PORTABLE, UAV FRIENDLY INFRARED CAMERA SYSTEM BASED ON RASPBERRY PI

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ABSTRACT:A portable infrared scanner is a valuable tool in household application & small business, ranging from product integrity check to housing infrastructure maintenance. We want to extend the usability of portable infrared scanners and introduce remote sensing techniques to the products listed on the market made only possible by recent progress in consumer grade UAV and open source hardware like Raspberry Pi. To introduce the insights from Remote Sensing to the daily life of the general population and help manage small-scale agricultural and forestry activities, we need first lower the bar in both platform and hardware cost while maintaining a high degree of user control and flexibility. In this paper, we make a general discussion about the design and construct of such system using compact open source computers like Raspberry Pi and conduct a preliminary test of the camera system with test shoots, image fusion in aide of direct interpretation to further deduct the feasibility of such system.

1. INTRODUCTION

The infrared section of electromagnetic spectrum is a hot topic for remote sensing research, large scanner on a satellite platform can scan through thousands of square miles of seas and mountains day and night, monitoring disasters and abnormalities ranging from forest fire to global ocean temperature disruptions like El Nino, etc (Guido R. van der Werf et al., 2004). Those are invaluable tools that facilitate environmental research on a macro level. However, down to the ground level of near to medium range sensing, infrared sensing also plays a key role in our modern society with wide varieties of applications in military, industrial production and academic research(Wang et al., 2010). Apart from thermal sensing systems on the satellite platform, close to medium range thermal sensing cameras are commonly seen in medium-sized mounted surveying camera system used in on-site infrared.

Hu Sheng et al, put up a low cost flying-wing airframe-borne uncooled TIR sensing system, and the authors designed a simple calibration methods based on TIR imaging principles that requires only a cup of pre-measured warm water against a dark carpet. Their methods shows that there are ways to satisfy the goals of cost controlling while guaranteeing data reliability and accuracy(Hu et al., 2010).

Di Gennaro et al., combined UAV based high resolution thermal and multispectral scanning with wireless sensor networks to realise vineyard botanical monitoring at individual vine level which shows an encouraging results about the potential in IoT working together with close range remote sensing applications.(Di Gennaro et al., 2017)

For a broader view of working with UAV and consumer-grade camera modules, Juliane et al., evaluate crop field biomass using UAV onboard RGB camera, compared against biomass estimations from near infrared vegetable index (NIVI) obtained from fixed measuring station (Juliane et al., 2015). And in the earlier years right before the dawn of iPhone, D.Akca et al., measured the geometric and radiometric of several popular smartphone cameras and found out that even there are systematic errors in some of the models, with proper calibration the authors believed tested devices can be used for many photogrammetric tasks (D.Akca et al., 2019). And almost ten years after this paper's release, we believe the potential only grows more than the expectation of D.Akca.

In general, those surveying infrared scanning systems are often way more expensive than a normal consumer-grade electronic camera, costing thousands of US dollars at least. High prices and regulations like International Traffic in Arms Regulations (ITAR) of US has further limited the availability of infrared data when conducting close-range small-scale experiments and research. There have been several low-performance add-on smartphone infrared camera modules on the markets that provide a limited resolution (no more than 320*160 pixels) with effective framerates no higher than 9 Hz that works more towards a gimmick and has provided little support for survey calculations and data exporting.

Therefore, a low-cost infrared camera system with open access to data exporting and processing would make infrared data more available to researchers in the close to medium range scenarios. Mounting such system to a UAV would generate infrared images with much finer resolution than a typical satellite scanning image. And the flexibility in post-processing would ensure the system's adaptability to various research cases. It is necessary to discuss the construction of such system to see if it is feasible in the first place, and the rest of this paper is organized as follows: Section 2 talks our thoughts and reasoning on the setups of the system and parts we chose for the preliminary tests. Section 3 displays the results and discuss further research steps. Section 4 concludes this paper.

2. METHODOLOGY

In order to achieve the goal of UAV friendly, the system should be light, and low in power consumption while providing enough processing capability; and to grant the user full access to data acquiring and processing, the components should be accessible through open source toolsets or SDK.

2.1 System Motherboard--Raspberry Pi as core components

We select Raspberry Pi 3 Model B, the third-generation Raspberry Pi that replaced the Raspberry Pi 2 Model B in February 2016 as our motherboard and system on board (SOC) solution for our system.

As the one who popularized the concept of compact card-sized open source mini computer, Raspberry Pi has the best receptions on the market resulted in numerous active developer communities which is crucial in our effort to build up a compatible system. Also, the Raspberry Pi is well supported by the manufacturer with frequent updates and has a wide choice over several major Linux distributions which grants us and possible future users sufficient flexibility of system modification and individual scenarios oriented tweaking, thus guaranteed our goal of system level open accessibility.

And according to the official website of Raspberry Pi, the whole package features:

- Quad-Core 1.2GHz Broadcom BCM2837 64bit CPU
- BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board
- 40-pin extended GPIO
- 4 USB 2 ports
- Full size HDMI
- CSI camera port for connecting a Raspberry Pi camera

The ARM architecture based CPU provides a great balance between performance and power consumption which means the whole system has the ability to do image processing on-the-fly relying only on lithium battery like power banks as its power source. The Wi-Fi and Bluetooth connectivity provide us the means to establish control and data links to the system should we conduct UAV survey missions. We will use the GPIO and CSI camera port to connect with our infrared sensor module and the RGB camera module. And the USB ports together with HDMI will help us through the initial OS installation and hardware debugging. With a weight of 42 gram in a package size of 3.35″ × 2.2″ × 0.8″, it is light and portable, satisfied our goal of being UAV friendly.

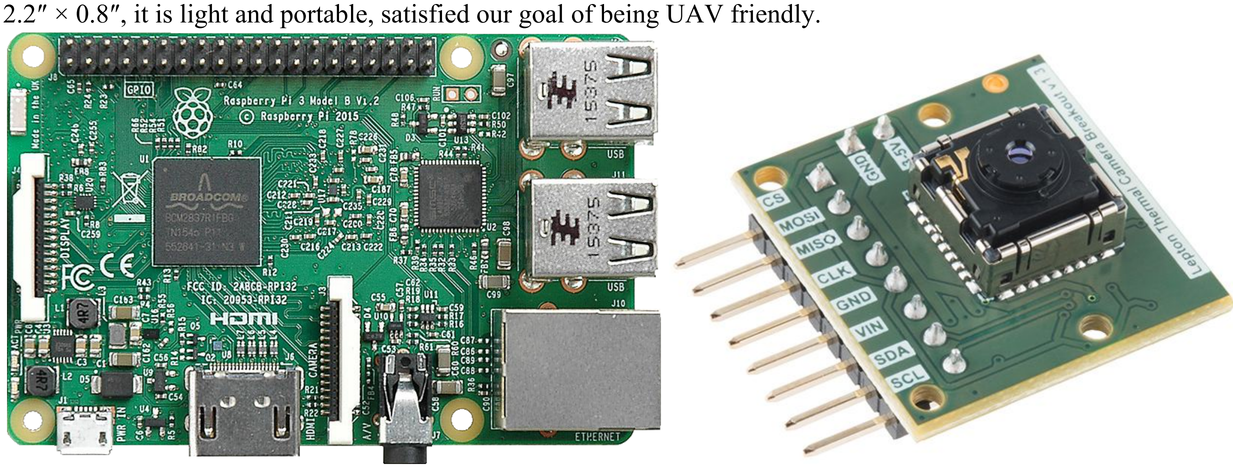


Figure 2.1 Raspberry Pi 3 Module B and FLiR Dev Kit

2.2 System Infrared Sensing Module--FLiR Dev Kit

With budget awareness in mind, we choose the FLIR Dev Kit provided by Sparkfun Electronics as the infrared sensing component. The kit provides the FLIR Lepton® 2.0 camera core with accompanying breakout board. With less than $200 price, we could have a long-wave infrared (LWIR) thermal sensor with the specs sheet shown below:

- Spectral Response: 8 - 14 microns (nominal) Long Wave Infrared (LWIR)
- Resolution: 80h x 60v pixels
- Frame Rate: 9 Hz.
- Horizontal Field of View (HFOV):50˚
- Size: 8.5 x 11.7 x 5.6 mm
- Required Digital Interfaces: I2C for command and control register get/set, SPI for image frame grab
- Required System Voltages: 1.2 V Core, 2.8 V Sensor, I/O tolerant from 2.5 V to 3.1 V
- Power Consumption: 150 mW

- Thermal sensitivity <50 mK

The compact size of this sensor makes the thermal module smaller than a coin even plugged in the breakout board socket which satisfies our design goal of being light and portable. And the low power consumption and voltage requirements make the module compatible with our system motherboard. Because this module is sold by the manufacturer as development parts intended, it is well supported with SDK and online community example projects. Thus the user accessibility on the data is guaranteed.

Given the limited resolution, we argue that a total number of 4800 pixels could be enough for close range recon and scanning missions. As a simple mathematical calculation suggests, an 80*60 image has a resolution of 0.25 m^2/Pixel when scanning a 40*30 m^2 area, and the number is 6.25 m^2/Pixel when surveying an area of 200*150 m^2 at one time. Also, by applying photogrammetry techniques, we could be able to acquire image covering a large area with a high per pixel resolution.

2.3 System RGB Camera -- Raspberry Pi Camera Module v2

We will also use the Pi Camera as an accompanying camera to help test and evaluate the motherboard and infrared sensor module through visual assist. Powered by a Sony IMX219 8 megapixel RGB camera sensor, we can access the camera through the MMAL and V4L APIs plus numerous third-party libraries that can complement different tasking situations.

2.4 System Power Source -- 5V DC Power Supply & Power Bank

As suggested in 3.1, the whole system can be powered a standard 5V DC charger. If we were to install the system on a drone, we could use a normal power bank as its power source. In this paper, we would test the system on a 2015 model Mi power bank. The power bank weighed around 250 gram and the whole system's weight can be controlled under 500 gram making sure it won't be too much of a burden to the drone or any other platform of choice.

2.5 System Control Scheme

Since our motherboard has Wifi capability, we could control the whole unit without direct cable connection, so the control link would be using SSH to connect to the system through a local WiFi network.

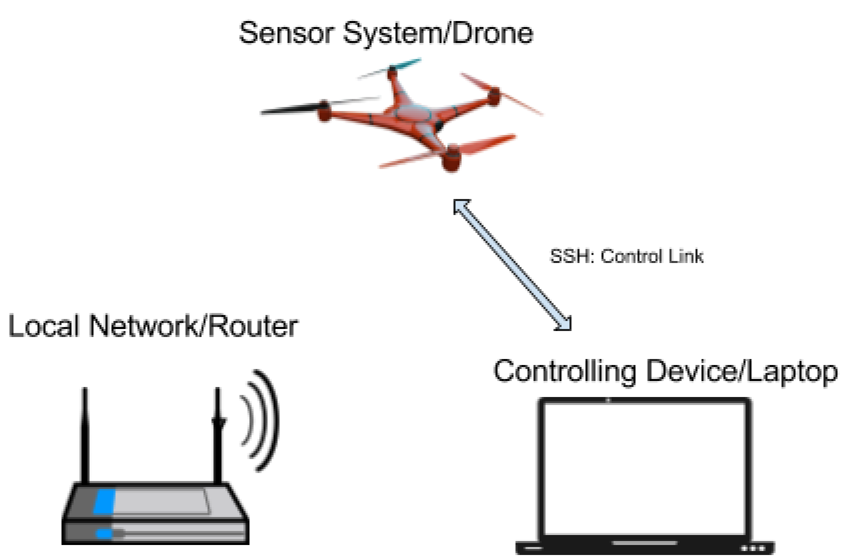


Figure 2.2 System Control Link diagram

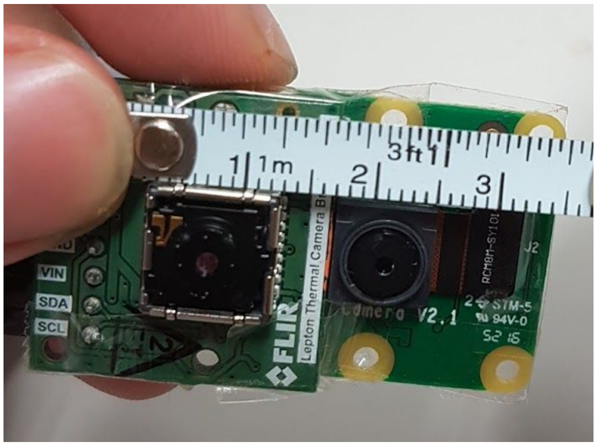
For the purpose of fast prototype testing, we would omit the data link configuration for now and use the only onboard system to hold and process data captured.

3. RESULTS AND DISCUSSION

3.1 System Initialization and test shots

We set up the system referring to FLIR Lepton product manual, connecting a thermal sensor to the GPIO port on Raspberry Pi using female-female jumper wires. Then attach the Pi Camera to the motherboard through CSI connector. We finished initial OS installation and initialization using a wireless keyboard/mouse set with the Raspberry Pi hooked up to a monitor using HDMI. And in order to take an adjacent photo from both of the infrared sensor and RGB camera, we bundle the two together, the intra-axial distance is 15 mm. Since 15 mm is smaller than the intra-ocular distance that is 63.5 mm, the image pair we get from the cameras will overlay in the central.

And we test the infrared sensor using a git repository LeptonModule by Groupgets (https://github.com/groupgets/LeptonModule). And a working instance is shown down below:



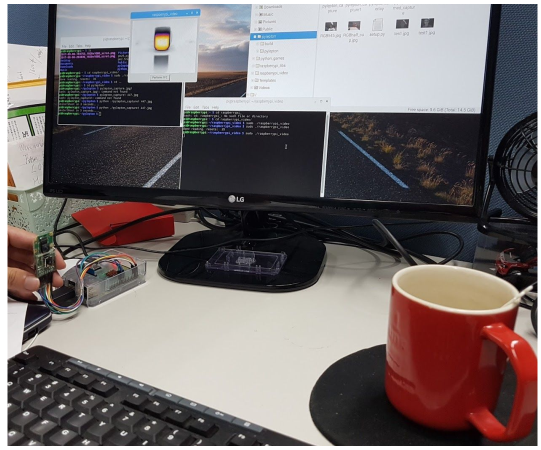


Figure 3.1 FLiR infrared sensor(left) and Pi Camera(right) Figure 3.2 Infrared sensor successfully booted up

The infrared sensor works as expected highlighting the hot surface of the mug containing water in 90℃. Next, we make observations using the camera pairs, the RGB camera can provide a good visual assistance in analyzing the thermal images. We use the camera pair to shoot the same mug on the desk with and without a black mattress under. Images captured were run on another Python package called Pylepton (https://github.com/groupgets/pylepton) with modifications on the pylepton_capture file.

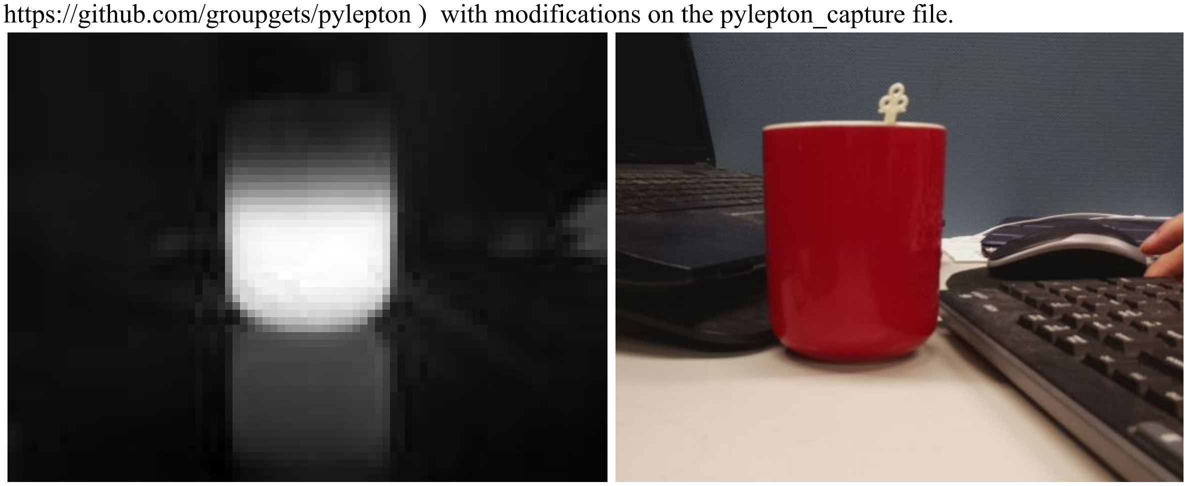


Figure 3.3 Mug half full with hot water

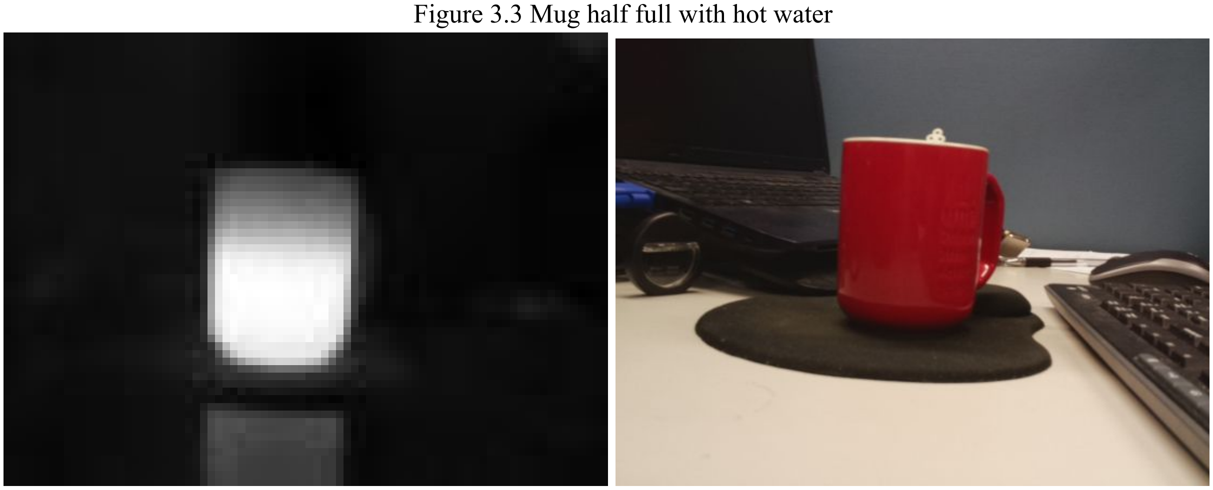


Figure 3.4 Same mug insulated on a black mattress(as a blackbody)

The thermal images showed the gradual warming up of the mug. Also, the desk which is nonreflective in RGB image demonstrates mirror reflection of infrared radiation and the black mattress as a blackbody absorbs the heat radiation as shown in Figure 4.4.

3.2 RGB camera visual assisted overlay test

While being a valuable data in research, the infrared images can be difficult to interpret directly without the visual assistant. Here using the pylepton_overlay files from the Pylepton repository mentioned above with modifications on the parameters of zoom() function, we could create an overlay video stream combining the RGB camera and infrared sensor.

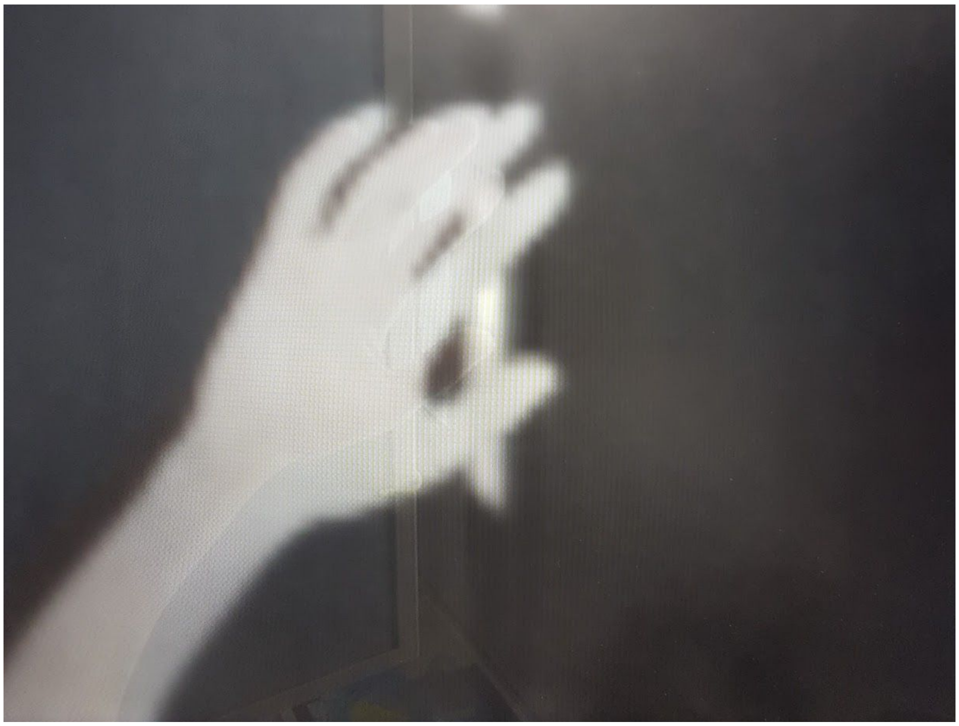


Figure 3.5 video feeds overlay test

With the RGB camera video feed as background, we could easily discern not just the hand (obviously) but can also notice the light bulb behind. However, without rigorous mathematical models, it is difficult to create a perfect overlay.

3.3 Further research propositions on geometric and radiometric calibrations

So far we had selected parts, set up the system and tested its basic functions. However, it is still far from scientifically applicable in surveying and photogrammetry tasks. Here we propose two simple methods for further geometric and radiometric calibrations:

-Geometric Calibration

It is difficult to measure and modeling a camera that captures invisible lights. We can do this by taking cues from normal camera calibrations:

Print out a calibration mosaic board put it under the sun for a while in orthodox position. The parallel sunlight will heat the board evenly, then we can put it against a blackbody background to take images and proceed calibrations as a usual camera.

-Radiometric Calibration

We need to know the curve between image DN value to target surface temperature. We can attach a thermometer to the Raspberry Pi and while point the infrared camera to the target. In this way, we could automate the calibration process and get a relationship curve tailored to our need.

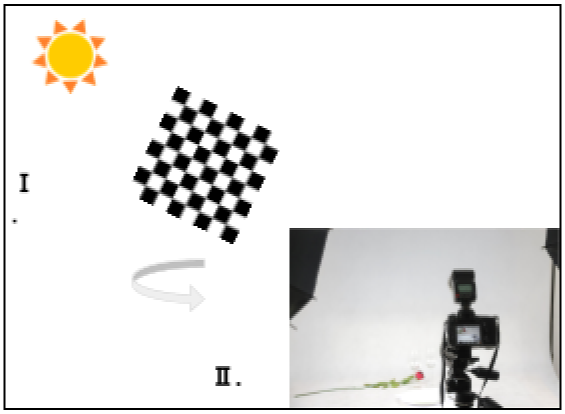


Figure 3.6 Geometric Calibration

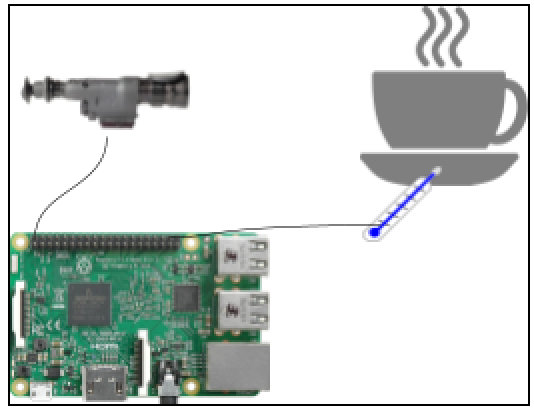


Figure 3.7 Radiation Calibration

These tests will be conducted in our next phase of experiments and research. After rigorous mathematical models being established, we would further conduct flying tests on popular consumer-grade UAV like DJI drones.

4. CONCLUSION

A light, low-cost both in purchasing and maintenance open architecture infrared sensing system would be a valuable to research in small-scale experiments and field tests. Furthermore, the system can pave way for innovations in micro-management in small business and agricultural productions. In this paper, we propose such system and our picks for its components. Basic imaging tests have been conducted and show potential for further developing. With the two simple calibration methods proposed, we would establish mathematical models for the system in our future researches.

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