

Sustainable and Portable Vertiports Enabling Autonomous Drone Swarm Inspection in the Oil and Gas Industry

Fahad Mannan¹, Jorge Quiroga², Logan Moore³, Sihua Shao⁴, Xiang Sun⁵,
Mostafa Hassanalian⁶

The aim of this paper is to showcase the work that has been done and the planned path that the STEER (Sustainable verTiport framework for autonomous drone swarm methane emission measurement over orphaned wells) project will take. The goal of STEER is to develop an autonomous system that is isolated and assists in locating hard to reach orphaned wells. Using drones is a cost-effective method in locating and plugging up these wells to reduce the emissions of greenhouse gases into the atmosphere. This system will need to detect methane (CH₄) to find abandoned wells out in the environment. The system will consist of a vertiport system that will be bio inspired from trees and the drone swarm that will head out to do surveys to find orphaned wells. The vertiport will house and charge the drones via contact pads, but will also ensure that the environment is safe to fly in before sending the drone off on a mission. The drones themselves will need to be driven by a ROS software making it possible to autonomously take off, survey, then return to the vertiport for landing.

I. Introduction

Using drones for measurement and quantification of methane emission is not new, but has become more common [1-10]. The purpose of this study is to design a fully autonomous system that is both portable and sustainable for a swarm of drones to identify and measure methane emissions on difficult to reach regions. The name of this system is called STEER, and is composed of 2 different parts. The first one is the vertiport and the second one is the drone swarm. Each playing a part in the project to accomplish the goal of detecting sources of methane due to orphaned wells.

The vertiport is the main tree-like structure of the system, and is where the drones will be housed and charge via a contact base charging system [11-16]. The structure of the vertiport is bio inspired by a tree. Housing for the drones will be located at the branches of the vertiport. While the main computing system and the battery are located at the trunk near the bottom. Lastly the vertiport is self-sustainable via the use of solar panels with actuators for positioning at the top, but this is not the only component that is located at the top of the vertiport. The weather station is at the center of the four solar panels sending information down to the main computing system.

The drones are the second part of the system, where they are the main component that is used to detect and locate the sources of methane. The drones are required to be autonomous throughout the entire mission

¹ Graduate Student, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM, 87801, USA.
² Undergraduate Student, Department of Electrical Engineering, New Mexico Tech, Socorro, NM, 87801, USA.
³ Undergraduate Student, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM, 87801, USA.
⁴ Assistant Professor, Department of Electrical Engineering, New Mexico Tech, Socorro, NM, 87801, USA.
⁵ Assistant Professor, Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque, NM 87131, USA.
⁶ Associate Professor, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM, 87801, USA.

that it is sent in. The software used to have the drones automated is ROS (Robot Operating System). ROS is a set of libraries and packages that allow the development of robotic application software using C++ or Python. ROS is just the middleware that allows different components to work together as one from sensors to the motors and to the computer onboard the drone.

II. Background and Setup

The vertiport is a portable, sustainable and robust solution to sheltering drones in different environmental conditions. One of the design criteria was that the structure should ideally be deployable by two people. The system employs simple deployment mechanisms and a light weight mobile aluminum structure to achieve the intended simplicity. The Vertiport structure utilizes telescoping sections that allow for adjustment on both the base and height of the structure. Along the main telescoping trunk of the structure sits two mounting brackets for the branch system. The branch system is for capsule attachment, this elevates the capsules from the ground for dust mitigation and security. The capsules serve as a habitat for the drone creating protection from the elements as well as charging the drone. The main challenge in housing drones autonomously is the landing procedures due to environmental factors and landing precision [17, 18]. To accommodate this need and reduce the required precision of the drones, the solution entailed a dynamic platform for landing and centering. This mechanism is a platform that expands upon the opening of the capsule lids, this doubles the landing and takeoff area. Upon the closing of the capsule lid the platform serves as a centering mechanism that will nudge the drones to the center and onto the charger. Finally, the main purpose of the capsules is to protect the drones and charging pads from external elements (rain, winds, and dust). below are examples of the capsule design:

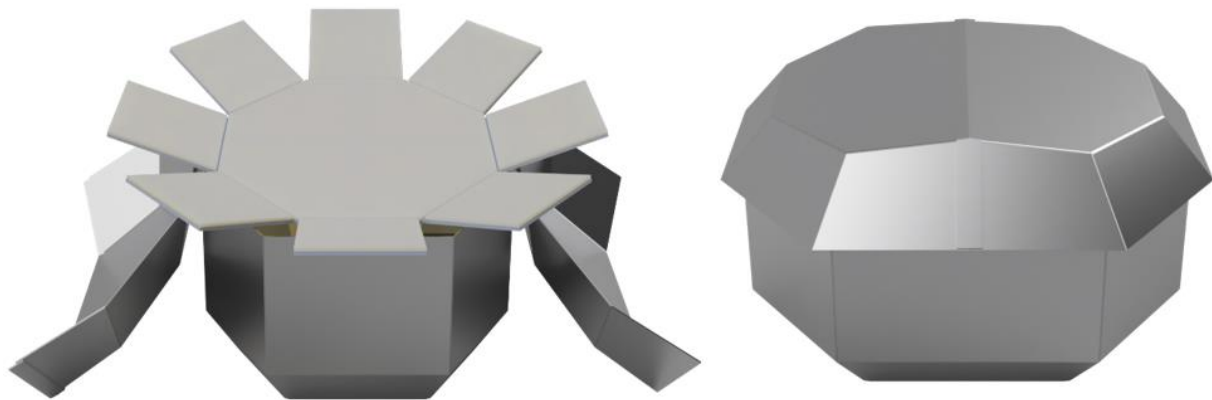


Figure 1. Capsule design.

The power grid of the vertiport will be also sustainable by using solar panels to generate the energy needed to run the system. Extra power generated by the panels will be saved to the power bank. The power bank will ensure that the system won't power off during cloudy days or during the night. The isolated grid of the vertiport will be powering the charging system for the drones and the main computing system connected to the weather station. The solar panels and weather station will be located at the top of the vertiport; the power bank and computing system is located near the base. The charging system will be located near the middle of the vertiport connecting to the pads at the branches inside of the capsules holding the drone. Below is a view of the current vertiport design and prototype.



Figure 2: Full vertiport

The tall structure of the Vertiport presented some challenges, particularly due to the central pole extending upwards of 21 feet, which generates a significant tilting force. It is crucial that the structure does not reach a critical load under any wind loading conditions. To determine the load on the structure due to wind, COMSOL was used to simulate these conditions (see Figure 3(a)). Figure 3(b) illustrates the model in the software after it has been wind loaded. Although the solar panels are not visible in the figure, their impact was pre-calculated to determine the point load at the top.

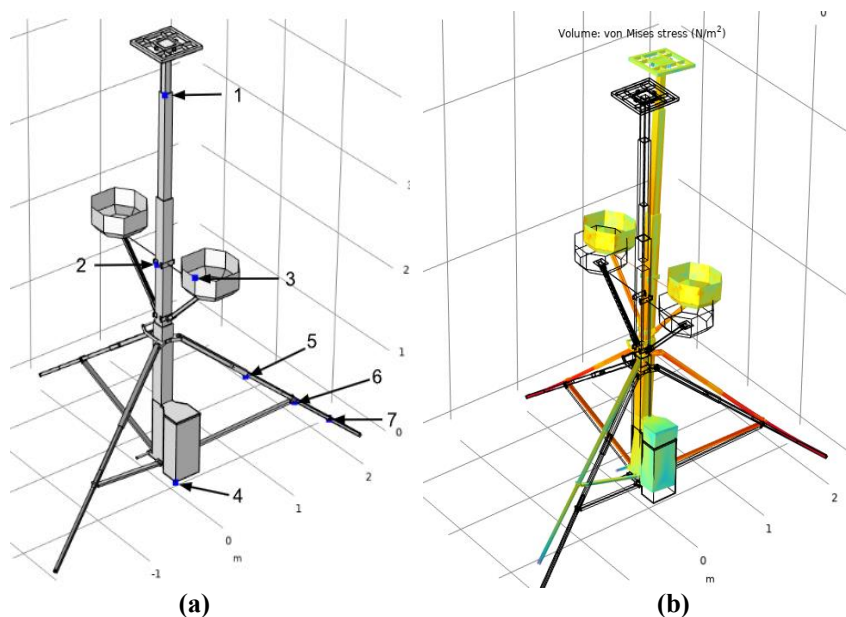


Figure 3. Views of (a) point distribution and (b) deflection from wind load

In the simulation, the model was positioned with its widest cross-section facing the wind to create the largest tipping force. The results indicated that the structure would fail at a wind speed of 30 m/s (67.1 mph). While this is within acceptable limits, it can be further improved by using stronger materials for the telescoping legs.

Table 1. COMSOL results; tabulated displacement and stress, gravity applied and 30 m/s (67.1081mph) wind loading

Point	Displacement in x (m)	Displacement in y (m)	Displacement in z (m)	Von Mises Stress (N/m ²)
1	4.16E-01	2.70E-01	0.12864	7.36E+05
2	2.12E-01	1.40E-01	0.1255	1.77E+06
3	2.54E-01	1.69E-01	2.15E-01	3.12E+06
4	-2.96E-02	-1.46E-02	0.16679	1.29E+05
5	5.81E-02	4.13E-02	0.057984	1.01E+07
6	1.99E-02	1.53E-02	0.020503	3.86E+07
7	4.61E-03	3.78E-03	0.0046386	1.46E+08

The drone portion of the project is the mobile portion, giving us the ability to survey the region for methane. The software used to ensure effective use of the attached sensors both internal (IMU/GPS) and external (gas sensors) is ROS. What ROS does is break down the different parts of the system (software/hardware) into nodes, where each node handles different aspects of the drone in an effective manner. Another benefit in learning and applying ROS is the fact that later down the project, an extra component needs to be integrated into the drone; it becomes easy to change or add an extra node for the component. Yet the complexity for learning ROS is an entirely different story, as one has to be proficient in robotic operations, programming, and Linux operating systems; hence the steep learning curve is the most difficult to overcome in the process of developing an ROS program.

The model and type of drone used for the project is called the m500 development drone (refer to Figure 5). The hardware that the drone is equipped with allows the use of ROS, TensorFlow lite, and PX4. The major component that allows the use of these programs is the Qualcomm Snapdragon-based voxel computer. In the region where the vertiport is deployed, there are different methods of navigation that takes advantage of the VIO GPS-denied navigation.

Once the drone is done with its mission or needs to be charged, the drone will return to the vertiport then precisely land on the capsule's pad using the software of TensorFlow lite CNN (convolutional neural network) to detect a QR code with a specific ID number. Once the drone has a clear view of the QR code, the drone will then measure and calculate the needed directions to maneuver towards the landing pad using the orientation of Roll, Pitch, and Yaw. Below is a picture of the drone used in the project:

In total, the amount of ROS nodes needed for the entire drone system is 3. The first will be in charge of controlling the drone's movement, and the second will be taking GPS/VIO/CNN data then post the required maneuvers for the first node. Finally the last node will be the data collection and management of the Arduino circuit for the methane gas sensor. This planned structure is subject to change later down the line, but this is the basic structure of the ROS nodes. The major issues that our team ran into is the fact that the drone is limited to ROS 1, limiting the use of the latest, more supported, version of ROS.

III. Result and Discussion

The Vertiport development project has made significant advancements, including weather station development, capsule design, and solar panel mounting and deployment systems. The entire system is engineered to withstand harsh environmental conditions, ensuring long-term deployments. The current implementation of the capsule onto the Vertiport structure has been successful, allowing for comprehensive testing. Although the first iteration of the capsule faced challenges with reliable actuation due to its many moving components, subsequent designs have improved its performance.

The weather station development is centered around the Raspberry Pi processing system and includes an anemometer, barometer, rain gauge, and wind direction sensor. These instruments enable drones to determine the downwind direction for aligning with methane plumes. Given the rugged conditions the Vertiport is designed for, confirming its ability to withstand allowable wind loads is crucial. Tests and simulations have demonstrated that the branches, capsules, and Vertiport structure can endure high wind

loads, ensuring reliable deployment in rural areas. The deployment system has been rigorously tested and proven effective, with setup procedures frequently practiced. The system can be safely deployed by two people. Its telescoping feature, utilizing a pulley system, allows the main trunk to be raised to its full length by simply turning a handle.

To ensure that the vertiport isolated electrical grid is sustainable and reliable, there has been extensive experimentation on the solar panels, power bank, and the contact-based charging system. Each component was initially tested individually to see the power consumption of the charging system for a single drone battery, and the power production of the solar panels throughout the day. With the final test confirming that the electrical grid can work all together as a single system. The conditions for the initial tests were not optimized to produce the most power. Each test during the experiments the solar panels were laid out flat instead of being perpendicular to the sun's wavefront. This effectively cut the power production in half. The first test was to measure the output of a singular panel. The plotted data showed what was expected, a sinusoidal structure where the peak was at noon (the highest point where the sun was at the center).

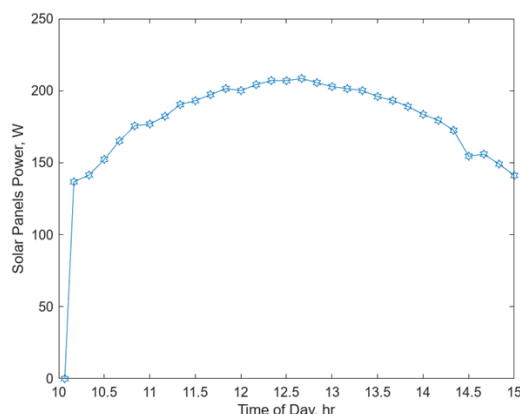


Figure 4. Plot of the solar data throughout the day; power .

The contact-based charging system is the main component that will draw the most power from the grid, close to 80 watts for the drone battery chosen for the experiment. Yet the charger can draw up to 750 watts. Another known issue is the conversion of DC to AC back into DC within the charger. Meaning that there will be loss in that conversion due to the heat generated within the inverter changing the DC to AC. It is possible to remove the unnecessary transitions of the current flow, but there is a cost of functionality of the charging system. This function is the control over the voltage and current output meaning that whatever power is fed into the input, the output will be equal.

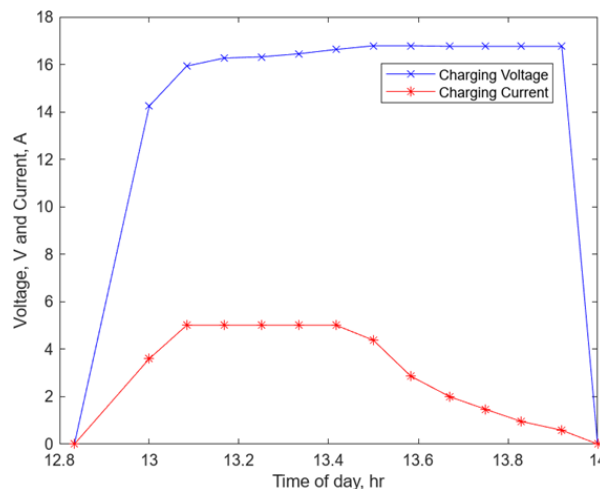


Figure 5. Plot of the sky charge system.

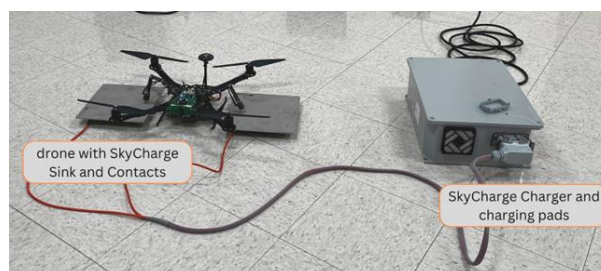


Figure 6: Contact based charging system

The Figure 6 shows the charging pattern of the battery using the contact-based system. The major part that is important is that when the current starts to decrease, it signifies that the battery is around 90% charged within 45 minutes. At this stage of charging would be the best time to send out the drone for a mission.

The last part that has progressed is the development and exploration of software for the autonomous drone portion of the project. Due to using an older version of the SDK (Software Development Kit), we are limited to using ROS 1. Currently the drone is pre-loaded with ROS indigo. Now this limits us to 2 versions to work with in the host computer ROS Indigo and ROS Melodic. Another benefit of keeping the older version of the SDK is that a useful package is installed that allows it to act as a bridge between the ROS program and the PX4 sub-systems (IMU, VIO, and VIO-ga). For now, the team is still in the learning phase of ROS and its tools for autonomous systems development.

For the return phase of the mission, when landing, the drone is required to have high precision for the pins to connect to the charging pads. Using Apriltags will help the drone precisely land on the landing pad of the capsule. The main software that is used is TensorFlow lite. The information that the drone can gather from the QR code is the location of the QR code relative to the drone in a XYZ coordinate system in meters. The second set of information is the maneuver values needed to adjust and land the drone at a set point relative to the QR code. lastly Each Apriltag as a unique ID # attached that the drones CNN can identify and give a value. This allows the use of multiple drones, each having a different spot on the vertiport. below is a screenshot of what the drone sees and the terminal showing the information processed by the Apriltag pipeline:

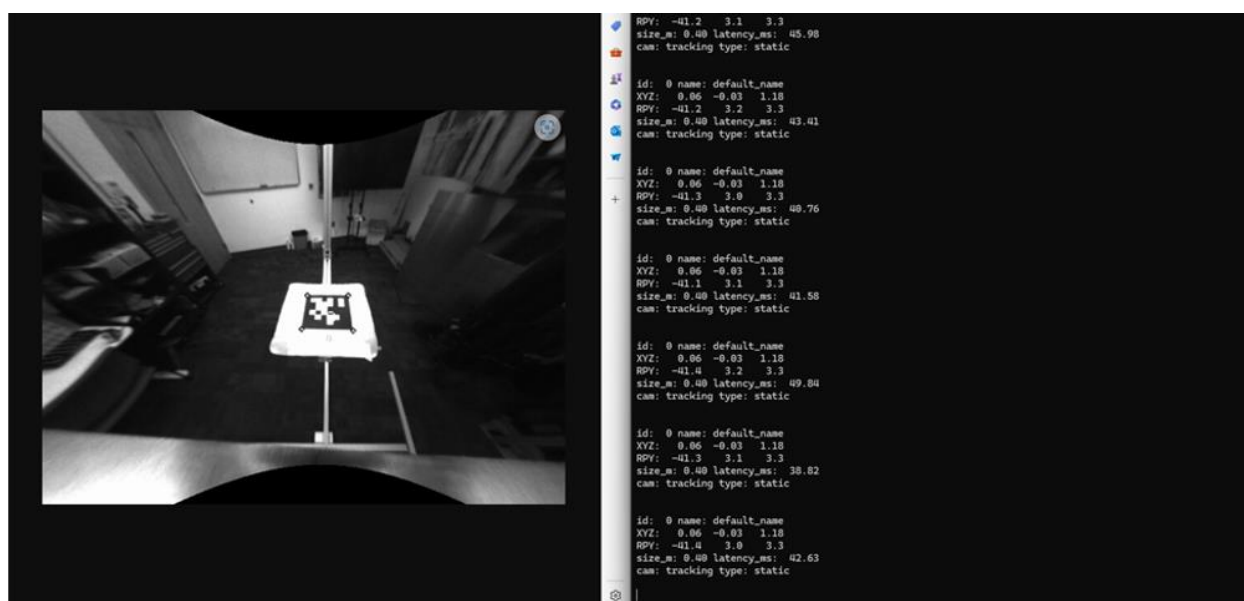


Figure 7. Screenshots of the drone terminal and tracking camera.

The methane detection portion of the project has only been discussed briefly as the main concern is having the drone move autonomously first. One of the major concerns that was brought up is the propellers effect on the surrounding air. If the air has a drastic effect on the efficiency of the methane sensor, what could be possible solutions.

IV. Future Research

There is still much work to be done before the consideration of a completed project. The major concern is to have the drone fly autonomously without the use of an external flight planning application. For example, Qgroundcontrol was initially used to test out the VIO and PX4 capabilities of the development drone, so the planned expansion on the automation is to apply what was learned about ROS to fly autonomously from point A to B. This is not the only ROS application that is being worked on, but also taking advantage of the tag detector service to precisely land on the landing pad. Once both the path planning and the april tag-based precision landing is developed; The last step is to then use both in a single mission, from takeoff to flight then landing on the pad of the capsule.

Another issue that is faced with the drone is the integration of the charging pins of the contact-based charger system. The drone will act as a load while both the battery and the charger will act as sources, the major issue is if we are not careful there may be potential damage to the battery and a potential risk of fire, explosion, or exposure to toxic gas. The potential solution in the integration of the drone battery and the charging system is via the creation of a BMS(battery management system) and the use of the MPPT software that came with the charger. The BMS is to ensure that the voltage and current of the charger is regulated for the battery that is in use will booting off the drone, this ensures the safety of the battery and the drone. This should not be complicated as there are many different methods of developing a BMS, the easiest being the use of a microcontroller and the hardest is to create analog circuits.

Moving on to the vertiport capsules, in its initial iteration, actuation predominantly centered around the expandable base, where the movement of the lids was managed by the landing base. As we progress in our research, our focus is on advancing to a hemispherical capsule design. This iteration is expected to bring substantial improvements, including enhanced aerodynamic resilience against wind forces and a more robust, weather-resistant lid system that ensures stability in various environmental conditions. This design will also address the foundational issues with the first capsule design such as lid vulnerability to wind, unreliable actuation, weather resistance and expanding base size.



Figure 8. New capsule concept iteration.

The planned electrical grid and computing system needs to be integrated with the vertiport structure. As well the design for the adjustable solar panels and the weather station at the top. The last component that needs to be added is the contact tiles for the charging system.

The final step of the project is then to apply the software and hardware to the problem of orphaned wells greenhouse gas emission. As this is in the late stage of the project, there has been only a small amount of work that was placed into the development of the hardware. The use of a gas sensor is anticipated, but most sensors need an amplification circuit to give a bigger signal. The clarity of the signal can be ruined if amplification is done wrong. Another issue that was discussed was the placement of a gas sensor on the drone, the major concern is the constant airflow making it difficult for the sensor to work properly.

V. Conclusion

The progress that has been made in the project STEER gives more insight into the different issues and difficulties of the vertiport structure or the atomization of the drone. STEER as a whole is giving a more cost-effective solution in detecting orphaned wells in regions where it becomes difficult to navigate. The vertiport is designed to be portable and self-sustaining, while the drones will be able to carry out surveying missions throughout a given region. There is still much to work on for the STEER project; yet as the research progresses, there are more discoveries and solutions are found for improving the software and hardware of the STEER system.

VI. Acknowledgments

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