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An Outdoor Scientific Data Drone Ground Truthing Test Site

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***Abstract*— As unmanned aerial systems (UASs) become ever more ubiquitous with National Airspace (NAS) commercial and civilian operations, test sites and proving grounds need to be developed and heavily researched. Small UASs are being used as remote sensing systems, on demand, at the personal level, thus "personal remote sensing" scientific data drones urgently need Ground Truthing Test Sites beyond compliance adherence. The Federal Aviation Administration (FAA) has established six national UAS test sites and there are numerous amounts of indoor test sites found in literature and research; however, the national UAS test sites may be out of range for most researchers or exclusive and indoor test sites lack the variability and testing capabilities for GPS that an outdoor test site has to offer. The Mechatronics, Embedded Systems and Automation (MESA) Lab at the University of California, Merced has begun development of an innovative outdoor test site for small scientific data drones. Careful adherence to FAA regulation is achieved through the use of a hangar and netted structure, ensuring all flights are in an enclosed environment while maintaining an adequate and crucial GPS signal. The convergent thinking, design and development are presented in this paper.**

I. INTRODUCTION

The unmanned aerial system (UAS) field has gone through a significant growth in technology over the past 15 years and is projected to continue to grow exponentially. New technology, algorithms, improved flight safety, and applications for UASs are being introduced at a rapid pace with little sign of decelerating. In the crowded UAS market, a rapid and efficient UAS development cycle is necessary to remain competitive and innovative. While much has been described for indoor development test arenas, outdoor testing sites have become an ever increasing need and an obvious next step for the UAS development cycle. Within the U.S., the Federal Aviation Administration (FAA) initiated a project in 2013 to establish six national UAS test sites for this very reason. These test sites fill a very critical need; however, there remain additional needs for UAS researchers to establish their own UAS test site or field. A local UAS test site provides a plethora of opportunities for UAS development as well as recurring UAS operational needs such as drone operator training and certification.

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Previous developments of UAS test sites have primarily targeted indoor development that utilizes motion-capture systems to provide high fidelity orientation and position information for flight control system developments [1] or mission planning and multi-agent coordination simulations [2]. Listed below are several outdoor and indoor test sites cited in [2]:

- MIT - RAVEN [3]
- Berkeley - BEAR
- Hybrid Systems Laboratory - STARMAC [4]
- University of Illinois Ubana-Champaign - HOTDEC [5]
- Vanderbilt - Vanderbilt Embedded Computing Platform for Autonomous Vehicles
- University of Essex - UltraSwarm Project
- Oklahoma State University - COMET
- Virginia Tech - VaCAS [6]
- Ohio State University - CITR

As an example, the Massachusetts Institute of Technology's testbed, Real-time indoor Autonomous Vehicle test ENvironment (RAVEN), was developed as a grounds for the development of experimental and novel flight control and navigation techniques [3] and [7]. The concept behind developing the testbed was that current outdoor test sites were inadequate for small autonomous multi-vehicle systems due to weather constraints and environment control. While this environment is key in the initial stages of algorithm development, the hurdle of real-world experimentation rapidly approaches. These test environments provide substantial developmental support and allow the developers to absolutely control the disturbances within the test site, but are often costly and limited in size, which throttles their effectiveness for larger projects or for the evaluation of real-world applications. Outdoor testing environments are an absolute necessity for real-world and scalable systems.

Moving development and testing outdoors enables UAS developers to engage in these application and real-world driven system developments. Within remote sensing UASs, or "Scientific Data Drones" (SDD), it is common to develop calibration methodology through the use of portable ground targets. However, with the use of a more permanent UAS test site, these sites can be utilized to provide a standardized approach to evaluating UAS imaging systems as adapted from existing methodologies for evaluating digital photogrammetry systems [8]. The use of the permanent field reduces the necessary support work involved in imaging system calibration and evaluation as described by [9] and [10]. Additionally, this adds a level of consistency to UAS development, equipment calibration and UAS operator training.

Consistency, reliability and repeatability resonates throughout the UAS research community, and is what sets it apart from the hobbyist remote control (R/C) community. True UAS research leans upon these keywords as a foundation to validate experimentation. Investments towards improving the repeatability of an experiment must be made, which is the ultimate purpose of building a test site. A test site or test bed enables a research group in a way that provides a net positive return on investment. This return can be in the form of publications with reproducible reported results and further funding (academia), income (commercial) or general experimentation (academia, government or commercial). In most cases, maximizing return entails developing a multi-purpose test site that can be re-purposed during or after ongoing projects through temporary structures and movable objects.

Realizing this fundamental need for a regulated investment into the research of integrating UAS into NAS, the FAA approved six national UAS test sites. These test sites are located: University of Alaska (includes test ranges in Hawaii and Oregon); State of Nevada; New York Griffis International Airport (includes test range locations in Massachusetts); North Dakota Department of Commerce; Texas A&M - Corpus Christi; Virginia Polytechnic Institute and State University. Each test has an individual task to explore and disseminate seen in Table I, in addition to the overarching goals set out by the FAA, collecting data regarding the integration of UAS into the National Airspace (NAS). Two of the sites operate at an active airport, which can become cumbersome when performing experimental and novel applications of UASs.

While these test sites are convenient for the institutions that have been granted the approval, every research group in the U.S. may not able to easily reap the benefits in a direct or even indirect manner. Therefore, there must be a development towards an FAA compliant, ground truthing test site for SDDs.

The purpose of this paper is to introduce the design and development of a Scientific Data Drone Ground Truthing Test Site. In Section II, an introduction to University of California at Merced proposed test site is given. An overview of the technological development occurring at the test site is presented in Section III. Section IV discusses the software and algorithm development. Future and continued UAS operations is discussed in Section V. Concluding remarks are given in Section VI.

II. The Scientific Data Drone Test Site

The University of California at Merced currently occupies a $4,300$ meters-squared area designated as the "Scientific Data Drone Test Site" (SDDTS), seen in Fig. 1. This area contains an 18m × 7m × 5m hangar that has been outfitted with a netted extension, a 25m × 25m miniature almond orchard with controlled watering system and a 8m × 8m chessboard. These current experimental areas are completely removable and there is the ability to reorganize all scenarios located on the test site, which lends to easy implementation for future projects.

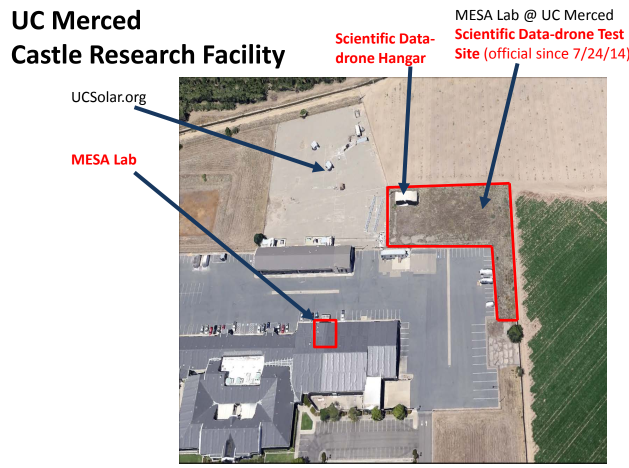

Fig. 1: UAS Test Site at the MESA Lab, UC Merced

Under the netted extension to the hangar, research on water-proof multi-rotor flight control robustness and payload development is conducted. A pool with recirculating pump system and industrial fans mimic a real world scenario of running water and winds. The hangar extension, shown in Fig. 2, is 18m × 11m × 5m and provides enough working space for the above ground pool, plumbing and sufficient flight ceiling for performing take-offs and landings on the pool surface with a vertical take-off and landing (VTOL) small UAS (sUAS). The recirculating pump system consists of three Hayward® SP3400VSP variable speed pool pumps [17], operating in parallel, which collectively outputs a maximum of $1,800$ L/min flow rate to simulate a river environment. Three industrial fans provide the ability to variably control a simulated windy scenario that might be experienced while operating in the field and collecting water samples. Together, the netting, pool, simulated river and fans allow for a GPS confirmed simulated real world scenario for an environmental sampling UAS.

Another current research project performed at the SDDTS is the drone chessboard, where the main focus is on GPS denied object manipulation of Chess pieces. The chessboard consists of sixty-four 1m × 1m squares, and each chess piece is approximately .25m × .25m × .5m in dimension. The board is assembled under the hangar, and black rubber mats are laid out to provide a consistent surface, as well as cushion. The tiles are constructed of white corrugated acrylic, which allow for easy assembly and disassembly of the chessboard. In operation, two drones identify through RT (real-time) vision and optical flow the desired chess piece, pick up the said piece with an electromagnetic robotic arm and place the piece at the desired location. This process will be discussed in further detail in Section IV. A top down view

Test Site	Research	UAS(s)
University of Alaska	Surveying wildlife	Aeryon Scout [11]
State of Nevada	Operator Standards, certification requirements, air traffic integration and NextGen	Insitu ScanEagle [12]
New York Griffis International Airport	Agricultural monitoring and sense & avoid	PrecisionHawk Lancaster Platform [13]
North Dakota Department of Commerce	Soil quality, agriculture, airworthiness and maintenance	Draganflyer X4ES [14]
Texas A&M - Corpus Christi	Safety operations, data gathering, airworthiness, command and control link, human factors, detect-and-avoid, preservation and restoration of ocean and ocean wetlands, and support law enforcement	AAI RS-16 [15]
Virginia Polytechnic Institute and State University	Vehicle and highway systems, agricultural, and training and operational procedures	Smart Road Flyer, eSPAARO, Aeryon Sky Ranger, MANTRA2, Sig Rascal and AVID EDG-8 [16]

TABLE I: List of FAA UAS Test Sites with respective research and UAS systems granted COA approval

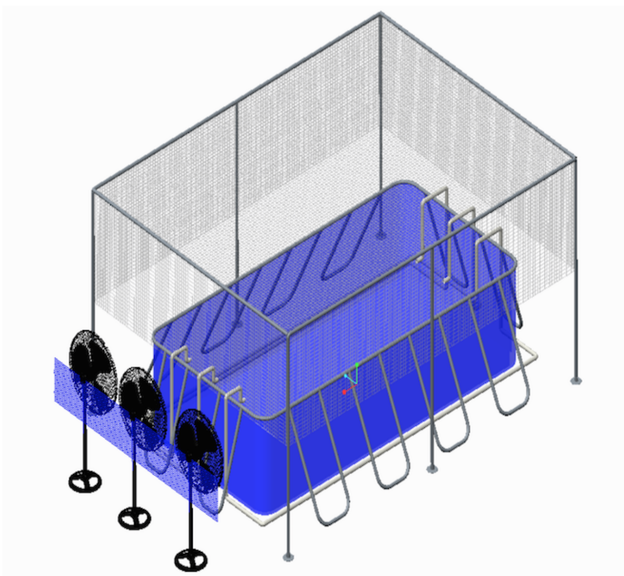

Fig. 2: Pool test bed for water sampling scientific data drones

of the drone chessboard can be seen in Fig. 3, where the tiles have been indexed to reflect a typical chess board.

Fig. 3: View of the drone chess board with marked tile indices

MESA Lab has additionally begun a collaboration with the Merced County's University of California Cooperative Extension (UCCE), in which research based upon the crop water stress index (CWSI) on almond trees is performed through the use of multi-spectral imagery analysis. UCCE Merced donated twenty-five juvenile almond trees that are distributed equally in a 25m × 25m orchard, as pictured in Fig. 4. Currently, the trees are juvenile, and can be watered by hand. For future development, each tree will be outfitted with a drip irrigation system that is connected to a water "fuse-box", where each tree can be individually controlled for water flow. Each row will receive 70%, 80%, 90%, 100% and 110% of the average amount of water flow currently supplied to almond trees during the growing season. This will also allow for the optimal water flow control of each tree individually, based upon the RT current need as determined through imagery and other data fusion.

Fig. 4: Drawing of the hangar and extension, shown as a blue recatngle with a grid infill, (left) and the 25 almond trees, shown as green circles, equally spaced in 5 rows × 5 columns square (right)

Ground truthing, in a general sense, is calibrating a relative measurement of one instrument to an absolute measurement or truth. In a looser sense, this can be taking a measurement with a piece of higher accuracy equipment and developing a method or algorithm to increase the accuracy of a lower accuracy piece of equipment. At the SDDTS, higher accuracy and precision equipment is able to be utilized in a middle ground that is not as controlled as a lab environment, yet not exactly field work. This transitional period between lab to field, is believed to be the key to reliability, consistency and repeatability. During this time, most calibration and ground truthing can be achieved in a real-world environment.

III. Technological Development Support

Through the development of a SDDTS, several UAV capabilities are able to be explored. One such capability is vertical takeoff and landing on the water surface while maintaining the current latitudinal and longitudinal location (within a reasonable accuracy). This multi-layered problem initiates with a still pond or lake, where landing and taking off simply requires a buoyant VTOL that is waterproof/resistant coupled with a waypoint enabled autopilot. Even the slightest breeze introduces a complexity to this scenario. The UAS must now combat force from the wind, viscous and drag forces from the water and maintain a relatively accurate GPS location. Yet another added complexity, which is well within real world implementation, is a small current that may be on the surface of the pond or a larger current on a river or stream. The UAS has an increased opposing force due to the current of the water. These scenarios cannot be adequately tested and experimented upon in a real-world environment. There are not only consistency and reliability issues associated with the lack of scenario control, but safety hazards and risk of loss of equipment. On the other hand, a completely controlled indoor testbed may not inject enough real-world complexities into the system; therefore, nullifying large portions of experimental findings. The only true solution to this problem is to build a testbed like the one outlined in this paper.

Indoor test sites have been created, and have value in their own right when it comes to initial stages of prototyping design and functionality [18]. However, for a true glimpse into a real world application, an outdoor test site is optimal and necessary. In an optimal situation, water flow and wind speed can be controlled and a set of ground-truth location points are known.

In this scenario, it is necessary to have visual servoing system to help UAV landing on and taking off the water surface, utilizing similar algorithms and techniques found in [19]. First, real-time vision provides the ability of object detection, enabling the UAV to sense and avoid obstacles on the water surface, such as typical debris found in natural bodies of water: rocks, trees, branches, logs and small islands. Second, water speed must also be estimated by means such as particle image velocimetry before landing on the surface, especially in rivers and streams, so the drone will land and maintain positional accuracy. Failure to do so may lead to catastrophic failures such as flip overs, damaged propellers or damaged frames, due to the shear force caused at the boundary between the air and free stream velocity of the water. Furthermore, there is typically a significant amount of turbulence on the natural water surface caused by wind and objects at the edges and under the water. In rivers and streams, a phenomenon known as a standing wave can occur due to these sub surface objects, determining the height of wave with stereo vision will yield more flexibility in determining when and where to land and collect water samples.

Similarly, when it comes to soil sampling in the field, both obstacle avoidance and ROI (region of interest) detection will depend on real-time understanding of the environment with cameras. However, this aspect of RT vision is mainly geared towards VTOL aircraft, in which takeoff and landing locations are routinely constricted laterally.

At the beginning phase of test site consideration, determining the launch and recovery methods prior to test site design and construction is crucial. If the test site is developed specifically for VTOL aircraft, then small takeoff and landing locations may be desired and are acceptable. Test sites designed for fixed wing aircraft are slightly more complicated, especially in regards to scalability. In this case, runways are required for aircraft with landing gear and large soft ground areas are needed for belly landing aircraft. Smaller, lighter fixed-wings without landing gear may require only 25 meters of runway space for landing and can be hand tossed, bungee launched or catapulted into the air; however, if future research requires a larger fixed-wing UAV, 25 meters will not be adequate. An alternative to this technique, is net recovery [20], hook recovery, deep stall or a novel approach for which the test site can facilitate the research and development. Lastly, tall objects should be considered near the launch and recovery zones where they may impeded line of sight or increase the rate of descent for landing.

Upon construction of the SDDTS, MESA Lab has made strides towards efficient and optimal water sampling for the purpose of collecting environmental DNA (eDNA) [21]. This project, which is a multi-campus University of California collaboration through the Center for Information Technology in the Interest of Society (CITRIS), centers around invasive and native species detection and population density via eDNA analysis. The pool testbed at the SDDTS plays a key role in the development of the payload and landing robustness.

IV. Algorithm Development Support

While the main focus of this work is placed upon the design and development of the physical test site, an equally important aspect is the algorithm architecture. Architecture is critical for consistency, ease of implementation and cross-vehicle integration during experimentation, where cross-vehicle integration refers to multiple vehicles of different mobility: VTOL, fixed-wing, ground-mobile, hover, etc. An indoor test site developed in [2] centers around hardware and software that is utilized in the test site. Future work will delve further into applied hardware and software architecture to be used at an outdoor test facility.

When it comes to UAS and real world implementation, obstacle avoidance is the "elephant in the room" that is unavoidable. Even the most sophisticated application and implementation struggles with obstacle avoidance, and is often pawned off to a human operator monitoring the UAS that has the ability to take control and avoid the object. RT Vision is slowly filling this void, especially with cheaper, more efficient and lighter GPUs that can be placed onboard a UAV; whereas, the alternative is offboard processing via a base station computer and uplinking the trajectory based on an updated estimate of the environment. While it is easier to perform the latter, an issue arises when near-autonomy is required, such as in a lost link, GPS denied or long range missions. For these types of missions, an outdoor test site is of great help. Intermittent GPS can be imitated and thus the algorithms developed for robust positional control can be tested. If such a system relies on ultrasonic or RT vision, random noise that is native to outdoor environments can be noted and dealt with. At the SDDTS, cylindrical obstacles are placed for such cases, and future work is targeted towards mobile obstacles that can also be found in real world testing.

Currently, progress has been achieved for autonomous UAV with the help of GPS and MEMS inertial sensors in outdoor environments [22]. However, it still has limited ability to fly in the GPS-denied environment, like most indoor environments and urban canyons created by buildings and features. Based on the scientific test site, a GPS-denied test environment is provided under the roof of the hangar, where RT vision and other sensor arrays must be utilized to maintain sufficient positional accuracy. Additionally, a configurable array of cylindrical obstacles will be set up for the research of sensing and avoid, and path planning. How to utilize real-time vision based on multiples cameras to improve autonomous ability will be discussed in this scenario.

Another scenario to test GPS-denied ability is playing chess using remote controlled UAVs. Under the hangar at the SDDTS, a chessboard is designed on the mat floor. The UAV will pick up the chess piece and move it to the desired square, according to the human player. The player will draw move the chess piece in the software, thus triggering the move by the UAV. There are four steps in each operation: chess detection, desired square detection, picking up the chess piece and placing the chess piece. These moves translate into three challenges for UAV to handle this task: square detection, GPS-denied path planning and object manipulation.

Since there are no obvious features to differentiate the squares on the chessboard, it is hard to recognize the specific square. Scale adaptive vision is necessary for this task, i.e. the UAV will first go to the altitude high enough to have an overview of the chessboard and then decrease the altitude while tracking the desired square. The next problem is navigating the UAV or path planning to the destination square while not leaving the other pieces undisturbed.

To prevent down washing the chess pieces by propellers, the chess piece will be designed with iron on the bottom and electric magnet is equipped under the chessboard. In the process of picking up the chess, all the chess pieces are fixed with electromagnet. A current will be applied to the electromagnet, until the UAV approaches the desired chess piece and is within an acceptable proximity of the piece. Then, only the electric magnet under this chess is turned off, while the other magnets remain in the on in order to fix the chess pieces. While the chess piece is being put down, the magnet under the destination square will be turned on only when the chess piece is on the center of that square. All these operations rely on communications between the chess clamp, electric magnets and the autopilot. Meanwhile, combination of multiple sensors, like sonar sensors, barometers and cameras are considered to enhance its GPS-denied performance.

In addition to GPS-denied sensor fusion, the Scientific Data Drone Test Site provides the necessary resource to conduct research vegetation index research utilizing COTS cameras that have been modified for scientific research. As mentioned previously, a plot composed of 5 by 5 almond trees is planted at the SDDTS. For each individual tree, a wireless soil moisture sensor is installed, which indicates the ground truth of water stress level for each tree. At the same time, a mobile tall pole mounted with a camera is set up at the specific position for each tree to reduce the influence of bidirectional reflectance distribution function (BRDF). New vegetation index will be developed by comparison between images and ground truth, which in turn can be utilized to control either stationary or mobile actuators (i.e. water valves, fertilizer injection or pesticide dispersement).

Moreover, this orchard is an ideal platform for UAV based actuator tests like the sprayer. It is reported about 2.5 million tons of pesticide are used around the world each year [23]. With conventional aerial application of pesticides less than 0.3% of the sprayed pesticide comes in contact with the target pest [24]. It is beneficial to use UAVs for spraying in the aspects of reducing human contact with chemicals and avoiding spraying drift, which help preserve the neighborhood fields [25]. To meet with this need, a low cost and low volume spraying package, Fig. 5, was designed in MESA Lab, composed of a flat-fan nozzle, a pressure gauge and a reservoir tank. Next, this system will be modified to fit the UAV platform to do the field tests. Research about site specific spraying application will be conducted depending on this orchard. Varying application rate control, attitude control of both nozzles and drones, and cooperation between attitude of nozzles and drone are the three topics to be discussed under the objective of minimum chemicals usage and spraying drift.

V. Continued UAS Operations

While there are remains plenty of development work necessary for UASs, there are several infrastructure needs for continued UAS operations. Equipment management and maintenance, as well as more human-centric operations such as UAS flight training and certification, benefit from a permanent UAS test flight site.

Fig. 5: Low cost and low volume sprayer for small VTOL drones

A. Equipment Management

While regular maintenance of the aircraft is expected, the payload systems of UASs also require regular management and maintenance to ensure the accuracy and reliability of its measurements. The use of ground targets has been extensively described in literature, however, these are often set up on site for evaluation purposes as well as mission applications [9]. This mission infrastructure is a challenge to maintain and keep reliable. Future developments will utilize in-house calibration setups to improve reliability and accuracy. These setups can range from the geometric and radiometric setups as described in [10], but may also be utilized in the same fashion as described in [8], to evaluate other systems. Portable systems, such as the one in Fig 6, may still be utilized, thought as these targets require expensive calibration, they should be used sparingly.

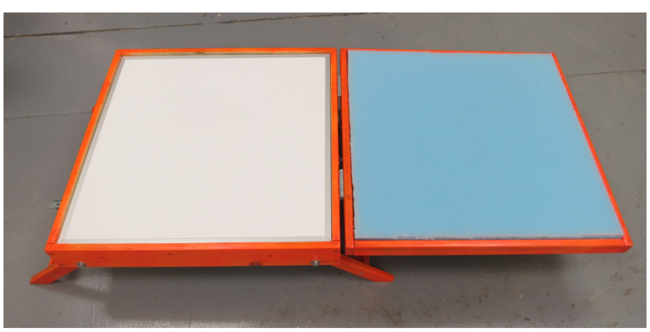

Fig. 6: The white panel, left, in the MESA Lab designed and constructed target carrying box for field calibration

B. Equipment and Software Evaluations

UAS technology has undergone significant advances in the past decade. While some groups may have the ability to develop systems and solutions in-house, many groups will often utilize commercially off-the-shelf technology and software to fulfill missing steps. The selection of the correct or best solution can be a costly endeavor and without a static testing field, it may be impossible to evaluate options effectively. Currently, many UASs utilize photogrammetry software packages for analysis of aerial imagery and estimation of digital elevation models. Analysis of these photogrammetry software packages, such as described in [26], can be significantly improve with the use of a known setup and can be effectively compared with other software packages.

C. Human-Centric Operations

1) Flight Training: Training time is precious, and only one student can fly at a given time. The less time spent having to prepare students in the field, the more time can be spent teaching them to actually fly.

Having a small, but proximate outdoor training area has several advantages. One such advantage is it greatly increases the efficiency of training in the field, allowing students to be prepared to make the most of their time at the R/C club. For basic multi-rotor training it even eliminates the need for a trip to the RC field altogether. Being close by, it also increases training flexibility, as instruction can take place on short notice, and for small groups of students. This is not only effective, but also convenient in an environment where lab members have very diverse schedules.

Lessons taught at the MESA Outdoor Lab include everything previously taught at the RC club, with the exception of fixed-wing flight instruction. Lessons run the gamut from ground school to launch training as well as safety pilot and ground station operations training on multi-rotors:

Launch Training - Being able to properly launch a UAV is essential, both to becoming a qualified drone operator, and to keeping our training program running smoothly - an inept launch can end a flight before it even begins, or even ends the entire day of training prematurely. The SDDTS high fences allow for the performance of launch training safely, enabling students to practice their launch tosses without subtracting from other students' flight time.

Multi-rotor Training - As one student typically goes through 2-3 batteries in a half hour session, recharging cannot keep up with power consumption, making multi-rotor training off-site extremely inefficient. It is possible to teach a full lesson at the outdoor lab in the time as it takes to pack up and drive to the RC club.

2) Operator Certification: Certification is a critical step in ensuring the longevity of UAS platforms for testing and missions. While the FAA is imposing a "sUAS Operator" certification, it is important to recognize that this is a baseline for commercial UAS operation under 55lbs. This proposed rule is in light of the economic benefits sUAS may offer in the fields of crop monitoring/inspection, power-line/pipeline inspection and wildlife nesting area evaluations, to name a few. As currently written, the certification process would require a potential operator to pass an aeronautical knowledge test, vetted by the Transportation Security Administration (TSA), obtain a sUAS operator certificate, and the list continues from there [27]. The SDDTS offers the ability

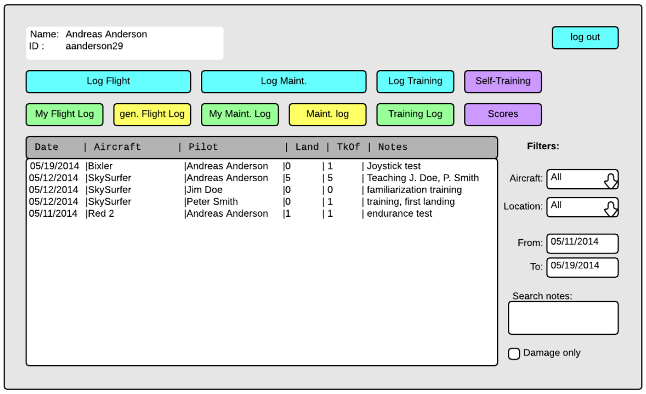

Fig. 7: MESA Lab Flight Log Software

to not only test UAS and train pilots prior to application for sUAS operator's license, but to also enhance a drone pilot certification course for commercial, industry or research specific missions.

D. Additional Ongoing and Future Projects

As with any research lab, MESA Lab has a number of ongoing and future projects at the SDDTS that are unable to fit into one work. These projects center around the concept of remote sensing (RS), utilizing UAS as the vessel. In most cases, the RS instrument is a camera, but it is noticed that the need for physical data collection for validation and further testing has become greater. MESA Lab integrates this concept of physical sampling into most of the environmental sampling research performed. Specifically, these projects are water, air and soil sampling. Where many of the properties cannot be easily obtained through an image, regardless of the spectral band in which it is taken. In these instances, the SDDTS plays a key role in UAS development.

Below is a list of current and future projects performed at the SDDTS:

- Ground truth targets for thermal IR (TIR) camera in-situ calibration;
- Ground truth targets for short-wave IR (SWIR) camera in-situ calibration;
- Ground truth targets for mid-wave IR (MWIR) camera in-situ calibration;
- Ground truth targets for Coastal Blue Band camera in-situ calibration;
- Moving target tracking;
- Airworthiness and Crashworthiness tests;
- Qualifying/certifiable ConOps design/setup;
- Sense and avoid, ADS-B/GSM;
- Vision-based autonomous landing;
- True wind measurement testbed;
- Methane mapping testbed;
- Salinity mapping utilizing multispectral imagery;
- Mud flat mapping utilizing the coastal blue band;
- Valley Fever air sampling testbed.

Excellent insight into the world of remote sensing is given by a review assembled by Ganzalo Pajares [28]. This work outlines sensor technologies, swarming and future trends in the field of UAS as remote sensing platforms. Additionally, a guide to selecting UAS provided by Stark et al. delivers better insight into sUAS technologies available [29].

VI. CONCLUSION

Ensuring scientific and consistent data is a difficult task when utilizing UAVs for scientific research. A UAS outdoor test site can aid the user in his/her endeavors to achieve such data, while providing a sufficient area to research and develop UAS and their applications. UAS outdoor test sites open up a number of opportunities that might not be achievable with a controlled outdoor environment, which is easily validated through the FAA's choice to develop six official UAS test sites. A Scientific Data Drone Test Site developed by MESA Lab at UC Merced was introduced and discussed. The SDDTS is utilized as a UAS arena and proving grounds for pilot training, UAS development and UAS application/payload development. Through this test site, a reduction in developmental costs can be immediately seen through reduced travel costs and a reduction in time from development to experimentation due to the close proximity to the workshop and lab. Future work will delve deeper upon specific aspects of the SDDTS and ongoing UAS projects, as well as any challenges encountered throughout the use of the site. The SDDTS will also be expanded to mobile ground robots and swarming robotics.

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