Review of Light-weight Payloads for MAVs and Experiments with Thermopiles

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May 21, 2012

1 Introduction

This report investigates different payloads that could fit a small hovering indoor flying robot. First a review of useful equipment satisfying the strong weight constraint is realized, then work on a particular piece of equipment (thermal imaging sensors) is presented.

2 Review of <20g payloads

In this chapter, a short review of different equipment weighting less than 20 grams is performed. The targeted platform for these sensors, the AirBurr, is a 100g robot that will be able of robust autonomous navigation in cluttered indoor environments. The low-weight of the complete platform constrains the payload's weight to 20g. It will be assumed that the power source of the robot itself will be used to power the payload, so no battery is included in the systems investigated below. The payload is either an equipment enhancing the sensor suite of the robot for specific autonomous behaviors, or giving feedback to a remote human operator. If the sensors is meant to be used by a remote human operator, the transmission of the data will be considered. It will be assumed that data of reasonable transmission rate (<10kB/s) can be transmitted thanks to the wireless communication used by the robot. On the other hand, additional equipment will be investigated for data transmission of sensors requiring more bandwidth.

Different types of equipment are considered, that are mountable on a flying robot and that can be used in one of those applications:

- **Search and rescue**: Equipment targeted at finding humans in order to initiate a rescue mission.
- **Surveillance**: Equipment targeted at detecting hazardous phenomenon (fire, dangerous gas, suspicious human presence, ...)

(a) (b) (c)

Figure 1: (a-b) Two 2.5gr and 16g camera/transmitter sets from RC-tech providing respectively 320x240px and 480x360px video streams through analog 2.4GHz wireless communication.(c) A pair of glasses displaying a video feed to each eye to reproduce 3d vision when two cameras are transmitting images. This could help a human operator get a better sense of the surroundings of the remotely operated robot.

2.1 Vision

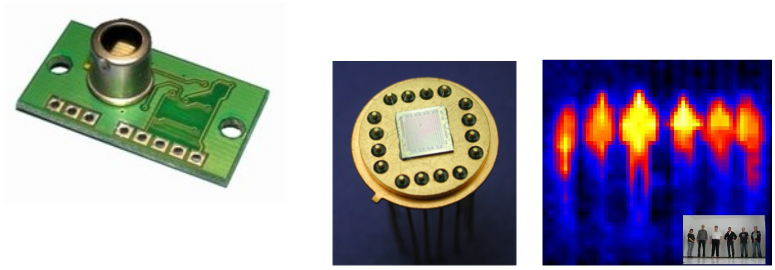
Vision is a major source of information for human operators guiding the robot and looking for interesting visual features in the environment. To convey images to a human operator, a camera has to be coupled with an addition wireless transmitter, as a video stream is too much data to be handled by the standard communication of the robot. Two solutions are available: analog or digital transmitters. The lightest solution is a digital camera coupled with an analog transmitter. For example, a 2.5gr set (see fig. 1(a)) can be found in the *RC-tech*[1] shop. Thanks to the small camera size and weight, several of them can be used on the same platform to achieve omnidirectional vision (with cameras placed all around), or stereo vision (with two cameras separated by a small distance looking in the same direction). Glasses such as the ones presented in fig 1(c) can be used by the human operator to see what the robot sees, and can even display the environment in 3D, by projecting one video stream to each eye.

Vision could also be used by the robot to achieve particular tasks autonomously if it were able to process the images. Such a setup requires more payload to account for the on-board image conversion and processing unit, which makes it currently impossible or very difficult to go below the 20g limit. Indeed, a linux board (required for the image processing) weights around 20g and compatible USB cameras around 10g, to which a WiFi dongle (8g) should be added if image transmission to an operator is desired. However, the weight of these components might decrease thanks to the fast advances in portable computers.

2.2 Infrared

Since common digital camera sensors also measure near infra-red (NIR - 2,500 to 750 nm wavelengths) intensity, similar hardware as shown in fig 1(a) can be used to take NIR images. These can be useful in various cases, as it provides

[1] `http://www.rc-tech.ch`



(a) (b) (c)

Figure 2: (a) A 7.8g sensor providing a 8 pixels thermal profile using pyroelectric materials (it is estimated that the weight can be reduced by half if miniaturization of the pcb is performed). (b) Similar thermal imager providing 32x32 pixels (weight unknown, but estimated to be similar to (a)). (c) Example of image that could be obtained by using four of these sensors, where the humans can clearly be detected as they are much warmer than the background.

additional information about the scene, as well as better visibility in some cases. No small enough NIR camera could be found on the market, but fairly simple methods[2] exist to replace the infra-red filter present in most lenses by a visible light filter, which allows to transform any common camera (such as the one in fig 1(a)) into a NIR camera. Night vision can be achieved with such a setup by using an infrared light source, but only short range can be achieved with the limited weight and power available for the light source.

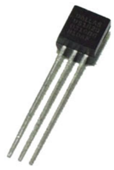
Measuring mid-infrared (10 to 2.5 μm wavelengths) can also provide very interesting information, as it is the frequency at which strong black-body radiations can be detected. Black-body radiations are emitted by any object and depend on temperature, which allow to use mid-infrared images for night vision or thermal imaging. This has numerous applications in security, surveillance or search and rescue as it could help detecting humans (as they are generally at a higher temperature than the environment), fire, or warm/cold airflows corresponding to a particular gas, etc. Detecting mid-infrared radiations require a quite different setup than traditional visible light imagers. High precision thermal imagers are quite complex (they use cooled infrared detectors in vacuum-sealed cases) and weight a lot more than the 20g limit, but light-weight systems using pyroelectric materials can be found. The pyroelectric materials generate a voltage when they are heated or cooled by the black-body radiations, and a low-resolution thermal image can be obtained if several pyroelectric parts are used. For example, the sensor from Devantech[3] shown in fig 2(a) provides a 8px linear profile of temperatures in a 41° x 6° field of view. This is one of the sensors that will be studied in more details in chapter 3. More precise sensors are becoming available thanks to miniaturization techniques, such as the small soon-to-be-released 32px by 32px thermal imager[4] shown in fig 2(b) which is very promising for

[2] such as presented here: `http://www.hoagieshouse.com/IR/`

[3] `http://www.robotshop.ca/devantech-8-pixel-thermal-array-sensor-1.html`

[4] From Heimann sensor: `http://www.heimannsensor.com`

(a)



(b)

Figure 3: Two extremely simple and light-weight sensors for air temperature measurement. Their principle rely on thermistors, which are resistors that change value with the temperature.

low-weight thermal imaging. The field of view depends on the lens that is used and can be adapted, and the low weight of these sensors make possible the use of several of them. Finally, they are simple enough to be used by the onboard computer to achieve autonomous behaviors based on their output, or to send the data back to an operator through standard communication.

2.3 Temperature

Temperature sensors can provide valuable information if the robot is sent in hostile environments, as it can indicate fire situations, etc. Very simple and light-weight solutions (below 1g) exist for air temperature sensing, as shown in fig 3.

2.4 Sound

A listening device might provide very valuable information when the mission is to search and rescue humans, who might be screaming or calling for help, or to detect suspicious noise produced by humans or machines. Several low-weight (below 1g) microphones exist, such as the one pictured in fig 4. For a microphone to be useful, the sound of the robot itself needs to be characterized and suppressed from the soundtrack. It is unclear how easy this process is, as the motor and propeller noise cover several ranges of frequencies, but it is thought to be feasible with a simple microcontroller such as the flight controller.

For better sound quality, the microphone could also be used when the robot is not flying but resting on the ground or attached to a wall. Also, to identify in 3D the origin of a sound, several microphones could be used. This would allow autonomous behavior based on the sound source location for example. In order to transmit the sound to an operator, a light-weight setup using analog wireless transmission like for video can be used (see fig 1(a)).

Figure 4: 1g microphone

(a) (b) (c)

Figure 5: Examples of gas sensors: a CO2 sensor (a), a smoke sensor (b) and a flammable/explosive gas sensor (c). Their exact weights are not provided, but they are estimated to weigh less than 20g according to their dimensions (diameters 12-19mm)

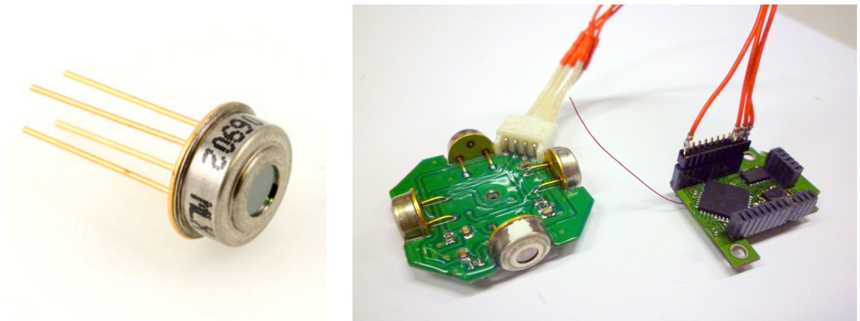
2.5 Gas

Several gases are of interest, as they can indicate human presence or dangerous situations (for example explosive gases, or smoke, etc.). A huge amount of gas sensors exist, which provide a large panel of solutions to choose from depending on the application, as shown in fig 5(a)[5], fig 5(b)[6] and fig 5(c)[7]. Various techniques are used in gas sensors, and most of them can be miniaturized in a package weighting less than 20g, such as electrochemical detectors, infrared point detectors and semiconductor detectors. The sensors can usually detect a large number of gases simultaneously and without differentiation, or can target only a specific gas if a porous membrane is used to let only the gas of interest reach the sensor. Gas sensors generally have a slow response time (up to 30s-1min), which makes them hard to use to measure gas in very local areas (such as CO2 produced by humans), especially if the robot is constantly moving. On the other hand, if the gas is present everywhere in the air, the constant airflow generated by the robot's propellers accelerates the sensor response time which makes a flying platform a very suitable mean of detecting gases or smoke.

[5]from: `http://www.futurlec.com/Gas_Sensors.shtml`

[6]from: `http://www.robotshop.com/seeedstudio-electronic-brick-mq2-smoke-sensor-4.html`

[7]from: `http://www.nemoto.eu/gassensors.htm`



(a) (b)

Figure 6: (a) The MLX90247 thermopile. (b) Connection to the Burrsens of the pcb.

3 Experiments with thermopile sensors

A thermal imager was selected as a very interesting and promising sensor to be carried by the AirBurr, as it would allow to localize humans in catastrophe situations, or follow them in surveillance tasks, or finally detect and find fires. Two main sensors were tested during this work, both using pyroelectric materials. These sensors are called thermopiles.

3.1 Single thermopiles

A first sensor was tested, to validate the idea that humans can be detected using thermopiles. This sensor is the MLX90247[8] from Melexis (see fig 6(a)), mounted on a PCB produced by FMA Direct. It was connected to the BurrSens board as shown in fig 6(b), and a graphical user interface was programmed in order to visualize the response of this sensor. It showed promising results, as humans could be detected up to a distance of 3 to 4 meters. It was observed that the signal is larger the closer the sensor is from the human. Also, that the background behind the subject plays a role: the colder it is, the better human detection will work (all experiments were performed at a room temperature of about 21°). The concept of thermopiles for human detection was validated, however a sensor with a more precise field of view (FOV) should be used to be really useful. Indeed, the MLX90247 has a FOV of about 90°, which might be enough to detect human presence, but not suitable to detect its location.

3.2 Thermopile array

The second sensor that was investigated is the TPA81 from Devantech (shown in fig 2(a)). This sensor provides a 8px linear profile of temperatures in a 41° x 6° FOV, which is precise enough to detect rather precisely where a hot spot

[8]http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail&name=MLX90247ESF-DSA-ND

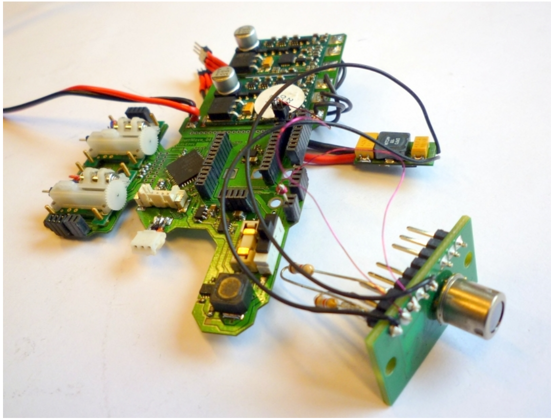


Figure 7: Connection of the TPA81 to the electronic board, and to the external voltage source.

is. It could not be connected to the BurrSens like the previous sensor because of voltage compatibility issues, and had therefore to be interfaced from another board (see fig 7). Also, an additional DC converter had to be built and connected to the TPA81 to supply the appropriate voltage. The communication with the TPA81 uses the I2C protocol and retrieves the temperature data at 25Hz from the sensor.

Figure 8 shows that a successful human detection and localization could be achieved, thanks to the temperature change between the human and the background. The FOV of each pixel seems to be appropriate for heat source localization, and it is expected that autonomous behavior of the robot could be achieved using this sensor (or a few of them to cover a larger FOV). It could for example be possible to detect humans in a room and fly toward them, or follow the closest (or warmest) hot spot. A technical issue still has to be solved at the time of this project: the communication of the data from the new electronic board (used to interface the sensor) to the BurrSens (the flight controller) has to be implemented in order to make the sensor fly. Steps were taken toward that direction, so that an autonomous behavior using a thermal sensor could be part of a future work.

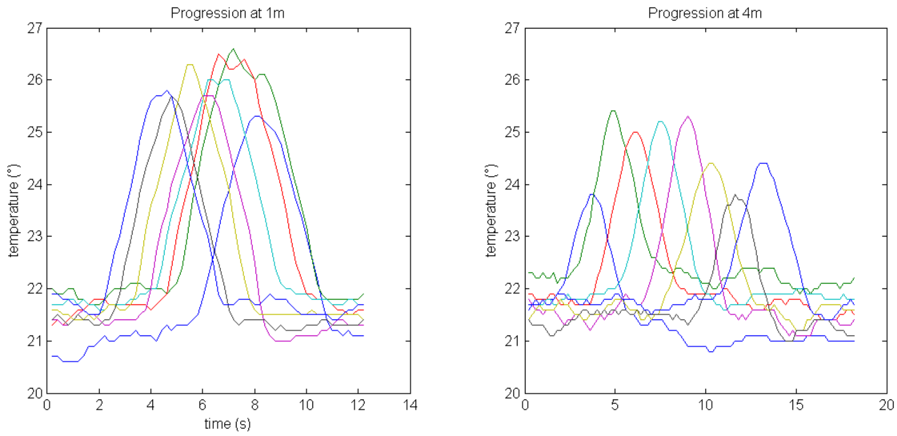


Figure 8: Response of the sensor when a human is walking in front of it at different distances. Each curve corresponds to the temperature one pixel senses along time. It can be observed that when a human walks at 1 meter from the sensor, it covers several pixels simultaneously whereas at 4 meters the person only covers a FOV of about two pixels. Furthermore, the human temperature sensed at 1 meter is higher (around 26°) than at 4 meters (around 24.5°). Distances higher than 4 meters could not be tested for practical reasons, but it is expected that this sensor would work at higher distances, especially with colder background (as the human detection relies on the detection of temperature difference with the background, which is around 21.5°in this case)