Automated Building Energy Efficiency Analysis
AggiE Challenge Project: Automated Energy Assessment of Building Envelope and Baseline Operation
Jerry Harlipin, David Johnstone, Daniel Whaley, Austin Wright
Cathy O'kman, Kevin Saygi

Introduction

The objective for our project is to construct a portable device capable of performing an autonomous energy audit of a building. Our team is composed of four senior mechanical engineering students, a sophomore computer engineering student, and a freshman electrical engineering student. By working in a multi-disciplinary team we are able to effectively tackle the software, hardware, and logistics concerning this project. The senior mechanical engineering students are able to provide guidance to the underclassmen in regards to certain engineering and design considerations. This semesters goal’s were to effectively design and organize this project. A major goal was to select and make design decisions on the required sensor package and vehicle required to meet our objective. We have ordered all of the equipment necessary to construct and begin testing our concepts. Overall this semester has remained on schedule and we have successfully achieved our preliminary objectives.

Vehicle Selection

One of the initial design decisions that needed to be made was the vehicle that would be responsible for transporting our sensor package. A previous AggiE Challenge team utilized a hexacopter which we took as a proof of concept. However we made the decision to use a quadcopter which is more feasible for our projects needs and its selection allowed for more time and resources to be allocated to the sensor package.

In order to collect the required information to meet an energy audit’s usual standards several sensors had to be integrated and configured in a logical fashion. Each sensor is utilized in a way that is feasible for collecting the required data streams.

Sensors:
- Temperature and Humidity Sensor Pro-
  - Space Temperature- needs to be determined in order to detect if the room set point is being met.
  - Relative Humidity- needs to be determined in order to find the amount of moisture present in the air for a comparison to the dehumidification quality required of a client.
- Supply Air Temperature- needs to be determined in order to see if the Air Handling Unit (AHU) is meeting temperature levels to heat or cool the space.
- Light Intensity Sensor-
  - Space Lighting- need to determine the lighting present in order to require the lights that are appropriate for a given space.
- PIR Motion Sensor-
  - Occupancy- needs to be determined in order to detect if the room set point is being met.
- Reflectance Sensor-
  - Roof Reflectance- needs to be determined in order to estimate the energy absorption through radiant sunlight and ambient temperature.
- Carbon Dioxide Sensor-
  - Carbon Dioxide Levels- needs to be determined in order to detect if the Carbon Dioxide is at a level which would not be appropriate for a given space.
- Thermal Camera-
  - Window Insulation/Fenestration- needs to be determined in order to check building envelope integrity and the occurring heat transfer.

We are planning to have some of the sensors taking measurements continuously throughout the flight while others will only do so periodically at specified times.
- Space Temperature, Relative Humidity- An average will be taken of a continuous data stream that is collected from a perimeter flight.
- Supply Air Temperature- This data will be collected when the position is directly under a supply air vent.
- Light Intensity- Data will be collected at locations throughout a room which require sufficient light, i.e. auditorium stage lighting, front of a classroom, above workspaces, etc.
- Occupancy- Readings will be taken when the occupancy meter is in a stationary position.
- Reflectance- Data will be collected when the hexacopter is landed on the roof.
- Carbon Dioxide- An average will be taken of a continuous data stream that is collected while flying.
- Thermal Camera- Pictures will be taken of the building envelope and will require calibrating when images are taken.

The thermal images taken will be analyzed using a MATLAB program we created. Adjacent pixels are compared to try and determine if significant temperature differences are present. Colored dots are placed in regions of concern depending on the magnitude of the difference. MATLAB was chosen to perform the analysis because of its built in image toolbox and the familiarity the team has with the programming language.

Data Collection and Processing

Energy auditing a building often requires several workers. These workers must spend a few hours on site taking readings of various parameters around the building such as temperature, carbon dioxide, and lighting levels. Following the site visit more time must be spent processing the data to make recommendations on how to make improvements to the buildings energy operations. Through the creation of vehicles that are capable of autonomously performing energy audits many man-hours can potentially be saved. As technology continues to develop, sensors and other devices used will become smaller and cheaper eventually leading to such vehicles becoming more common and widely available. The intent is to use multiple vehicles and create increasingly smaller UAV’s which will continually automate the energy auditing process resulting in a cost effective, time saving method. Other developments in the future will hopefully include: autonomous navigation, and in flight data processing.

Next semester our intention is to develop the necessary programs, implement those programs and begin testing. There will be a significant amount of iteration as we work towards optimizing the design to work as well as possible.

Vehicle Selection Rating Matrix – Pugh’s Method

<table>
<thead>
<tr>
<th>Vehicle Selection Rating Matrix – Pugh’s Method</th>
<th>Drone</th>
<th>Octocopter</th>
<th>Airplane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight Acceptance</td>
<td>Drone</td>
<td>Octocopter</td>
<td>Airplane</td>
</tr>
<tr>
<td>Manoeuvrability</td>
<td>Drone</td>
<td>Octocopter</td>
<td>Airplane</td>
</tr>
<tr>
<td>Ability to Silence Wind</td>
<td>Drone</td>
<td>Octocopter</td>
<td>Airplane</td>
</tr>
<tr>
<td>Vertical Movement</td>
<td>Drone</td>
<td>Octocopter</td>
<td>Airplane</td>
</tr>
<tr>
<td>Capabilities</td>
<td>Drone</td>
<td>Octocopter</td>
<td>Airplane</td>
</tr>
<tr>
<td>Space for Additional Hardware</td>
<td>Drone</td>
<td>Octocopter</td>
<td>Airplane</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Drone</td>
<td>Octocopter</td>
<td>Airplane</td>
</tr>
</tbody>
</table>

The diagram above shows the interactions between various hardware components. The Grove Shield is a device that allows plug and play capability for three of our sensors. The Grove Shield is compatible with the Arduino Mega which allows for additional sensors that aren’t necessarily plug and play to be utilized. The Arduino platform was selected due to its simplicity, open-source environment, compatibility with a variety of sensors, and cost. Everything flows towards the Raspberry Pi which allows for additional devices not compatible with Arduino to be used. The thermal camera we selected is able to plug into the USB port on the Raspberry Pi. Additionally the Raspberry Pi has an SD card slot which will be utilized to store all sensor data. The battery selected meets the required voltages of all of the components and can be reduced where necessary. The energy storage capabilities should be enough for a sufficient flight time.

Future Work

Next semester our intention is to develop the necessary programs, implement those programs and begin testing. There will be a significant amount of iteration as we work towards optimizing the design to work as well as possible.

Acknowledgements

Sponsor: AggiE Challenge, Dr. Rasmussen
AggiE Challenge Mentor: Christopher Bay
Senior Design Studio Instructor: Yevai Doron
Image References:
Temperature and Humidity Sensor, Motion Detection Sensor, Ambient Light Sensor, Grove Shield, www.seeedstudio.com
Light Reflectivity Sensor, www.polytech.com
Thermal Image, www.sheerstudio.com
Thermal Camera, www.topcom.com
Raspberry Pi, www.raspberrypi.co.uk
Arduino-Mega, www.makergr.co.nz
Carbon Dioxide Sensor, www.sandvogeltechnik.com
SD Card, www.sandvogeltechnik.com
Battery, www.rcxmodels.com

Sensor Package Hardware

The diagram above shows the interactions between various hardware components. The Grove Shield is a device that allows plug and play capability for three of our sensors. The Grove Shield is compatible with the Arduino Mega which allows for additional sensors that aren’t necessarily plug and play to be utilized. The Arduino platform was selected due to its simplicity, open-source environment, compatibility with a variety of sensors, and cost. Everything flows towards the Raspberry Pi which allows for additional devices not compatible with Arduino to be used. The thermal camera we selected is able to plug into the USB port on the Raspberry Pi. Additionally the Raspberry Pi has an SD card slot which will be utilized to store all sensor data. The battery selected meets the required voltages of all of the components and can be reduced where necessary. The energy storage capabilities should be enough for a sufficient flight time.