Use of UAVs for Oilfield Equipment Inventory

Tali Freed, Professor, Industrial and Manufacturing Engineering, California Polytechnic State University, San Luis Obispo

Director, PolyGAIT – The Cal Poly Center for Global Automatic Identification Technologies

Mason M. Medizade, Professor, Mechanical Engineering, California Polytechnic State University, San Luis Obispo

Allen Duong, MS Mechanical Engineering, California Polytechnic State University, San Luis Obispo

Abstract

Oilfield tubulars (typically metallic pipes) and other types of oilfield equipment are typically stored in outdoor areas and may be scattered around the field. Managing these types of inventory is challenging and costly, as it requires significant labor resources. Therefore, inventory inaccuracy is common, and data-driven decisions may not be possible in a timely manner.

We propose the use of radio frequency identification (RFID) for tracking oilfield tubulars and similar, outdoor-stored, equipment. Our proposed application utilizes passive ultra-high frequency (UHF) RFID technology that enables capturing unique serial identification numbers that are attached to inventory items from a distance of several meters.

Passive UHF RFID tags require no batteries to operate. Typical tag cost is low. Each tag is placed on an inventory item and corresponds to a database entry containing specific information about this item. The tag communicates its serial number using power provided by an RFID reader radio transmission. The RFID reader is securely mounted to the underside of a UAV flown over the field. Captured RFID tags are either stored locally and retrieved once the UAV lands, or are wirelessly transmitted to a constantly updating inventory database. In addition to tag ID, the captured data typically includes time and date stamp, as well as location data.

This research project included the design and manufacturing of an enclosure to house a RFID reader system which includes a host computer, embedded reader, antenna, power source, and necessary components for user interface. Specialized mounts were designed and manufactured to attach the enclosure and antenna to the UAV. The project incorporated the development of “middleware”, specialized software installed on the host computer to communicate with the reader. The reader handles low-level communication with the antenna. To reduce network traffic, event management and data filtering are efficiently performed.

The results of several UAV flights in experimental areas are presented and discussed. Various brands of passive RFID tags for oilfield applications were tested. Particular attention was given to population density of the items, stacking configuration, vertical altitude distance between reader and tags, and time to collect inventory data for a given area of surveillance. As RFID applications are increasing in the oil, gas, solar, and
other sectors of the energy production industries, UAVs can effectively be used to get important operational and inventory data. UAV use is particularly appealing in inaccessible and remote locations.

Introduction

The integration of radio-frequency identification (RFID) technology with small unmanned aircraft systems (sUAS), or unmanned aerial vehicles (UAV), for purposes of inventory management, asset traceability, and remote sensing have grown immensely in recent years. This growth in interest can be demonstrated by numerous research papers and commercialization efforts.

The University of Roma Tor Vergata developed a RFID-UAV system, titled RFIUAV, for purposes of remote monitoring a building’s structural integrity. Their research encompassed theoretical models and experimental tests of the effective RFID interrogation footprint resulting from varied parameters including tag orientation, mounting surface, reader altitude, and flight velocity [1].

An IEEE publication by Envisens Technologies explored the feasibility of using RFID-UAV systems as monitoring instruments by delving into storage and transmission of sensor data. The study conducted tests of stored sensor data transmission between remote active RFID tags and a ground control station (GCS) via RFID-UAV system as an intermediary interrogator [2].

A paper published by the Industrial and Systems Engineering department of GyeongSang National University in South Korea explicitly acknowledges the benefits UAVs would provide for RFID in open storage yard inventory. The paper states two common practices currently implemented in storage yards that can be superseded by a RFID-UAV system: 1) laborious and time-consuming method of manual scanning and 2) expensive and stationary installation of antennas to provide coverage of a storage facility [3].

The Auto-ID Lab from Massachusetts Institute of Technology is expanding inventory automation through research of a multi RFID-UAV system. The MIT authors have preliminary simulations that compare the coverage area for a fixed duration versus the number of UAVs in simultaneous flight. The theoretical flight paths are generated using a three-dimensional path algorithm constructed by the authors [4].

A collaboration between Purdue University and North China Electric University explored feasibility of UAV use on construction site. “Results of this study indicate that the RFID equipped UAV can be used to provide data that can be implemented in supply chain management systems and connected with Building Information Models (BIM)” [5].

PINC Solutions, a company located in Union City, California, provides service for yard management, finished vehicles, and inventory robotics based around a RFID-UAV system. The company advertises inventory-management software that provides numerous graphics for users to quickly grasp real-time location of assets [6].

SmartX Technology Inc., established in Florida in 2014, offers variety of inventory management platforms based around the Industrial Internet of Things (IIOT). One such service is called SmartUAV which the company
The site describes a service for “inventory by air”. Data collected by the UAV is transmitted wirelessly to SmartX’s SmartHub cloud platform with access limited only by the extent of an enterprise's network [7].

**RFID**

Radio-frequency identification (RFID) is a wireless communication technology developed to identify and track assets using electromagnetic waves. Conventionally, inventory management implements the use of barcode technology which requires the alignment and relative proximity of scanner and UPC (universal product code—the technical term for barcode) label to accurately capture a read. The use of barcode technology in automated or semi-automated inventory management systems consequently incurs additional costs and complexity [8]. RFID, on the other hand, detects assets regardless of line-of-sight (LoS). An RFID reader detects compatible RFID tags in a three-dimensional space defined by the RFID antenna’s radiation pattern. The basic components of an RFID system are the tags, affixed to items of interest, and the reader, also called interrogator [9]. Two general types of RFID systems exist – passive and active. The essential difference between these two types is whether the tag has a power source present onboard (active), or relies solely on the absorption of broadcasted electromagnetic waves in order to backscatter its ID (passive). Cost, range, and complexity are all trade-offs between the two tag types. Generally, passive tags will offer much shorter reading ranges, but are simpler and, as a result, cost-effective to implement in inventory management.

Passive RFID can be further classified into a set of operating frequencies: 125 or 134 KHz for low frequency (LF), 13.56 MHz for high frequency (HF), and 860 to 960 MHz for ultra-high frequency (UHF) in the United States. Of these frequencies, UHF provides the greatest reading range, which commonly encompasses 2 to 10 meters [10]. The data transmitted by the tag to the reader includes an ID code (often Electronic Product Code or EPC) which may or may not be programmable depending on the generation and class of the tag. Middleware is then used to correlate tag IDs to entries in a database which contains meaningful data about the items such as Names, descriptions, SKUs, weights, classifications, etc. The current standard set forth for the interrogator-tag UHF communication protocol is defined by EPCglobal Generation 2. The EPCglobal Gen2 standard was published and is currently maintained by GS1 (https://www.gs1.org/epcglobal).

**UAV**

Growth in hobbyist and commercial application of unmanned aerial vehicles (UAV) has consequently reduced costs to own and operate small unmanned aircraft systems (sUAS) for the civil market. The Federal Aviation Administration (FAA) defines a UAV as “an aircraft that is operated without the possibility of direct human intervention from within or on the aircraft”. To be classified particularly as a sUAS, the FAA states that takeoff weight of the UAV must not exceed 55 pounds [11]. The major components of a sUAS are the vehicle and the transmitter. Vehicles can be categorized into two broad types based on method of lift generation: fixed-wing and multi-rotor. Similar to RFID, there are advantages and drawbacks to each technology. Fixed-wing aircraft are best suited for long duration, high elevation, distant travel, quiet operation applications. Multi-rotor UAVs have emerged as best suited for high-payload, slow-speed, steady flight. These characteristics of multi-rotor vehicles are of particular interest for RFID scanning due to the confined flight maneuverability necessary for navigating complex and densely stocked storage facilities. In addition, a multi-rotor would operate at much slower and controllable flight velocity which aid in experimentation and is preferable for safety when flown within vicinity of people. A multi-rotor vehicle must have at least the following components to be functional:
frame, motors, propellers, electronic speed controllers (ESC), flight controller, receiver, and battery. The exact specifications of vehicle components are chosen based on intended application. Multi-rotor vehicles, most often, are constructed with four- to eight-rotor configurations. A system’s price can vary widely based on desired features such as autonomy and payload capacity. The FAA has established guidelines by which operators of UAVs must adhere, including having unobstructed view of the aircraft during flight, remaining within boundaries of restricted airspace, and operating during daylight [12,13]. Remote pilots operating for purposes other than personal recreation must be certified under FAA CFR 14 Part 107.

Research Statement

In this paper we present a study on implementation feasibility of RFID-UAV systems for inventorying oil and gas (O&G) equipment and tubulars. The task of inventorying equipment and tubulars for O&G meets the criteria for robotic intervention - dull, dirty, and dangerous (D3) tasks. The task of inventorying is mundane and repetitive making it highly susceptible to human error. Additionally, storage yards are located on-site in relatively remote areas and are commonly impractical to upkeep. This results in a potentially dangerous and dirty environment for workers to access and navigate. The implementation of UAVs can provide benefits of improved inventory accuracy, increased drill site productivity, while concurrently limiting the hazardous risks to employees. As explained in the next section, due to the capabilities and low cost of passive ultra-high frequency (UHF) RFID technology, a passive UHF RFID system was selected for use in this research. Preliminary static tests were conducted with a UHF RFID reader separated from the UAV. These tests verified correct functionality of RFID tag read captures and benchmarked optimal read distance. Test flights were then conducted at California Polytechnic State University’s Experimental Flight Research (EFR) field and Santa Maria Energy Holdings oilfield for the purpose of observing RFID-UAV system integration capabilities and implications. Specifically, the UAV was verified to takeoff and sustain flight with the RFID reader and antenna payload. The flight test data was analyzed to examine effects that flight parameters, such as altitude and velocity, and tag parameters, such as mounting method and orientation, may have on tag read rates.

Design and Integration

Consumer grade UAVs have made possible for RFID reader assemblies to be highly flexible and mobile for detecting relatively stationary RFID tags. A UAV carrying an RFID reader would accomplish the time-intensive and mundane task of tag scanning much more efficiently, especially in cases involving remote locations and extensive coverage area. The RFID-UAV system we designed, manufactured, and assembled consists mainly of a DJI s900 UAV and a Process Expert UHF RFID reader. The DJI s900 is a hexacopter capable of supporting up to a maximum takeoff weight (MTOW) of 19.4 pounds. With a vehicle weight of approximately 7.3 pounds, supported maximum payload weight rests around 12.1 pounds meaning the total weight of battery, reader, and accessories must not exceed this limit. Additionally, vehicle documentation lists the s900 capable of sustaining a flight time of approximately 18 minutes with a 12,000 mAh battery and 15-pound TOW. In addition to the standard UAV components shipped on the DJI s900, GPS and telemetry units were added to provide positioning data to a designated PC running DJI Ground Station application.
Figure 1: RFID-UAV – DJI s900, Telemetry and GPS Units, Process Expert RFID Reader and MTI Antenna

Figure 2: Process Expert RFID Reader and MTI Antenna
The Process Expert RFID reader is housed in an extruded aluminum enclosure with I/O ports on two sides of the unit. The top of the reader has LED indicator lights and a switch. The enclosure contains an embedded ThingMagic’s M6e reader, and an ARM computer. Mounted next to the enclosure is a MTI Wireless Edge MT-262024-TRH-A-K-RHCP passive UHF RFID antenna. The reader read-rate is up to 750 tags per second and its maximum reading distance is 30 feet. The ARM computer hosts custom-scripted services to interface with the M6e’s Mercury API. The computer handles storage of read RFID tags with associated timestamps, and formats the data into a .CSV (comma-separated values) file for export. With WiFi connection data can be extracted wirelessly. In the field users extract data using a USB flash drive. The combined reader and antenna weight is approximately 4.5 lbs. An application specific mounting system was also designed to mate the reader and antenna to the UAV. This system accommodates for ease of reader removal and installation, as well as minor variability in position of the reader to adjust center of gravity (CG) of vehicle and payload as needed.

**Experiment Design Methodology**

RFID tags used in testing were first verified for functionality and compatibility with the reader. In order to verify tag functionality, a batch of tags was selected and spread across a plywood platform inside a Faraday cage. A handheld UHF RFID reader was operated in detectable range of tags. Tag IDs captured by the handheld reader were designated as functional. The test was then repeated with the Process Expert reader, using only functional tags. 20 of the tags detected at this stage were designated as functional, compatible, and valid for the UAV flight experiment.

Originally, these tags are in the form of labels and thin cards, where the RFID tag itself is “sandwiched” between two paper layers for protection. However, UHF passive RFID tags are unlikely to be read if there is only a thin layer of paper between the tag conductive ink antenna and a metal pipe [10]. Therefore, a ¼” non-
conductive insulation tape piece was adhered to every tag prior to attaching it to a pipe. The insulation enabled tag reads despite the metallic environment of the experiment.

Two primary types of tests were conducted to observe viability of the RFID-UAV system. Firstly, a static test of the reader was conducted as a standalone unit to obtain a benchmark read range under optimal conditions. With reader operating, the UHF RFID reader antenna was manually positioned to focus the beam in direct LoS of a stationary set of tags. Reader was then transported away at fixed intervals until captures were no longer reliable. The reader was concluded to be capable of detecting tags up to a distance of approximately 25 feet under optimal conditions.

With a valid set of tags and benchmark for reader range, the second test of system integration proceeded. System integration testing was conducted at California Polytechnic State University’s experimental flight research (EFR) test center and Santa Maria Energy Holdings, LLC oilfield (see Figure 6). At least one Pilot in Command (PIC) certified by FAA with Remote Pilot license was present for all flight testing. In addition, tests conducted adhered to restrictions set forth by Part 107 regulation. The target metric for testing was read accuracy with tag mounted in simulated environment and flight at suitable reader altitude.

In order to conduct the experiments in a convenient and UAV-flight approved area we selected a nearby site that contained a large pile of stored steel pipes, simulating oilfield tubulars (see Figure 6). In this area we flew the UAV safely in altitudes that corresponded to the reader’s benchmark distances.
Figure 5: Pole with RFID Tags at the Cal Poly Experimental Flight Range

Figure 6: RFID-UAV and Tubulars with RFID Tags at the Santa Maria Energy Oilfield Site
Flight Test Results

Three experiments of reading RFID tags from the RFID-UAV were conducted. The results are reported below and in Figure 8.

**Experiment #1 – Experimental Flight Range**

The first experiment tested reading tags mounted at various heights on a vertical pole (see Figure 5). The tags were mounted facing up (away from the ground) at heights 0’, 2’, 4’, 6’, 8’, 10’, and 12’ from the ground. The RFID-UAV hovered above the pole for 2 minutes at heights of 13 meters, 12m, 11m, and so on until 5m above the ground. All the tags were read during this experiment, with increasing read rates as the elevation of the UAV decreased. The first tag read occurred when the UAV was 12m above ground, 30’ above the read tag.

**Experiment #2 – Santa Maria Energy Oilfield**

In this experiment tags were mounted on insulation strips, and the strips were adhered to the oilfield tubulars facing up, toward the sky and the RFID-UAV reader (see Figure 6). The RFID-UAV was flown for 2 minutes at a height of 5m above ground, approximately 3m (10’) above the tubulars. All the tags were read.

**Experiment #3 – Cal Poly Pipe Storage Area**

In the third experiment the RFID-UAV read range was tested. The results of this experiment are mixed, but encouraging (see Figure 7). From a distance of 2.5m (8.2’) 95% (19 out of 20) of the RFID tags were read by the RFID reader after 2 minutes of flight above the pipes. As the UAV altitude increased the percentage of read tags decreased to 90% (18 out of 20) at 3m altitude, and 65% (13 out of 20) at 5m altitude.
The UAV moved at low velocity such that it circled above the 15m by 11m pipe storage area three times in two minutes of flight. At the end of the flights one of the authors retrieved the tag data from the RFID reader using a USB flash drive.

**Conclusions and Future Directions**

Our study demonstrates that RFID-UAVs can be used very effectively for inventory management of oilfield tubulars and other equipment. Oilfield equipment is expensive, and requires careful monitoring and tracking. Tubulars may have unique characteristics (such as drilling history) that cannot be easily seen but nevertheless render the particular pipe important to locate quickly. Since oilfield environments are not necessarily easy to navigate through, tracking inventory is a labor-intensive and costly task.

This study explored several factors influencing read rates of passive UHF RFID tags by a RFID-UAV system. These factors include reading distance (height), reading reliability (number of reads), and hover time. The results clearly indicated that passive UHF RFID-UAV systems can perform necessary inventory tracking tasks in oil fields quickly and effectively.

The passive UHF RFID tags used in this study were of the simplest and cheapest type. Originally, these tags are in the form of labels and thin cards, where the RFID tag itself is “sandwiched” between two paper layers for protection. However, because UHF passive RFID tags are unlikely to be read if there is only a thin layer of paper between the tag conductive ink antenna and a metal pipe, a thin insulation tape piece was adhered to every tag prior to attaching it to a pipe. The insulation enabled tag reads despite the metallic environment of the experiment.
The cost of such tags, including insulation and water proofing, is approximately $1 each. With a remote-controlled (RC) hexacopter and an RFID system that includes an embedded tag database and antenna the total cost of our RFID-UAV system is approximately $6,000.

The current UAV configuration, with its light reader payload, is capable of flying up to 15 minutes without additional charge. In prior experiments it was determined that longer flight lead to higher tag read percentage. Therefore, we suspect that limiting the flight time to 2 minutes hindered the tag read percentage, and expect that longer flights will result in tag read percentages close to 100%.

Autonomous RFID-UAV systems that follow a sequence of GPS locations represent the next step for research and development. The GPS locations correspond to the locations of inventory at the oilfield. The current processes for inventory tracking tasks are laborious, hazardous, and expensive. Our study shows that implementing significantly more efficient processes can currently be achieved using RC RFID-UAV systems. In the near future autonomous RFID-UAV systems will be launched at periodic intervals, perform inventory tracking tasks, and return to the base station delivering current inventory data with ease.

Acknowledgements

Neil Wolfe, BS Aerospace Engineering, California Polytechnic State University, SLO
Ian Marquardt, Field Supervisor, Santa Maria Energy Holdings LLC
CPCONNECT and Dr. Lily Laiho, Biomedical Engineering, California Polytechnic State University, SLO
Dr. Aaron Drake, Aerospace Department, California Polytechnic State University, SLO
Industrial and Manufacturing Engineering Department, California Polytechnic State University, SLO
References


doi:10.1109/ICEAA.2015.7297235.


doi:10.1109/ICISSEC.2016.7885849.


doi:10.1109/RFIDEURASIA.2007.4368142.


[12] Federal Aviation Administration (FAA), C.F.R 14 § 107.29, 2018

[13] Federal Aviation Administration (FAA), C.F.R 14 § 107.31, 2018