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Evaluating Energy and Sizing of Electronic System For Environmental Monitoring In Madagascar Forest

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Abstract— **Deforestation poses a grave threat to biodiversity, resulting in substantial disruptions within forest ecosystems and impacting the plant and animal species inhabiting them. To address this imminent peril and safeguard our environment, government authorities collaborate closely with organizations dedicated to managing protected areas. Among these entities, Madagascar National Parks Association holds a prominent role in overseeing the national parks of Madagascar. In 2017, an inventive initiative was launched to monitor the Montagne d'Ambre forest, leveraging technological advancements in the fields of computing and electronics. This pioneering approach relies on a system that detects tree felling through the analysis of acoustic signals. The section pertaining to data processing has been successfully concluded. This present article emphasizes the material aspects of the study, with the primary goal of identifying solutions that best suit the site and its constraints. The central aim is to minimize energy consumption by optimizing the system's activation time while ensuring effective surveillance. The article provides a comparison of the system's energy consumption before and after optimization, highlighting the beneficial outcomes of this approach. Subsequently, an analysis of energy supply was undertaken. The challenges posed by shading from the forest on the solar panel are examined, resulting in a decrease in efficiency to 43% when compared to direct sunlight exposure. Consequently, this situation led to the determination of the appropriate solar panel power rating at 23 Wpeak and the battery capacity at 13.33 Ah, operating at 12 V to meet a daily consumption of 2.8 Ah, with a 4.76-day usage margin in the absence of sunlight. This article thus furnishes a comprehensive overview of the innovative monitoring techniques applied to the Montagne d'Ambre forest, highlighting the endeavors aimed at reducing energy consumption and overcoming challenges related to energy provisioning. These advancements hold considerable significance for the preservation of Madagascar's biodiversity and the protection of our delicate ecosystems.**

Keywords — Environmental Monitoring, Sound Processing, PV efficiency, Solar panel sizing, Shading, Energy management.

I. INTRODUCTION

Madagascar National Parks is a Malagasy association mandated by the state since 1991 to manage the Parks and Reserves of the island. Currently, we oversee 43 Protected Areas, which include both terrestrial and marine National Parks, Special Reserves, and Integral Natural Reserves [1].

A special Amber Forest reserve managed by the association is located in the north of Madagascar. Recognizing an increase

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in deforestation and land clearing in the vicinity of this site, which poses a threat to the local biodiversity, the organization initiated a forest monitoring project in 2017 [2]. This initiative harnesses technological advancements in computing and electronics to enhance the existing monitoring method.

This innovative approach is based on a system that detects tree cutting through the analysis of sound signals. Recently, the data processing aspect has been successfully completed and confirmed through a scientific publication [3]. We have developed a Machine Learning model capable of distinguishing tree cutting noises from other sounds on the site, including similar noises that we have added to the database for improved overall usability. In this section of study, we will place a greater emphasis on the hardware to identify solutions that are best suited to the site and its constraints. Specifically, we aim to find ways to minimize energy consumption and identify components that can meet the demand [4]. To reduce energy consumption, our approach relies on optimizing the system's activation time while ensuring effective surveillance. Following the system presentation, we will compare the energy consumption of the system before and after optimization. Subsequently, we will investigate the suitable system for energy provisioning.

II. METHODS

1) System overview

a) Overall operation of the monitoring system

The process begins with sound capture by a microphone, followed by its conversion into processable data by a microcontroller via a sound card [5]. Then, the recorded sound signal is analyzed to detect any cutting of trees with an ax. If detected, a siren is triggered, allowing rapid intervention by park managers. The hard component of system is shown in "fig.1":

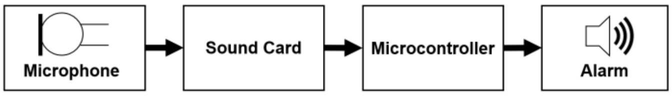

Fig. 1. Hard components of the monitoring system

The algorithm shown in "fig.2" describes the detection steps:

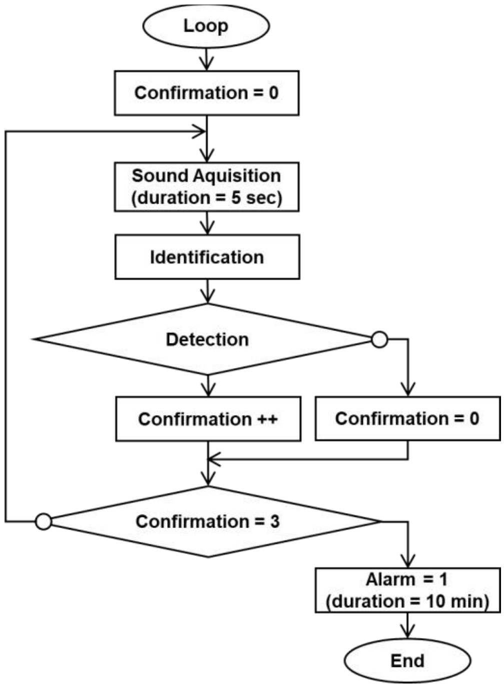

Fig. 2. Alarm triggering algorithm

When monitoring, the sound captured by the microphone is cut into 5 seconds. Within this time, an identification of the cut sound is carried out. In the event that a positive case occurs, a confirmation is made by carrying out a second identification, otherwise the system is reset. This identification step is repeated three times successively, i.e. for a period of 15 seconds. If the cutting is confirmed, the alarm is triggered for 10 minutes, the time for a forest guard to arrive. Study and management of system use with contextual consideration of the current situation.

According to our surveys with villagers and the MNP association, trees are cut down to make charcoal or for carpentry. The trees targeted are large, with a diameter greater than 30 cm and a length exceeding 3 meters. The cutting is done in slices from top to bottom, which takes more than 30 minutes. To monitor this, we recommend checking every ten minutes so as not to wait for the tree to fall.

Potential violations occur during the day when the sun is shining, from dawn to sunset. There, the sun rises at around 6 a.m. and sets at 6 p.m. throughout the year. We are considering a monitoring period of 2 hours before and 2 hours after, from 4 a.m. to 8 p.m.

2) Energy balance of the system

a) The technical characteristics of the system

Always with the aim of minimizing energy consumption, in line with the desired treatment, an electret microphone is used as an acquisition unit and a Raspberry PI 3 for data processing [6]. These two components are connected with a serial link sound card. And finally, the alarm is a sound generator with an intensity of 120dB [7].

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The following table details the technical characteristics of the system. To make writing an equation easier, we will designate a code in the second column to reference a component of the system [8]:

TABLE 1.TECHNICAL CHARACTERISTICS OF EACH COMPONENT

Component	Operating Voltage (V)	Current (A)	Active Power (W)
Microphone Electret	1,5 to 10	0,5 x 10^{-3}	4,5 x 10^{-3}
Sound Card	5	26 x 10^{-3}	0,13
Raspberry Pi 3 active	5	1	5
Raspberry Pi3 Idle	5	200 x 10^{-3}	1
Alarm	9 to 12	333 x 10^{-3}	4

b) Detailed assessment of usage time of each system component in uninterrupted monitoring

We are talking about uninterrupted monitoring for a system operating 24 hours a day. And the result is shown on "Table 2".

(Eq.1) defined the total energy consumed by the system [9]:

$$E = \sum P_i \times T_i \qquad (1)$$

- E [Wh]: Total energy
- Pi [W]: Active power for each component
- Ti [h]: Usage time

TABLE 2. ENERGY CONSUMPTION BY COMPONENTS OVER A 24-HOUR PERIOD ON UNINTERRUPTED MONITORING

Equipment	Duration (h)	Active Power (W)	Consumed Energy (Wh)
Microphone Electret	24	4,5 x 10^{-3}	0,108
Sound Card USB	24	0,13	3,12
Raspberry Pi3 Active	24	5	120
Alarm	n*(10/60)	4	4*n*(10/60)
Total Energy E_{tot1}			123,228 +4*n*(10/60)

For (n) number of detections in a day, of which the alarm sounds for 10 minutes. That is to say approximately add 0.67 Wh more for each detection.

Let's take an example that for four detections in 24 hours, the energy is estimated at approximately 123.228+4*4*(10/60) = 125.895 Wh.

c) Detailed assessment of optimizing component usage time considering the situation in the park Taking into account the site context investigation, here are some parameters we have considered:

- Start of monitoring: at 4 AM
- End of monitoring: at 8 PM
- System activation interval: every 10 minutes
- Maximum sound processing duration during activation: 15 seconds
- Alarm trigger duration upon detection of an infringement: 10 minutes

TABLE 3. TIME USAGE CALCULATION

Equipment	Number of hours (h)	Activation Duration (s)	Number per hour	Total Duration (h)
Microphone	16	15	6	0,4
Sound Card USB	16	15	6	0,4
Raspberry active	16	15	6	0,4
Alarm	-	10 x 60	Depending on (n), number of detections	n*(10/60)

Hence, the total energy over 24 hours calculated from "equation (1)" is presented in "Table (4)".

TABLE 4. ENERGY CONSUMPTION BY COMPONENTS OVER A 24-HOUR PERIOD ON OPTIMIZED MONITORING

Equipment	Total Duration (h)	Active Power (W)	Consumed Energy (Wh)
Microphone Electret	0,4	0,0045	0,0018
Sound Card	0,4	0,13	0,052
Raspberry PI3 Active (*)	0,4	5	2
Raspberry PI3 Idle (*)	23,6 – n*(10/60)	1	23,6 – n*(10/60)
Alarm	n*(10/60)	4	4*n*(10/60)
Total of consommed energy in 24 hours			25,65 + 3*n*(10/60)

When the alarm is triggered, the microcontroller wakes up from sleep mode. As a result, we deduct the standby energy and add the energy during activity, which means adding approximately 0.5 Wh for each detection.

For example, with four detections in a day, the total consumption is 27.65 Wh.

3) Sizing of the photovoltaic system

Due to the difficulty of maintenance in environmental monitoring, it is essential that the energy source be sustainable [10]. The use of the photovoltaic system as a source of energy is a solution [11].

a) Context of shading in the forest

In our case, the study site is a dense forest, so the positioning of the panels is in one of the totally or partially shaded areas.

Working in a forest environment, at certain times the trees generate shadows on the panels. Shading has a reducing impact on the performance of the panel [12]. It is complex to have a mathematical equation defining the rate of reduction in solar irradiation of the environment. The most favorable being to carry out empirical calculations in order to have a relationship between the performance of a panel in direct sunlight and a panel in a shaded area.

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Thus, we used two measuring device kits with identical characteristics consisting of a Solar Panel, a multimeter. The goal is to measure the output voltage of the two zones and make the comparison. Here is the table of the characteristics of the panel in STC conditions:

TABLE 5. PANEL CHARACTERISTICS

Maximum Power / Pmax (W)	100
Maximum Power Tolerance	(+-) 3%
Open-Circuit Voltage / Voc (V)	22,32
Short-Circuit Current/ Isc(A)	5,94
Max Power Voltage / Vmp(v)	18
Max Power Current / Imp(A)	5,56
Cell Technology	MONO-silicium

b) Collected measurement data

We took the measurements on November 04, 2023, from 1h56 p.m. to 3 54p.m. The measurement period is every 02 minutes. The distance between the two locations is 50m. "Table 6" presents the data collected on the panel under direct sunlight.

TABLE 6. DATA FROM SOLAR PANEL IN DIRECT SUNLIGHT

Time (.pm)	Voc (V)	Isc (A)	Time (.pm)	Voc (V)	Isc (A)
01:56	20,30	1,29	02:56	18,85	0,40
01:58	19,50	1,24	02:58	18,77	0,38
02:00	19,60	1,21	03:00	18,95	0,45
02:02	19,90	1,40	03:02	19,18	0,51
02:04	19,70	1,30	03:04	19,21	0,55
02:06	19,72	1,21	03:06	19,93	0,67
02:08	19,40	1,01	03:08	19,47	0,66
02:10	18,60	1,18	03:10	19,81	0,87
02:12	18,40	0,58	03:12	20,02	1,16
02:14	19,20	0,75	03:14	20,00	0,94
02:16	18,90	0,63	03:16	19,90	1,00
02:18	19,70	1,10	03:18	19,40	0,78
02:20	19,90	1,20	03:20	19,03	0,50
02:22	20,20	1,34	03:22	18,88	0,47
02:24	19,30	0,80	03:24	18,86	0,42
02:26	19,00	0,66	03:26	18,73	0,37
02:28	19,00	0,64	03:28	18,57	0,26
02:30	19,10	0,62	03:30	18,08	0,20
02:32	19,20	0,70	03:32	18,43	0,29
02:34	18,90	0,61	03:34	18,96	0,38
02:36	18,70	0,45	03:36	19,07	0,42
02:38	18,70	0,44	03:38	18,77	0,39
02:40	18,90	0,61	03:40	18,70	0,30
02:42	18,80	0,47	03:42	18,68	0,33
02:44	18,80	0,44	03:44	18,45	0,24
02:46	19,00	0,49	03:46	19,03	0,38
02:48	19,10	0,52	03:48	19,50	0,61
02:50	19,10	0,56	03:50	19,64	0,65
02:52	19,10	0,54	03:52	19,66	0,63
02:54	19,08	0,52	03:54	19,20	0,54

As for "Table 7", it represents the data collected on the panel in a location shaded by the forest.

TABLE 7. DATA COMING FROM A SOLAR PANEL PLACED IN A SHADED LOCATION

Time (.pm)	Voc (V)	Isc (A)	Time (.pm)	Voc (V)	Isc (A)
01:56	19,10	0,46	02:56	18,40	0,21
01:58	19,30	0,48	02:58	18,27	0,19
02:00	19,50	0,51	03:00	18,40	0,22
02:02	19,70	0,58	03:02	18,42	0,23
02:04	19,20	0,61	03:04	18,40	0,22
02:06	19,10	0,60	03:06	18,62	0,27
02:08	18,80	0,62	03:08	18,69	0,28
02:10	18,30	0,23	03:10	18,89	0,33
02:12	18,20	0,24	03:12	19,22	0,43
02:14	18,50	0,28	03:14	19,07	0,38
02:16	18,40	0,26	03:16	19,07	0,38
02:18	18,90	0,41	03:18	18,42	0,29
02:20	19,00	0,44	03:20	18,36	0,23
02:22	19,10	0,50	03:22	18,35	0,22
02:24	18,80	0,39	03:24	18,37	0,20
02:26	18,60	0,30	03:26	18,25	0,20
02:28	18,40	0,28	03:28	17,65	0,12
02:30	18,50	0,30	03:30	17,67	0,13
02:32	18,40	0,26	03:32	18,00	0,13
02:34	18,30	0,23	03:34	18,35	0,20
02:36	18,10	0,20	03:36	18,20	0,19
02:38	18,30	0,21	03:38	18,18	0,17
02:40	18,50	0,24	03:40	18,19	0,16
02:42	18,18	0,19	03:42	18,20	0,17
02:44	18,24	0,21	03:44	18,05	0,16
02:46	18,35	0,22	03:46	18,33	0,20
02:48	18,38	0,24	03:48	18,69	0,25
02:50	18,42	0,23	03:50	18,76	0,30
02:52	18,44	0,24	03:52	18,71	0,29
02:54	18,46	0,23	03:54	18,52	0,24

III. RESULTS AND INTERPRETATION

4) Comparison of voltage and current in the both location

- If we calculate and compare the open circuit voltage in direct sunlight with the voltage in a shaded situation, we obtain the following curve:

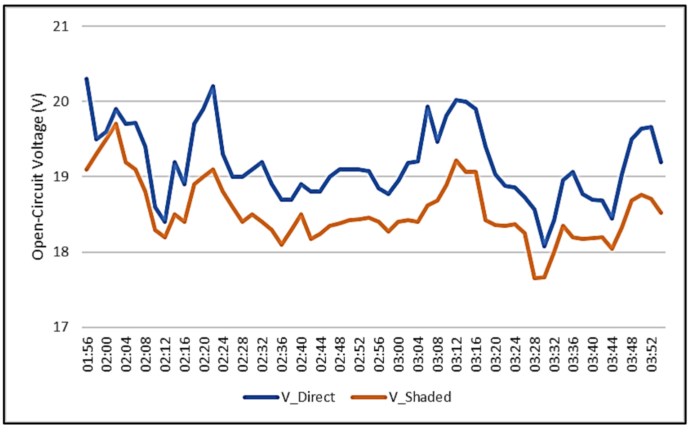

Fig. 3. Voltage comparison between panel on shaded area and panel in direct sunlight

It can be seen that the voltage varies constantly between the two locations with an average reduction rate of 3,32 percent with shading compared to direct sunlight.

- If we calculate and compare the short-circuit current in direct sunlight with the current in a shaded situation, presented in the following curve:

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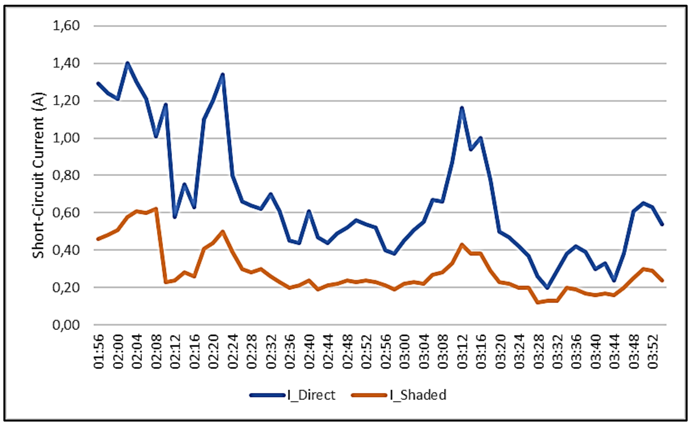

Fig. 4. Short-Circuit Current Comparison between panel on shaded area and panet in direct sunlight

We see here that the current curve of the two panels respectively in the shaded zone and in direct sunlight has a more or less identical appearance. However, we can still maintain that the more the value of the current increases, the greater the difference, the reduction of which goes down to 37% of the value in direct sunlight.

Since the voltage variation is not too great, the power variation rather follows the current variation. When we calculated the average value of the reduction in power, we obtained 43% compared to the power in direct sunlight.

5) Solar panel sizing

To determine the power of the photovoltaic panel required in direct sunlight, we will use the following equation [13]:

$$P_{panel} = \frac{E_{cj}}{Ir_{min} \times Ratio_{perf}} \qquad (2)$$

With :

- P_{panel}: Panel power [Wpeak]
- E_{cj}: Energy consumed daily [Wh]
- Ir_{min}: Minimum irradiation [kWh/m²/d]
- $Ratio_{perf}$: Panel performance ratio

However, the power of this panel will decrease by 43% in the shadowed area. So, we should then calculate the power of our panel with the following equation:

$$P_{SP} = \frac{E_{cj} \times 100}{43 \times Ir_{min} \times Ratio_{perf}} \qquad (3)$$

With P_{SP}: Panel power in shadowed area [Watt peak]

a) Energy consumed per day: It is calculated in the previous paragraphs, the value of which amounts to:

$$E_{cj} = 25.65 + n * 0.5 \qquad (4)$$

with n the number of detections per day.

Suppose that a maximum of 4 daily violations are detected, then Ecj becomes 27.65 Wh/d.Wh/j.

b) Minimum irradiation:

The monthly data provided by PVGIS7.0 from the Montagne d'Ambre site is given by the following table:

TABLE 8. GLOBAL IRRADIATION AND TEMPERATURE OF MONTAGNE D'AMBRE PARK

Months	Global Irradiation [kWh/m²/d]	Temperature [°C]
Jan.	4,94	22,20
Feb.	4,38	22,70
Mar.	5,07	22,90
Apr.	4,62	23,00
Mey	4,46	22,00
Jun.	4,00	21,00
Jul.	4,00	19,90
Aug.	4,19	19,80
Sep.	4,52	20,70
Oct.	5,50	22,40
Nov.	5,58	22,50
Dec.	5,01	22,70
Annual	**4,69**	**21,82**

Taking the value for the most unfavorable month, we have: Irmin = 4.00 kWh/m²/day.

c) System performance ratio:

The performance ratio of a system varies from 0.6 to 0.8. The value we will take will be the average value of 0.7.

d) Peak panel power

According to "equation.(4)", the power of the panel = 23 Wpeak.

$$P_{SP} = \frac{27{,}65 \times 100}{43 \times 4 \times 0{,}7} = 22{,}93\,Wpeak \approx 23\,Wpeak$$

6) Battery Sizing

The size of the battery is determined by several factors:

- Energy consumed and depth of discharge
- Maximum discharge intensity

a) In relation to the energy consumed and the depth of discharge, the capacity of the battery can be calculated by :

$$Capacity = \frac{Energy}{Deepth\ of\ discharge \times Voltage} \qquad (5)$$

Battery depth of discharge refers to the level of depletion of battery capacity following use. So, to ensure the life of our battery, we will choose a depth of discharge of 80%.

According to battery availability, we choose 12V battery, choice for low power systems.

The capacity of the battery is then dimensioned at:
C = 27.65 / (0.8*12) [Ah] = 2.8 [Ah].

b) Considering the maximum discharge intensity, the size of the battery must have a value of ten times compared to this value. The maximum discharge current is determined by adding up the maximum current intensities of all components operating concurrently.

As previously defined, there are three scenarios of simultaneous operation:

Case 1: Sleep mode, where the entire system is on standby.

Case 2: Capture and identification mode, involving the microcontroller, microphone, and sound card.

Case 3: Signaling mode and alarm activation, with both the microcontroller and alarm system in operation.

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TABLE 9. MAXIMUM CURRENT EVALUATION

Component	**Current per component [A]**	**Case 1 [A]**	**Case 2 [A]**	**Case 3 [A]**
Microphone Electret	0,5 x 10^{-3}	0	0,5 x 10^{-3}	0
Sound Card	26 x 10^{-3}	0	26 x 10^{-3}	0
Raspberry Pi 3	1	0	1	1
Raspberry Pi3 Idle	200 x 10^{-3}	200 x 10^{-3}	0	0
Alarm	333 x 10^{-3}	0	0	333 x 10^{-3}
Total		200 x 10^{-3}	1,0265	1,333

Therefore, the maximum capacity required is Cmax = 10*1.333 Ah = 13.33 Ah.

We see that the use of this maximum capacity is more favorable, because it is suitable both in relation to the demand when using the maximum intensity, but also, comparing to the daily requirement we have a margin of Cmax/Cmin = 13.33/2.8 = 4.76 days without sunlight.

III. CONCLUSION

After optimizing monitoring for the site context, a reduction in the energy consumption of our device was observed, bringing it to 27.56 Wh for a day of use, taking into account a maximum of 4 infractions per day in the same place. When it comes to energy supply, the shading created by the forest negatively impacts the amount of light reaching the solar panel, reducing its output to only 43 percent compared to the current under direct sunlight. Despite the small reduction in voltage which is 3,32 percent, this affects the power value of the panel in shaded areas.
Following this evaluation, we were able to size the power of the solar panel so that it was adapted to the system, set at 23Wpeak. Likewise, the battery capacity has been sized at 13.33 Ah, operating at 12 V for a daily consumption of 2.8 Ah, with a margin of 4.76 days of use in the absence of sunlight.

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