteration of the report.

Figure 16 - Picture of the connectorless sensor inside the tinfoil and with the orange cap on

Unlike the image above, the measures in the tinfoil were done with the orange cap off the sensor and connected the circuit.

5. Outside

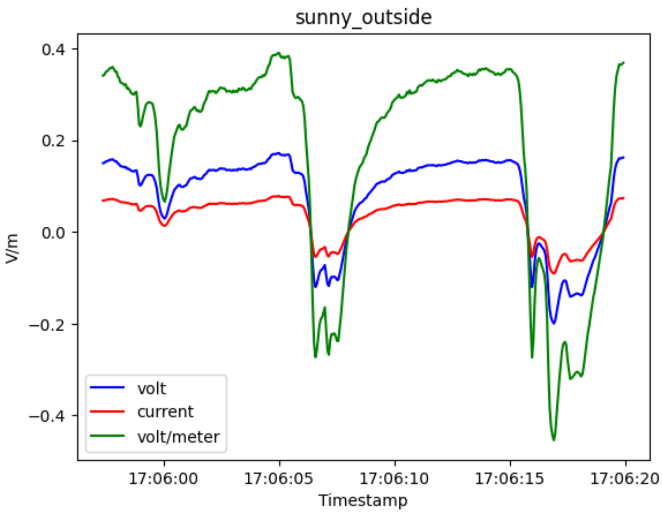


Figure 17 - Measures outside on a nearly spotless sunny day

This is probably the more interesting data set. It fluctuates from negative to positive and can even reach 400 V/m.

This dataset was taken on a nearly spotless sunny day, as showed in the next figure:

Figure 18 - Weather state on the 06.07.22, when the measures have been taken

While taking these measures, I tried to move as less as possible while avoiding any contact between my skin and the sensor.

9 Possible enhancements

Some possible enhancements of the project could be implementing additional sensors, making a protective box for the system and using a lower-level programming language to get more precise timestamps and optimize the use of ressources.

10 Conclusion

This project is going in the direction I was hoping for at the beginning because it follows the planning that was set, except for a few minor details. It took me a long time to write this report and I would have liked to refine it more.

Concerning the continuation of the project, I think that it would be interesting to have more frequent meetings. At the time of writing this project, I was not able to validate my results and I therefore have some doubts about their validity even if they seem to correspond to what was expected. The transition of rhythm between the end of last semester and this period dedicated to the thesis makes the process abrupt and difficult, despite some anticipation.

Particularly, I would have liked to get in touch with Professor Sebastien Guillaume more quickly in order to be able to discuss an RTK solution and to take advantage of a possible collaboration with INSIT more quickly, if it should take place.

Finally, all resources and documents (source code, planning, work diary, references, research) are available on the GitHub directory dedicated to this project and accessible in the bibliography.

11 Glossary

AD/ADC = Analog to Digital converter/conversion

HAT = Hardware Attached on Top, it is an extension board to connect to a Raspberry Pi through its GPIO

RPI = Raspberry Pi

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https://en.wikipedia.org/wiki/Real-time_kinematic_positioning

Other source documents like older thesis, works and datasheets can be found on the dedicated GitHub repository:

https://github.com/jwgit2/TB_Drone_Electromagnetic/