Applied Measurement & Control SS2023: Environmental monitoring with a smart bird house by:

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1.0 Introduction (Henrydon)

Due to massive urbanization efforts in cities and increasing demand for housing, industry and intensive agricultural approaches, there exists a need to compete for space against other species. The rise of unsustainable anthoropoligcal activity has been deemed a threat upon animal and plant populations, in addition to the disruption of food chains (particularly the declining insect populations that birds feed on to survive) which has put reportdly compromised the biodiversity of our ecosystems. (1) According to NABU (Naturschutzbund), bird inhabitants and species diversity in Germany are at risk and steadily declining. (2) Accordig to Fig. 1, the trend for forest, common and farmland bird species is shown. The number of forest birds remained almost stable between 1990 and 1993, then a declining trend was observed until 2009. Common and farmland avian species had a steadier trend of decreasing numbers. 15 percent of all bird breeding pairs in Germany disappeared between 1998 and 2009; in 12 years 12.7 million breeding pairs were lost. (3) Even though this has not affected all bird groups and breeding pairs with the same magnitude, there still is a necessity for environmental scienticts and protection unions to intervene and monitor the biodiveristy of birds around urban areas and living species. Due to the advancement of technology in the past decades, in addition to expanded production of realtively inexpensive sensors, microprocessors etc., monitoring devices and systems have been revolutionzed and spread around vastly, which makes it easier to observe changes in the equilbirium of nature, and accelerate further research efforts that make amends through proper environmental management and aim to reverse the disturbance caused to nature's dynamics. The objective of this project is to design and test an environmental monitoring system to monitor avian species in Kamp-Lintfort.

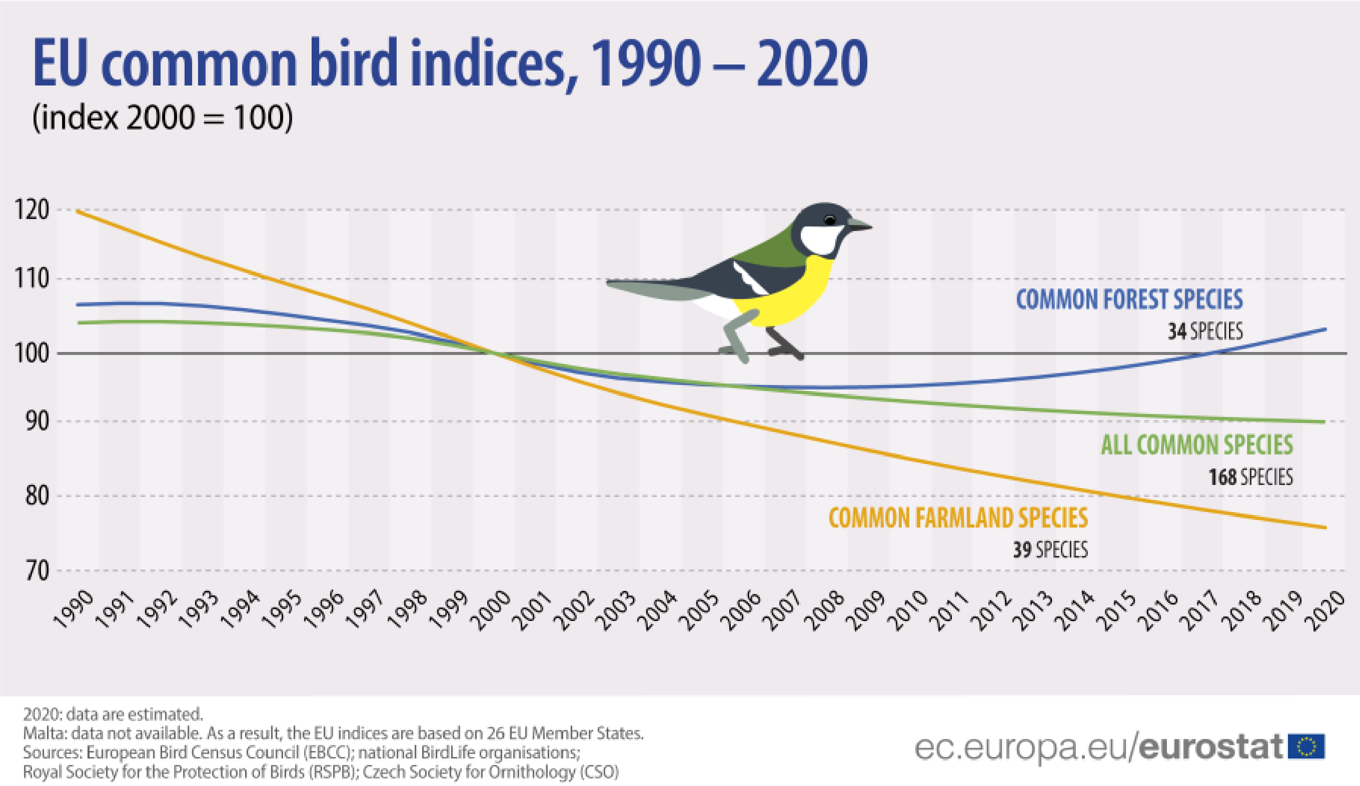


Fig 1: EU common bird indices

2.0 Materials and Methods

Quantitaive methods of biodiversity determination

To describe species diversity in natural communities, ecologists categorize several indices which based on what they measure and what they represent. No specific weights are assigned to species, except for abundances (and for biomass in some indices). The same holds for the individuals within a species. Species richness measures of biodiversity by counting the number of different species in a given area. This measure is strongly dependent on sampling size and effort, but does not depend on each species weight in the sample pool. Richness-Evenness (or Richess-Abundance) indices measure in a way similar to the information theory concerning a code or message; by accounting for the weight of each species in the sample pool. A prime example of this is the Shannon-Wiener diversity index, expressed as such:

H'= -∑pi x ln(pi)

It is calculated by first determining **pi**, which is the ratio of individual species' occurences to the total number of species' occurences, Every pi is then multiplied with its natural logarithm and then summed up. (4)

One shortcoming with the monitoring system is that it allows limited observation of the number of same-species i.e. it is difficult to notice repeated occurences of the same individual bird of a species (if, it visits the birdhouse more than once), and thus the sample size is cannot be precisley ascertained. This is explained in Table 1, For the sake of this experiment, unless clearly visible (or controlled by file metadata and data logs to the server), individual occurences of a bird species will not be assumed to be recurring. Further, this means that the photos collected can indicate species richness, but cannot accurately give results for species evenness or their distribution in a sample area

2.1 components

Through the intelligent capabilities of the birdhouse, communication and connecvitivty with the system can be simplified, to gather data and obtain insight into remote areas without directly controlling or maintaing the system following a scheduele. Of course, there should be an incentive to ensure the sustainability of this system. For the system to be categorized as environmentally sustainable, it has to be long-term obtain energy from a renewable resource. For it to fulfill the economical sustainability criterum, it has to be inexpensive to design and implement. The framework is based on the following materials and components:

2.1.1 ESP32CAM + SD card (ismail)

The ESP32-CAM is a compact and energy-efficient camera module built around ESP32. Equipped with the OV2640 camera, it boasts an onboard TF card slot. One of its standout features is the 4MB PSRAM, which efficiently stores camera images, enabling smooth video streaming and other processes without overwhelming the ESP32, thus allowing for higher picture quality. Additionally, the module includes an onboard LED for flash functionality and multiple GPIOs for seamless peripheral connections. Users can conveniently insert an SD card to preserve the captured photos for future review. (5)

2.1.2 FT232R UARTUartSBee V5 (FTDI) (henry)

Since the ESP32-CAM AI-Thinker lacks a built-in programmer and a serial port, it cannot be programmed directly, thus serial communication must be first established through a protocol. The FT232R is a single chip USB to serial UART interface with advanced features, including integrated USB termination resistors, EEPROM for storing device descriptors, support for various data transfer rates, FTDI's royalty-free Virtual Com Port and Direct drivers, and compatibility with different voltage levels, making it suitable for a wide range of applications. (6)

2.1.3 Solar module (ismail)

On the roof of the bird house lies a solar (or photovoltaic panel) module. This eco-friendly component absorbs sunlight to generate clean and sustainable energy, which is then stored in a built-in rechargeable battery. This ensures a continuous and uninterrupted power supply for the bird house camera, even during cloudy days.

The short-circuit current is the current through the solar cell when the voltage across the solar cell is zero (i.e., when the solar cell is short circuited). Usually written as ISC, the short-circuit current is shown on the IV curve below. The short-circuit current is due to the generation and collection of light-generated carriers. For an ideal solar cell at most moderate resistive loss mechanisms, the short-circuit current and the light-generated current are identical. Therefore, the short-circuit current is the largest current which may be drawn from the solar cell. (7)

Short circuit current ~1 A

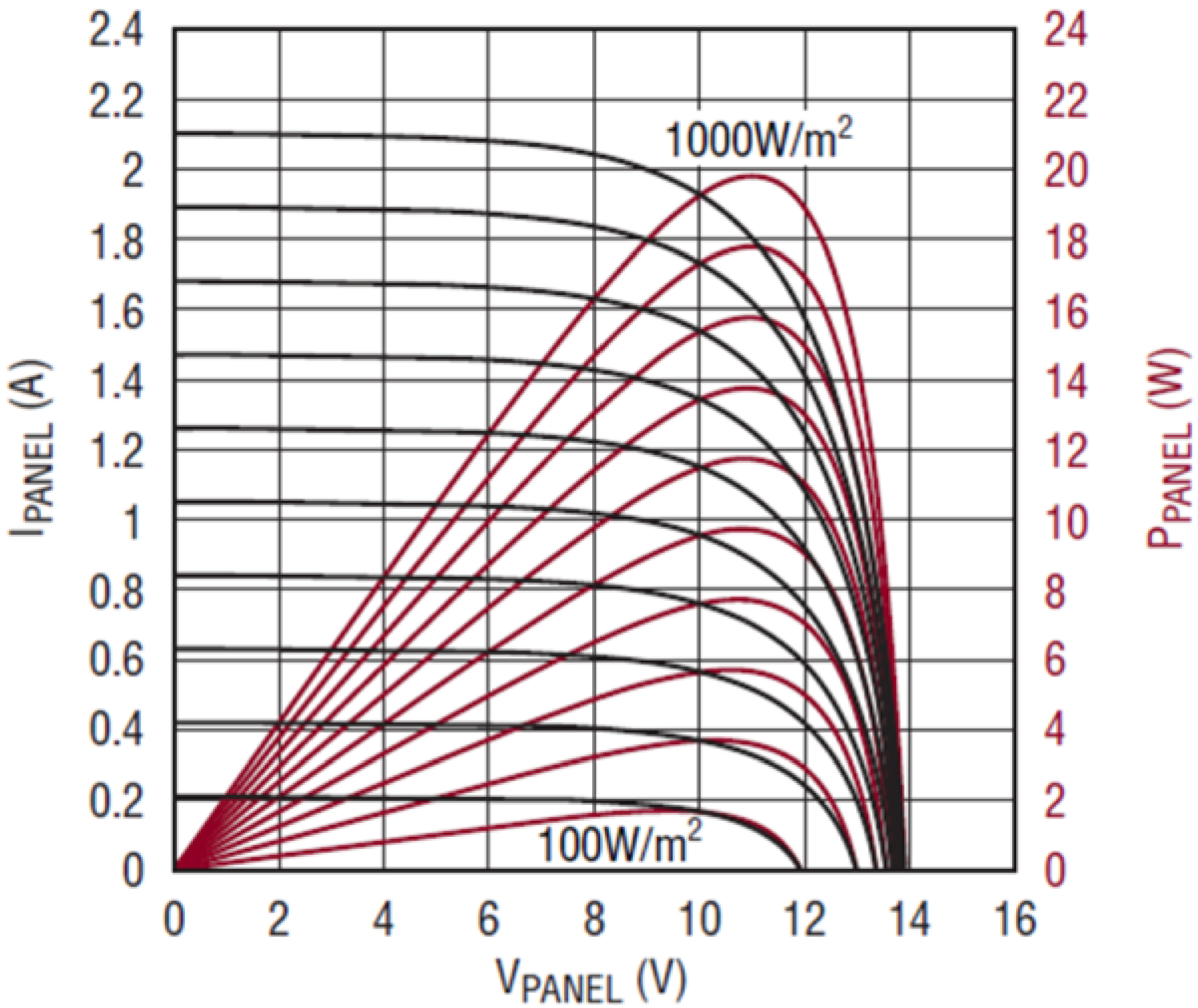
The open-circuit voltage, VOC, is the maximum voltage available from a solar cell, and this occurs at zero current. The open-circuit voltage corresponds to the amount of forward bias on the solar cell due to the bias of the solar cell junction with the light-generated current. The open-circuit voltage is shown on the IV curve below. (8)

Measuring the potential difference between the positive and negative terminals of the solar module yields a DC voltage of ~6V, which means it consists of 12 PV cells, with 0.5 V each connected serially.

panelvoltage.mp4

The open-circuit voltage ~ 6V

Its role in this project is to keep the battery charged at all times to ensure the constant recording done by the ESP32-CAM. Logically, the bird house is preferably placed at an elevated location, where it has direct contact to sunlight (a rooftop for instance).



2.1.4 PIR module (infrared module) (henry)

PIRs are basically made of a pyroelectric sensor, which can detect levels of infrared radiation. The sensor in a motion detector is actually split in two halves. The reason for that is that we are looking to detect motion (change) not average IR levels. The two halves are wired up so that they cancel each other out. If one half sees more or less IR radiation than the other, the output will swing high or low.

The sensor has a wide input voltage range (4. 5V to 12V), a High/Low output voltage of 3. 3V TTL, capable of distinguishing between object and human movement, featuring two operating modes, covering a 120° angle and a 7-meter range, with low power consumption (65mA) and an operating temperature range of -20° to +80° Celsius.

PIR sensors are more complicated than many of the other sensors explained in these tutorials (like photocells, FSRs and tilt switches) because there are multiple variables that affect the sensors input and output. To begin explaining how a basic sensor works, we'll use this rather nice diagram

The PIR sensor itself has two slots in it, each slot is made of a special material that is sensitive to IR. The lens used here is not really doing much and so we see that the two slots can 'see' out past some distance (basically the sensitivity of the sensor). When the sensor is idle, both slots detect the same amount of IR, the ambient amount radiated from the room or walls or outdoors. When a warm body like a human or animal passes by, it first intercepts one half of the PIR sensor, which causes a positive differential change between the two halves. When the warm body leaves the sensing area, the reverse happens, whereby the sensor generates a negative differential change. These change pulses are what is detected.

Below the dome:

The IR sensor itself is housed in a hermetically sealed metal can to improve noise/temperature/humidity immunity. There is a window made of IR-transmissive material (typically coated silicon since that is very easy to come by) that protects the sensing element. Behind the window are the two balanced sensors.

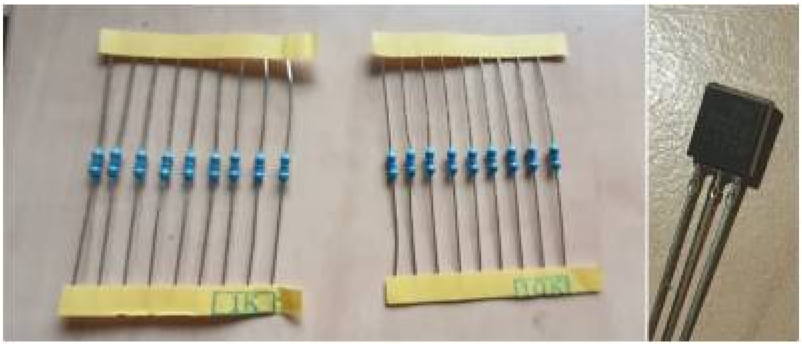
PIR sensors are rather generic and for the most part vary only in price and sensitivity. Most of the real magic happens with the optics. This is a pretty good idea for manufacturing: the PIR sensor and circuitry is fixed and costs a few dollars. The lens costs only a few cents and can change the breadth, range, sensing pattern, very easily. In the diagram up top, the lens is just a piece of plastic, but that means that the detection area is just two rectangles. Usually we'd like to have a detection area that is much larger. To do that, we use a simple lens such as those found in a camera: they condenses a large area (such as a landscape) into a small one (on film or a CCD sensor). For reasons that will be apparent soon, we would like to make the PIR lenses small and thin and moldable from cheap plastic, even though it may add distortion. For this reason the sensors are actually Fresnel lenses: The Fresnel lens condenses light, providing a larger range of IR to the sensor.

OK, so now we have a much larger range. However, remember that we actually have two sensors, and more importantly we dont want two really big sensing-area rectangles, but rather a scattering of multiple small areas. So what we do is split up the lens into multiple section, each section of which is a fresnel lens

The different faceting and sub-lenses create a range of detection areas, interleaved with each other. That's why the lens centers in the facets above are 'inconsistent' - every other one points to a different half of the PIR sensing element (9)

2.1.5 Resistors + Transistors



(10)

2.1.6 Battery + charge regulator (henry)

Lithium-ion polymer batteries are thin, light, and powerful with an output range of 4.2V to 3.7V and a capacity of 2000mAh. The battery comes with a pre-attached genuine 2-pin JST-PH connector preventing snags, smooth insertion, and removal, as well as built-in protection circuitry to prevent overcharging, overuse, and protect against output shorts. (11) The Adafruit Universal USB/DC/Solar Lithium Ion/Polymer Charger is a multifunctional charging device designed to efficiently and reliably charge lithium-ion/polymer batteries using USB, DC power sources, or solar panels, catering to a wide range of portable and renewable energy applications. It includes status indicators and protection features like overcharging and reverse polarity protection, ensuring safe and efficient charging for the battery and connected devices.

Adafruit LiPo charger: This charger is a breeze to use for solar projects: pick up any of our many 3.7V/4.2V LiIon batteries, and a 6V solar panel. Plug the battery into the BATT port using a 2-pin JST cable and the solar panel into the DC jack using a 2.1mm adapter cable Put the solar panel outside (and keep the battery out of the sun, it needs to be kept cool!) to start charging. You can power another project at the same time by connecting to the LOAD output port, which will never go above 4.4V.

The bq24074 which powers this design is great for solar charging, and will automatically draw the most current possible from the panel in any light condition Even thought it isn't a 'true' MPPT (max power point tracker), it has near-identical performance without the additional cost of a buck-converter. Our detailed tutorial on how to use this charger includes a design document explaining how it all works.

Maximum Power Point Tracking is a family of control algorithms that aims at optimizing the use of a power source that possesses a fluctuating power profile.

Indeed, some power sources, like solar panels, present power characteristics that strongly depend on the operating conditions. For instance, the cloud coverage significantly impacts the capability of a panel to deliver electricity. As such, maximizing the extracted power requires identifying – and tracking – the operating point that provides the highest power level as a function of the operating conditions.

Therefore, Maximum Power Point Tracking (MPPT) is often applied in renewable energy systems – e.g. photovoltaic plants or wind turbines – as their power delivery capability varies significantly and in an unpredictable manner. Other special operating points may be interesting to track, such as the maximum efficiency point tracking (MEPT), or other optimum, e.g. related to operating costs.

For practically all real power sources, the power that can be extracted varies with the operating point. While electrical sources are related to the voltage/current pair, the same principle also applies to force/speed, flux/surface, etc.

In all cases, the inevitable internal resistance (or equivalent quantity) limits the maximum possible output power. Non-linear or more complex characteristics also exist, but with the same result: the maximum power point is not located at the [max. voltage · max. current] point (or equivalent quantity). Therefore, the operating point that delivers the maximum power must be constantly tracked by searching for the best voltage · current combination.

OUT - Regulated load output. This pin will provide a regulated output when the input voltage is below the over voltage protection threshold and above the regulation voltage. It will never be higher than 4.4V (but it may dip down to 3V or whatever the LiPo battery voltage is at, if USB/DC isnt plugged in)

PGOOD - Power Good Status (active low). PGOOD pulls to GND (open drain) lighting the connected led when a valid input source is connected. If the input power source is not within specified limits, PGOOD is disconnected from ground (high impedance) and the LED will be off. CHG - Charge status (active low) pulls to GND (open drain) lighting the connected led when the battery is charging. If the battery is charged or the charger is disabled, CHG is disconnected from ground (high impedance) and the LED will be off.

OK so how do we fix this problem? The issue we have here is that the voltage collapses during high current draw. We need to find a way to keep the lipo charger from drawing too much current, and backing off when the voltage starts to droop.

The bq24074 is designed to handle this sort of situation, calls it Input Dynamic Power Managemtn Mode (Input DPM) and basically, it does precisely what we want. When the input drops below 4.5V approximately, the charger will back off and will automatically increase/reduce the charge rate to keep the voltage higher than 4.5V! this charger is dynamically stable and does not need an optional capacitor to keep solar charging from oscillating. (12)

2.2 schematic (osama)

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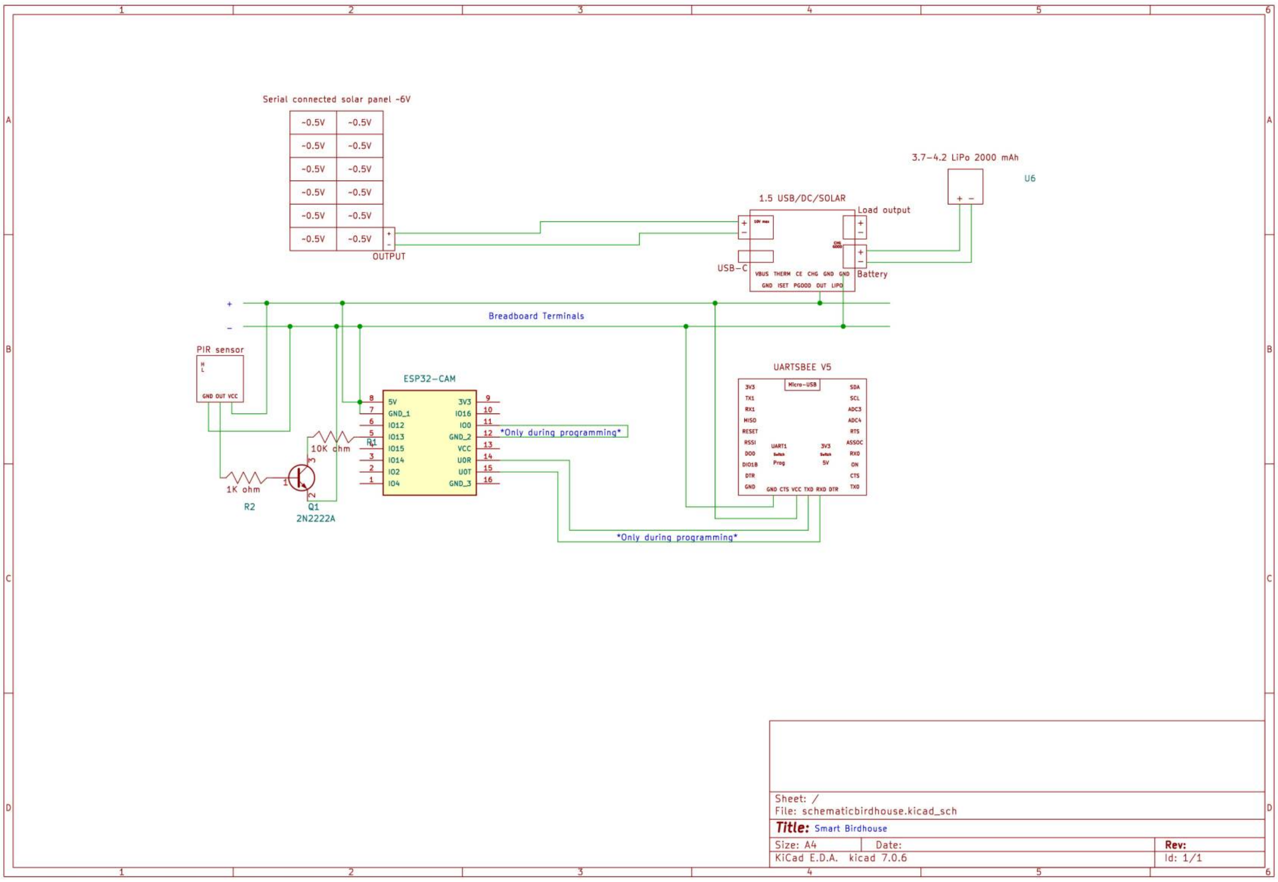

made with KiCad

3.0 Results (osama)

3.1 Arduino IDE C++ code(Osama)

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```
#include "esp_camera.h"
#include "Arduino.h"
#include "FS.h"                  // SD Card ESP32
#include "SD_MMC.h"              // SD Card ESP32
#include "soc/soc.h"             // Disable brownour problems
#include "soc/rtc_cntl_reg.h"    // Disable brownour problems
#include "driver/rtc_io.h"
```

```
#include <EEPROM.h>            // read and write from flash memory

// define the number of bytes you want to access
#define EEPROM_SIZE 1

// Pin definition for CAMERA_MODEL_AI_THINKER
#define PWDN_GPIO_NUM     32
#define RESET_GPIO_NUM    -1
#define XCLK_GPIO_NUM      0
#define SIOD_GPIO_NUM     26
#define SIOC_GPIO_NUM     27

#define Y9_GPIO_NUM       35
#define Y8_GPIO_NUM       34
#define Y7_GPIO_NUM       39
#define Y6_GPIO_NUM       36
#define Y5_GPIO_NUM       21
#define Y4_GPIO_NUM       19
#define Y3_GPIO_NUM       18
#define Y2_GPIO_NUM        5
#define VSYNC_GPIO_NUM    25
#define HREF_GPIO_NUM     23
#define PCLK_GPIO_NUM     22

int pictureNumber = 0;

void setup() {
  WRITE_PERI_REG(RTC_CNTL_BROWN_OUT_REG, 0); //disable brownout detector

  Serial.begin(115200);
  //Serial.setDebugOutput(true);
  //Serial.println();
  camera_config_t config;
  config.ledc_channel = LEDC_CHANNEL_0;
  config.ledc_timer = LEDC_TIMER_0;
  config.pin_d0 = Y2_GPIO_NUM;
  config.pin_d1 = Y3_GPIO_NUM;
  config.pin_d2 = Y4_GPIO_NUM;
  config.pin_d3 = Y5_GPIO_NUM;
  config.pin_d4 = Y6_GPIO_NUM;
  config.pin_d5 = Y7_GPIO_NUM;
  config.pin_d6 = Y8_GPIO_NUM;
  config.pin_d7 = Y9_GPIO_NUM;
  config.pin_xclk = XCLK_GPIO_NUM;
  config.pin_pclk = PCLK_GPIO_NUM;
  config.pin_vsync = VSYNC_GPIO_NUM;
  config.pin_href = HREF_GPIO_NUM;
  config.pin_sscb_sda = SIOD_GPIO_NUM;
  config.pin_sscb_scl = SIOC_GPIO_NUM;
  config.pin_pwdn = PWDN_GPIO_NUM;
```

```
  config.pin_reset = RESET_GPIO_NUM;
  config.xclk_freq_hz = 20000000;
  config.pixel_format = PIXFORMAT_JPEG;
  if(psramFound()){
    config.frame_size = FRAMESIZE_UXGA; // FRAMESIZE_ +
QVGA|CIF|VGA|SVGA|XGA|SXGA|UXGA
    config.jpeg_quality = 10;
    config.fb_count = 2;
  } else {
    config.frame_size = FRAMESIZE_SVGA;
    config.jpeg_quality = 12;
    config.fb_count = 1;
  }
  // Init Camera
  esp_err_t err = esp_camera_init(&config);
  if (err != ESP_OK) {
    Serial.printf("Camera init failed with error 0x%x", err);
    return;
  }
  //Serial.println("Starting SD Card");
  if(!SD_MMC.begin()){
    Serial.println("SD Card Mount Failed");
    return;
  }
  uint8_t cardType = SD_MMC.cardType();
  if(cardType == CARD_NONE){
    Serial.println("No SD Card attached");
    return;
  }
  camera_fb_t * fb = NULL;
  // Take Picture with Camera
  fb = esp_camera_fb_get();
  if(!fb) {
    Serial.println("Camera capture failed");
    return;
  }
  // initialize EEPROM with predefined size
  EEPROM.begin(EEPROM_SIZE);
  pictureNumber = EEPROM.read(0) + 1;
  // Path where new picture will be saved in SD Card
  String path = "/picture" + String(pictureNumber) +".jpg";
  fs::FS &fs = SD_MMC;
  Serial.printf("Picture file name: %s\n", path.c_str());
  File file = fs.open(path.c_str(), FILE_WRITE);
  if(!file){
    Serial.println("Failed to open file in writing mode");
  }
  else {
    file.write(fb->buf, fb->len); // payload (image), payload length
    Serial.printf("Saved file to path: %s\n", path.c_str());
    EEPROM.write(0, pictureNumber);
```

```
    EEPROM.commit();
  }
  file.close();
  esp_camera_fb_return(fb);
  // Turns off the ESP32-CAM white on-board LED (flash) connected to GPIO 4
  pinMode(4, OUTPUT);
  digitalWrite(4, LOW);
  rtc_gpio_hold_en(GPIO_NUM_4);
  delay(2000);
  Serial.println("Going to sleep now");
  delay(2000);
  esp_deep_sleep_start();
  Serial.println("This will never be printed"); }
```

3.2 Python script to transfer photos (Osama)

(14) The initial expriment ran for 1 week and did not attract any birds in fact, therefore a better location was chosen: GFL garden

The bird photos collected will be reviewed, and a conclusion about the bird species biodiversity in Kamp-Lintofrt, GFL timeline of experiment: 1 month

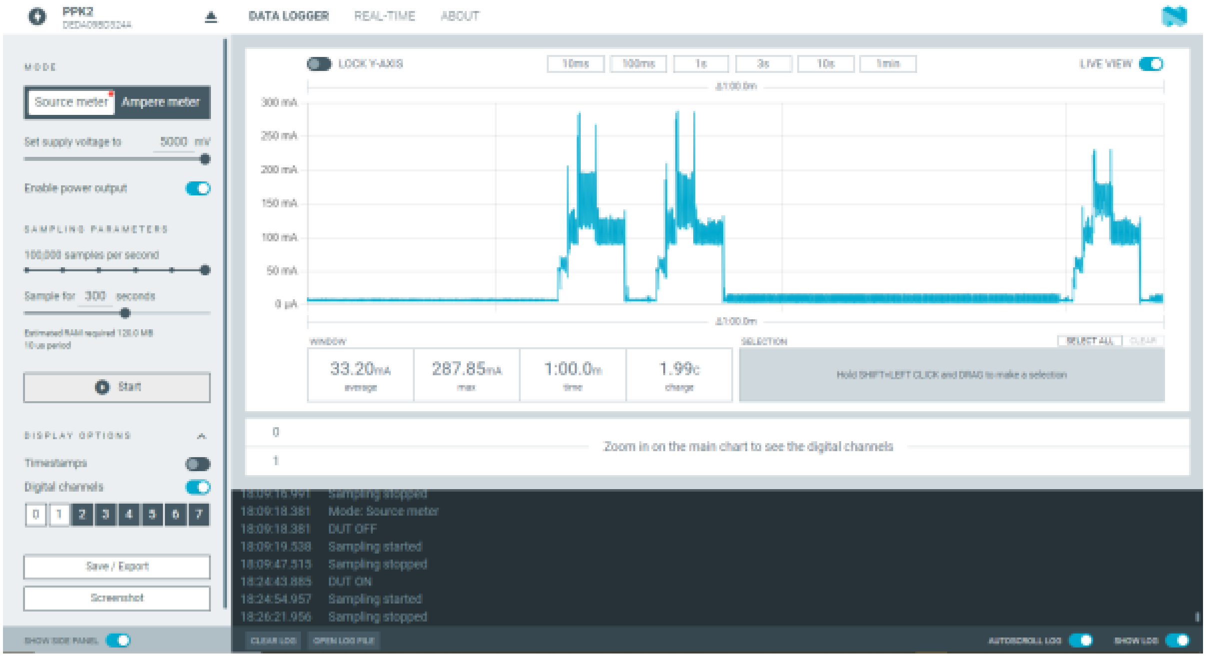
4.0 Discussion (osama)

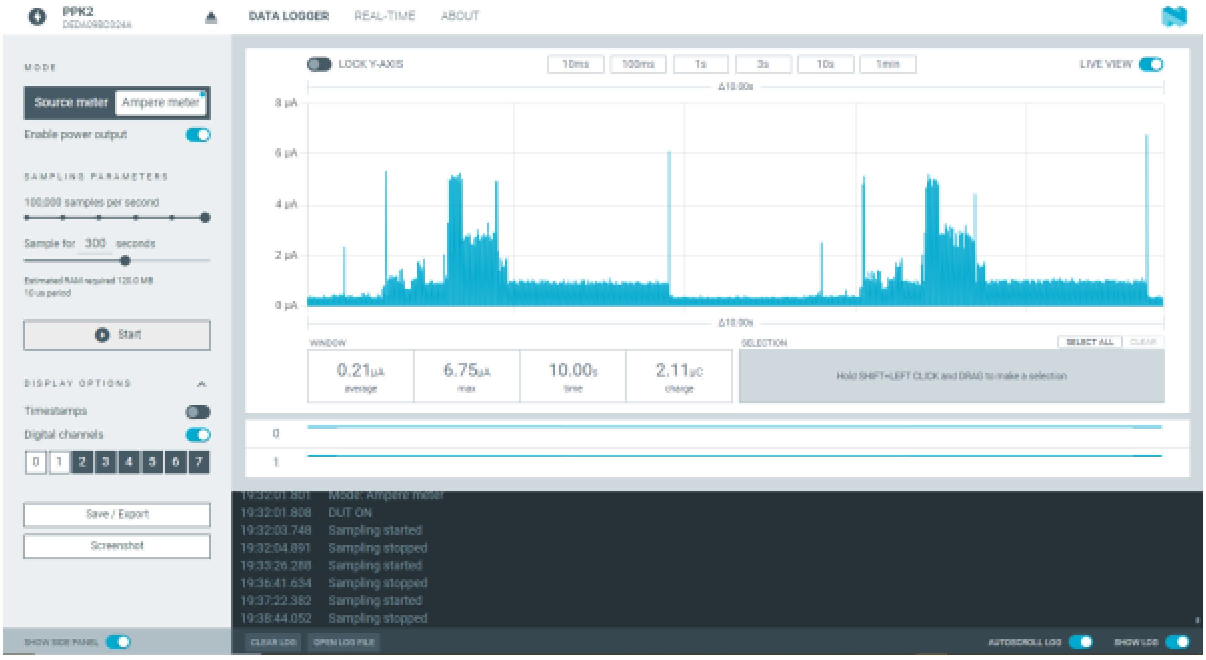
4.1 Design considerations, Power Profiler II Nordic + power saving considerations (henrydon)

The system should be optimized to consume the least power possible. This can be achieved by programming the ESP32-CAM to switch to several sleep modes, such as in the table:

as noted from the table, wireless communication requires a lot of power

By using the power profiler tool, the power consumption of the system can be examined to compare modem sleep and deep sleep:





Battery run time

by using a tool to calculate how long the provided battery can provide power to the whole system, all while being charged by a 6V 0.8A solar panel

This can also be estimated manually:

Generally, if a 5V battery has a 1 Ah capacity (or 1000 mAh), then it theoretically powers a 1 A consumer for 1 h based on the formula:

Charge capacity = discharge time x charge consumption and the power formula P = V x I,

If 2000 mAh battery runs to discharge into a system that consumes ~10 microamperes per second, and triggers 10 times day, each trigger consumes an average of 220 milliamperes for 6 seconds:

220 milli amperes x 6 x 10 = 13,200 mA or 13.2 Amperes when the system is triggered (this is of course increased if wireless communication is activated to send data to a server, for example.

There are 86,400 seconds in a day, 60 of them are considered for operation = 86,340 seconds, multiplied by 10 microamperes = 863.4 milliamperes or 0.8634 amperes

average daily current discharge = 13.2 + 0.8634 = 14 amperes

average daily power consumption = battery operating voltage x average daily current consumption = 4.2 v x 14 = 58.8

to fully discharge a 2 Ah LiPo battery, assuming it is not charged with a solar panel, find the time t = battery capacity/average current consumption = 2 A x 3600 / 14A = 514.2 h or 21.4 days

In this case, birdfood is placed outside in front of the birdhouse, and the camera is placed facing the outside. Ensure that the PIR sensor is protected one way or another, since it is imperative for monitoring purposes

when possible, design a pcb board for your system to make it more compact

when possible, take as many precautions to protect the birdhouse from damage or decay, caused by humidity or raifall. install a cover around the rims on the top so that the water can runoff (also for the sake of shading the birds) , drill or cut a hole in the bottom part and create a gradient or incline from the inside, to drain out any water inflitration. Seal any openings with waterproof tape or glue (between the solar panel roof and the top hatch)

temperature and humidity sensors can also be added on to the system, which can highlight behaviors and preferred conditions for certain avian species

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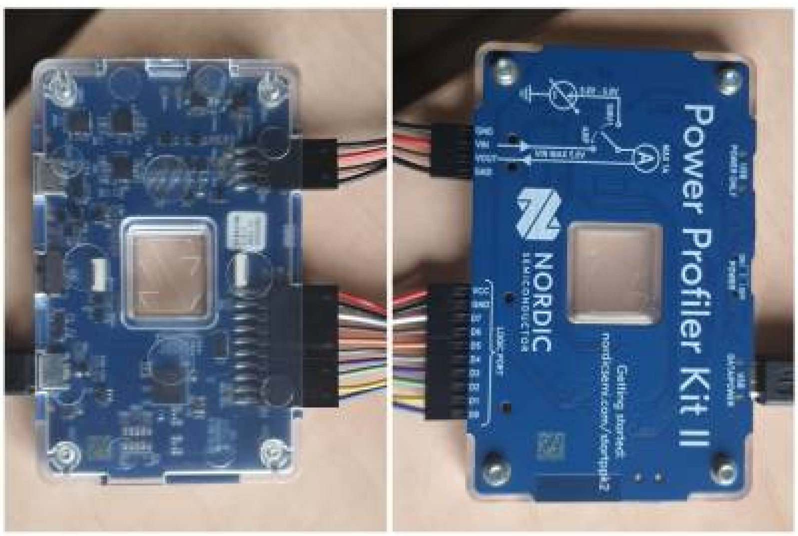

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5.0 Conclusion (Ismail)

To sum up the project and the effort that was put into it, we did face several challenges while developing a fully functioning bird house with integrated bird vision. For example, none of the group members had gained any experience with the utilized components in the past. Thus, it was quite overwhelming when we started working on the project. The number of components required for this project was relatively high; we used an ESP32-CAM along with an SD card, a FT232R UARTUartSBee V5 (FTDI), a solar module, a PIR module, and a battery along with a charge regulator. Each of these components had rather unique properties, which in turn intensified the challenge of getting them all to work simultaneously. However, with enough dedication, we managed to program and connect all components in the best feasible way. The knowledge gained from previous modules in the field of physics and programming greatly aided us while accomplishing this project.

6.0 References

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