Flare Emission Measurement and Mitigation Technologies: Air Emissions Technology Testing

Appendix H: Air Quality (Task 5.3.6)
H.3 Flare Emission Measurement and Mitigation Technologies Testing

Final Report
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Research Assistants: Travis Burks, Brian Musslewhite, Trent Tate
1 PROJECT SUMMARY

The objective of this project was to assess the technical feasibility of collecting air quality data from an unmanned aerial vehicle (UAV). The motivation behind the project is to determine the quality of the air being emitted from oil field operations. The research team successfully demonstrated that a gas monitor with multiple gas sensors could be attached to a UAV and flown in the proximity of oil field equipment; however, the gas monitor used in the project was not able to detect any gas emissions during the field trials. This report provides details on the research conducted, which included the following tasks.

- Flight Testing of a UAV mounted with a gas emissions monitor
- Literature Review of scientific studies specific to flying UAVs in the oil and gas industry
- Patent Search and review of similar technology was identifying gas emissions
- Laboratory Testing of gas emission monitor used in flight tests
- Development of a Flight Path Algorithm for sampling gas emissions
- Investigation of Thermal Camera Options for identifying and mapping a gas plume

2 RESEARCH TEAM

The research team consisted the principal investigator, Dr. Dale Cope, two graduate research assistants, Travis Burks and Brian Musslewhite, and one undergraduate research assistant, Trent Tate.

- Dr. Dale Cope – Dr. Cope is an Associate Professor of Practice in the Mechanical Engineering Department at Texas A&M University. Dale served in the Air Force for 30 years working as a structural engineer on various aircrafts, aircraft maintenance officer, and university professor. Dale served as the principal investigator on the project and provided expertise on UAVs.
- Travis Burks – Mr. Burks is a graduate student in the Department of Agriculture, Leadership and Education. Mr. Burks has experience in the agriculture industry, and he served as the lead UAV pilot.
- Brian Musslewhite – Mr. Musslewhite is a graduate student in the Department of Aerospace Engineering. Mr. Musslewhite has experience with developing flight control algorithms, and he assisted the team with flight mapping, planning and operations using the UAV.
- Trent Tate – Mr. Tate is an undergraduate student majoring in Electronic Systems Engineering Technology. Mr. Tate has experience with UAVs and designing electronic systems. He assisted with the planning and operation of the UAV during the field trials.
3 FLIGHT TESTING

A multi-rotor UAV was chosen as the vehicle of choice for the field trials due to its ability to hover in one specific location for extended time periods. This flight characteristic allows data to be collected at precisely known GPS coordinates and provides access to congested locations. Figure 1 shows the specific multi-rotor UAV used in the field trials with the gas monitor mounted on it. As seen in Figure 1, a camera can also be mounted to the UAV, but the major limiting capability of the UAV for this application is its payload capacity of 1.7 pounds.

![Multi-Rotor UAV with Gas Monitor](image)

In order to collect gas emission data, the concept was to mount a gas sensor payload to the UAV, and then, fly the UAV within the area of gas emissions. Therefore, the research team reviewed several commercially available gas monitors that are suitable for integrating on a small UAV. In addition to having the capability to sample air and identify gas emissions, such as Volatile Organic Compounds (VOCs), the gas monitor needed to weigh less than 1.7 pounds. Examples of suitable gas monitors are thermal imagers from FLIR, the Tiger hand-held VOC detector from Ion Science, and the GDC-150/350 gas sensor transmitter and monitor from Bacharach. Some of these monitors weighed more than 1.7 pounds, but they all weighed less than 5 pounds, which could be suitable for a small UAV with a larger payload capacity.

The handheld gas sensor chosen for the flight testing was the Ion Science Leo gas monitor. This robust, portable multi-gas monitor allows for measurements of 4 to 5 different gasses at once, and it has a pump that draws air over the sensors. It also only weighs only 0.9 pounds. While sensor options are available, the specific gas sensors installed on this monitor included sensors for measuring VOCs, oxygen (O₂), hydrogen sulfide (H₂S), and carbon monoxide (CO). As shown
in Figure 1, the gas monitor was mounted to the top of the aerial vehicle, and a hose extension could be attached to the pump inlet extruding horizontally into the air. The hose extension was added during flight testing in an attempt to access undisturbed air and minimize the interference from the propeller wash.

Field Trials of UAV with Gas Monitor

As shown in Figure 2, initial flights of the UAV with the gas monitor demonstrated that the UAV could definitely carry the payload, and it did not have any degradation into its flight handling qualities due to the gas monitor. Therefore, the research team quickly moved to conducting flight tests in actual oil and gas fields with active flares.

![Figure 2 – Multi-Rotor UAV with Gas Monitor (in flight)](image)

In order to assure that the gas monitor would capture measurements within emission plume, a grid of locations creating three walls, each with three different altitudes, was constructed as a flight path. This flight path was set up on the downwind side of the flare being examined. While in flight, the UAV was programmed to continually point towards the flare in order to provide consistency in data collection. An example of the flight grid is illustrated in Figure 3.

A total of fourteen flights, listed in Table 1, were conducted to collect air emission data from actual well pad sites with active flare activity or equipment operations. Four of the flights occurred at SHAPE ranch, and ten of the flights occurred at the AgriLife Research Farm. The locations of each emission source are shown in Figure 4.

These preliminary flight tests, specifically the ones at SHAPE Ranch, showed that the gas monitor did have intermittent measurements of gasses while the monitor was in-flight and attached to the UAV. However, these measurements were not reliable enough to come to a definitive conclusion that the monitor was picking up actual measurements from a gas plume or giving false positives of readings because the readings would occur randomly during the flights. Based on these preliminary and inconclusive test results, the research team decided to conduct further research into similar technology for gas emissions measurements and conduct a controlled laboratory test of the gas monitor.
Figure 3 – Flight Grid for Gas Emissions Sampling

Figure 4 – Gas Emission Sites for Field Trials

(a) Shape Ranch  
(b) AgriLife Research Farm
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Location</th>
<th>Coordinates</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/19/2015</td>
<td>11:07 AM</td>
<td>Research Farm Front Site</td>
<td>30.541753, -96.430042</td>
<td>Initial test flight, readings once a minute, no conclusive data</td>
</tr>
<tr>
<td>6/19/2015</td>
<td>2:16 PM</td>
<td>Research Farm Back Site</td>
<td>30.535327, -96.419300</td>
<td>Readings once a minute, no conclusive data</td>
</tr>
<tr>
<td>6/25/2015</td>
<td>10:34 AM</td>
<td>Research Farm Front Site</td>
<td>30.535327, -96.419300</td>
<td>Readings every 5 seconds; light readings of VOC, H₂S and CO over first minute, intermittent afterwards</td>
</tr>
<tr>
<td>6/25/2015</td>
<td>10:58 AM</td>
<td>Research Farm Front Site</td>
<td>30.541753, -96.430042</td>
<td>Readings every 5 seconds; light readings of CO at beginning of flight and midfield</td>
</tr>
<tr>
<td>6/30/2015</td>
<td>9:28 AM</td>
<td>Shape Central Main</td>
<td>28.347700, -100.090816</td>
<td>Readings every 5 seconds; moderate VOC &amp; CO, light H₂S at beginning of flight, intermittent afterwards</td>
</tr>
<tr>
<td>6/30/2015</td>
<td>10:13 AM</td>
<td>Shape Central Minor</td>
<td>28.347750, 100.092194</td>
<td>Readings every 5 seconds; moderate VOC &amp; CO, light H₂S at beginning of flight, intermittent afterwards</td>
</tr>
<tr>
<td>6/21/2015</td>
<td>11:18 AM</td>
<td>Research Farm Back Site</td>
<td>30.535327, -96.419300</td>
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<td>6/21/2015</td>
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<td>6/21/2015</td>
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</tr>
<tr>
<td>6/21/2015</td>
<td>3:49 PM</td>
<td>Research Farm Back Site</td>
<td>30.535327, -96.419300</td>
<td>No data recorded</td>
</tr>
<tr>
<td>7/2/2015</td>
<td>10:22 AM</td>
<td>Research Farm Back Site</td>
<td>30.535327, -96.419300</td>
<td>Readings every 5 seconds, no emissions detected</td>
</tr>
<tr>
<td>7/2/2015</td>
<td>1:57 PM</td>
<td>Research Farm Front Site</td>
<td>30.541753, -96.430042</td>
<td>Readings every 5 seconds, heavy CO, moderate VOC and light H₂S at beginning of flight; intermittent light CO after beginning</td>
</tr>
<tr>
<td>7/2/2015</td>
<td>8:53 AM</td>
<td>Shape Central Main</td>
<td>28.347700, -100.090816</td>
<td>Readings every 5 seconds, moderate VOC, O₂ alarm mid-flight with light CO, light CO &amp; VOC throughout flight</td>
</tr>
<tr>
<td>7/2/2015</td>
<td>10:30 AM</td>
<td>Shape Southern</td>
<td>28.316661, -100.091096</td>
<td>Readings every 5 seconds, moderate CO, light VOC &amp; H₂S at beginning of flight; light CO near end of flight</td>
</tr>
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</table>

4 LITERATURE REVIEW

Many industries are considering the use of UAVs in their commercial operations due to the low cost of operating UAVs and the multitude of potential uses for this new technology. In the oil and gas industry, they are being explored for many forms of data collection such as surveying and infrastructure inspections.\textsuperscript{1,2} However, very limited interest has been explored in using UAV’s for gas emission analysis.

In the research literature, it has been concluded that the impact of flare gas emissions can be significant, and a substantial need exists for accurately measuring what is being released into the atmosphere.\textsuperscript{3} Furthermore, it has been shown that prolonged exposure to flare emissions can cause undesired health effects, such as deterioration of hematological parameters.\textsuperscript{4}

Although not much interest has been expressed in analyzing flare stack emissions, scientists have significant interest in sampling gases from volcanoes using UAV’s.\textsuperscript{5-7} In addition, the National Oceanic and Atmospheric Administration (NOAA) has used UAV’s to detect specific gases in the atmosphere.\textsuperscript{8} These projects help to validate the feasibility of using a UAV to detect airborne particulate matter.

5 PATENT SEARCHES

In addition to the literature review, the research team investigated patents related to flare stack inspections and collecting gas emissions data in the oil and gas industry. Utilizing Texas A&M University Libraries resources, the research team identified several patents pertaining to UAVs for commercial applications in the oil and gas industry. However, many of these patents are filed in China, and none of them pertained to measuring gas emissions.

6 LABORATORY TESTING

Due to inconclusive field trials, the research team conducted a controlled gas emissions test in the laboratory in order to verify the capability of the gas monitor to detect emissions. Utilizing the Combustion and Reaction Characterization Laboratory at Texas A&M University, the team tested the reliability and accuracy of the Leo gas monitor under controlled conditions with a known gas source at a known emissions rate. The purpose of the tests were to measure the reliability, response time, and ability of the Leo gas monitor to read gas emissions of a controlled gas at a known flow rate and distance from the monitor.

As shown in Figure 5, the Leo gas monitor was tested in a laboratory fume hood for control and safety measures with the gas being emitted through a tube placed below the tube attachment on the gas monitor. Nitrogen, Isobutylene gas, and pure Oxygen were used to test the different sensors installed in the Leo. Each gas had a 5% concentration (50,000 ppm), and they were released at a flow rate of one liter/minute in order for the gas monitor to detect the emission.
Throughout the testing, the Leo gas monitor was measured at various heights above the source of the gas emission in order to test the impact of the gas displacement on the monitor’s capabilities. The purpose of this testing was to verify that the monitor could detect the gas emission regardless of the distance from the source of the emission. The Leo gas monitor was only able to detect the gas if the emission source was placed directly into the tube leading to the gas chamber of the monitor. Otherwise, it would not give any readings of a gas emission.

Therefore, the research team decided to test the pull rate of the pump inside the Leo gas monitor. Using a Gilibrator flow meter, shown in Figure 6, attached to the Leo gas monitor, the research team determined that the pump pull rate was not strong enough to draw the gas into the sensor chamber unless the emission source was directed into the tube.
As an alternative to the Leo gas monitor, the research team also tested the Ion Science Cub Personal PID Gas Monitor. The Cub is a personal photoionisation detection (PID) gas monitor for the fast, accurate detection of volatile organic and total aromatic compounds. While the Cub provides a warning when a VOC gas exceeds a specified level, it does not provide the capability of measuring and recording the level of the gas emission. The laboratory test verified that the Cub was able to detect displaced gasses. As shown in Figure 7, a tube is emitting the gas at the bottom of the fume hood, and the Cub is able to detect this emission a couple of feet above, as indicated by the red lights on the Cub when the alarm is triggered. These preliminary test results show that the Cub PID gas monitor can detect displaced VOC gases, but the research team would need to complete more testing in order to validate the capability of the Cub to measure actual concentration levels within and around a known gas emission.

Based on the laboratory test results, the research team concluded that, as currently designed and manufactured, the Leo gas monitor is not sufficient or able to detect displaced gases at any distance from a known emission source. The gas emission must be directly flowing into the pump and sensor chamber. Therefore, it is not currently suitable for use on a UAV for measuring gas emissions. The Cub, on the other hand, showed the capability to detect displaced VOC gasses, but it does not the ability to measure concentrations levels. While the technology currently exists to measure gas emissions using UAVs, re-design of gas sensors and their integration into the UAV need to be completed in order to effectively and accurately measure gas emissions.

### 7 Flight Path Algorithm

One outcome of the research project was the development of a flight path algorithm that takes into account the location of the emission source and the wind direction. In order to quickly set up a flight plan with appropriate locations for taking gas measurements, the research team developed an algorithm for writing a mission plan for the UAV. The inputs to this algorithm are simply the latitude and longitude of the emission source as well as the wind direction. Based on these inputs, the algorithm provides an output file with the appropriate flight path for the UAV to take gas measurements at multiple, precise locations downwind of the emissions source. This output file can then be written to the UAV in order to fly the prescribed flight path. Figure 8 illustrates an example of this output for a known GPS location with a Southwest wind.
8 Thermal Camera Options

One sensor option that was not tested in this research project, but could be useful for mapping a gas plume, is the use of a thermal camera in conjunction with a gas emissions monitor while attached to an UAV. Integrating an thermal camera onboard an UAV could provide a real-time visual representation of the gas emissions plume in the infrared spectrum allowing for a better means of deciding where precisely to fly the UAV for measuring the gas emissions. A thermal camera would allow the operator to do a quick survey of the area, and based on the video footage, determine which piece of infrastructure or equipment is emitting gas and the exact location of the emission.

FLIR currently manufactures two thermal infrared cameras that can be integrated with commercial UAVs. Shown in Figure 9, these two cameras are the FLIR Vue and FLIR Tau2.
The two cameras have different tradeoffs between each camera. The Tau2 can handle hotter situations as it has a larger temperature operating range. The Vue has a slightly larger weight than the Tau2, and it has a center of gravity (CG) that is further forward on the camera body. The forward CG location may hinder UAV operations depending on the weight and payload requirements. The Vue has fewer lens options than the Tau2, but both cameras have zoom capability. Both cameras also have a resolution of 640x512 pixels. The Vue is designed specifically to be integrated with UAVs much easier than the Tau 2. The Tau2 has been commercially available longer, and therefore, hobbyists have integrated the Tau2 into their personal UAVs. However, the Tau2 is not currently integrated with any commercially available UAVs. The Vue was just released in summer of 2015 and can be purchased already integrated into popular UAVs, such as the DJI Inspire with live streaming capabilities.

9 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the flight and laboratory testing, the research team has come to the following conclusions and recommendations.

- A small gas monitor with multiple sensors CAN be mounted onto a UAV and flown in the proximity of a gas emissions source.
- The issue of air displacement caused by “prop wash” from the rotors of the UAV would need to be addressed when taking actual gas measurements.
- Based on the literature review and patent search, the use of UAVs for gas sensing and monitoring has not been commercialized yet.
- While the Leo and Cub gas monitors have the capability of detecting gas emissions, neither one proved suitable for use on an UAV.
The Leo gas monitor was not able to intake gas at a high enough volume in order to detect the gas unless the emission source was directly applied into the gas chamber without much assistance from the pump within the monitor.

The Cub gas monitor was able to detect displaced gas, but it only has the capability to detect VOC gases. It also was not able to provide recordings of concentration levels.

- Using available electro-chemical and PID sensors, a gas monitor with multiple sensors could be integrated into a UAV for use in remotely detecting gas emissions.
- Integration of a thermal camera with the UAV could also prove useful in mapping and measuring gas emissions from a known source.

10 References