Investigation of sUAS in Prescribed Fire Teams

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Abstract
Prescribed fire ignitions are a dirty and dangerous job which have the potential to be made safer through the use of small Unmanned Aerial Systems for interior ignitions. Adopting this technology will necessitate a change in role for the firefighters as they move outside the fire lines and a new method for the vehicles to interact with multiple people who may not be controlling them. Interior fire ignitions currently involve firefighters walking or riding all-terrain vehicles in the burn area with drip torches to light the fires. This technique works well for small, flat spaces but quickly becomes dangerous when elevation changes or barriers (such as fences or waterways) are encountered. When considering introducing a new technology to a high-performing team and changing the workflow that they have developed and trained within, there are several team questions that we are addressing throughout the life cycle of the project. Primarily, we aim to model commonalities in the current processes across groups (ranging from collectives of farmers to highly trained firefighting teams), understand where we could provide the most benefit, and design a system that will best augment their work. This work is of interest to the workshop because it will impact the dynamics of the team, potentially change how the humans interact with each other, and improve the safety and performance of these teams through speeding deployment of fire lines while reducing risk to people.

Author Keywords
sUAS; Prescribed Fire; Field Robotics; Teams.

ACM Classification Keywords
H.1.2 [User/Machine Systems]: Human factors

Introduction
This paper describes field demonstrations of a small Unmanned Aerial System (sUAS) for prescribed fire ignitions, proposes an investigation of the current processes, and discusses the questions from and about the practitioners in this setting. One challenge in this work is the variability in the practitioners that perform prescribed fires, with teams ranging from highly trained firefighting professionals to collectives of land-owners who form alliances, which can result in highly variable skill sets, processes, and regulatory requirements.

The primary question that this work is addressing within the scope of this workshop is: "how do robots shape the dynamics of groups and teams in existing settings?" This work will propose a set of open questions addressing four topic areas: process, platform, system, and team. Next steps will also be described, which seek to answer the open questions as well as address a secondary question of this workshop, which is: "how does a robot's behavior shape how humans interact with each other in dyads and in larger groups and teams?"

sUAS for Prescribed Burns
The small Unmanned Aerial System for Prescribed Fires (UAS-RX) is a joint project between the Computer Science and Engineering Department, Department of Agronomy and Horticulture, and Public Policy Center at the University of Nebraska-Lincoln in cooperation with the Nebraska Cooperative Fish and Wildlife Unit from the U.S. Geological Survey. The ultimate goal of this project is to produce a UAS that can be added to a firefighter's backpack and deployed as a part of the standard team, or for more specialized missions such as those that would require large elevation changes or crossing multiple barriers. For more information about the vision for the project see [2]. Details on the two field tests described here, as well as the mechanical designs of the vehicle can be found in [1].

At a high level, the UAS-RX is currently deployed as an Ascending Technologies Firefly UAS with a "Dropper" which contains off-the-shelf ignition spheres and an injection mechanism to create a chemical reaction to ignite the spheres 30-60 seconds after injection. The entire Dropper mechanism was designed within the Nebraska Intelligent MoBile Unmanned Systems (NIMBUS) lab. Currently the system is controlled through custom Robot Operating System (ROS) running on a laptop and maintains a backup pilot for compliance with FAA regulations.

Field Test 1: Loess Canyon Rangeland Alliance
The first full field test of the UAS-RX took place with the Loess Canyon Rangeland Alliance (LCRA) in south-western Nebraska to burn an area of approximately 40 acres within a burn area of over 2000 acres. The LCRA burned large areas on the perimeter, while holding an interior area with large elevation changes and dense Eastern Red-Cedar coverage for the UAS-RX to burn while the members of the alliance gathered to watch near the conclusion of the burn. This test was successful in lighting areas (see Figure 1) and learning lessons to improve before the second field test at Homestead National Monument.

One surprising finding from this test was that a single ignition sphere could ignite a large area, which was due in part to the way the land was prepared for the prescribed

Figure 1: UAS-RX version 3 flying in front of a fire started at the Loess Canyon Rangeland Alliance burn.

Figure 2: A volunteer at the Loess Canyon Rangeland Alliance burn lighting a gully from an ATV, notice the proximity to fire, unburned fuel, and uneven terrain.

Figure 3: A volunteer at the Loess Canyon Rangeland Alliance burn lighting a gully from an ATV, notice the other ATV on the right.

burn. The Eastern Red-Cedar trees are an invasive species in Nebraska and were a primary target of this burn, so the landowners piled dry, dead vegetation around the live trees in order to create a hot enough fire to kill them. This led to easily ignited areas that the UAS-RX was requested to fly over due to the density of the vegetation and drastic changes in elevation, which made these areas difficult to access by people and dangerous to access by ATV because of difficulties in oversight (see Figures 2 and 3).

Field Test 2: Homestead National Monument

The Homestead National Monument burn was primarily held due to land management concerns, but offered a testbed to demonstrate the capabilities of the UAS-RX and to gain perspectives from the stakeholders. The purpose of the burn was to: reduce trees and fuel, suppress bluegrass, and support bio-diversity in the native tall grass prairie in order to protect the monument. Primary goals for the UAS-RX were to: test flight patterns, gain feedback on the preliminary designs, and assess attitudes towards the technology through a survey. The UAS-RX testing group who attended the burn can be seen with the platform in Figure 4.

The conditions for this test were ideal for the UAS to be able to test various flight paths, described in [1]. In this test, 23 acres were burned in 2 hours and 5 flight paths were tested. The lead firefighter remarked in the after-action review that the low winds were ideal for this test because in normal conditions, the field would likely have been burned before the second flight (approximately 15 minutes into the burn), but overall the impressions of the demonstration were good. The fire lines lit by the UAS were approximately 48m long (12 spheres spaced 4m apart) and in future demonstrations it was recommended that they cover about 150m lengths to go all the way across the field. Another strong recommendation was increased flight time or decreased time between flights, which was recommended because each 5-6 minute flight was followed by a 5 minute preparation for the next flight (including moving the control station).

Once the after-action review was complete, 19 of the 22 firefighters took the survey to allow us to gather information about their thoughts on the test and future applications, input for planned additions to the platform, and free responses for what they felt could be improved. These surveys primarily focused on platform and system concerns, but also raised some questions about processes and team interactions. Survey results were combined with observations from the deployment team to develop the "Open Questions" in the next section.

Open Questions

The open questions raised by the feedback and observations from the initial deployments are varied and fall under four main categories: process, platform, system, and team.

Figure 4: sUAS team with UAS-RX version 4 after a successful burn at Homestead National Monument. Left to Right: Horzewski, Duncan, Allen, Laney, Elbaum, Detweiler, Twidwell, Beachly, and Higgins.

One major challenge when considering new technologies for the domain of prescribed burns is the variability in the scale of the burns and size of the team based on the organization that is conducting the operation. This is highlighted through the description of the two different test sites for the initial demonstrations of the system.

Open process questions include:

- How many firefighters generally go into the interior of a fire, and how does this scale based on the size and constraints of the burn?
- What granularity is necessary for the ignition spheres to light lines similar to those produced by the drip torches, and how fast will lines have to be deployed to rival traditional methods?

- Which tasks currently require the most personnel or team coordination and can the UAS be used to ease this burden?
- Are there different mission types which will require different ignition patterns or additional sensing capabilities?
- What types of natural and artificial barriers are generally encountered in ignitions and how are they commonly dealt with?

The platform questions are currently being resolved, but from the firefighters' view were:

- How many balls could be carried on a larger platform?
- Could range and duration of flight be increased with current commercial systems?

At a system design level, the initial demonstration was conducted with a larger equipment footprint than would be appropriate for the envisioned "additional tool in the firefighter's backpack", which has necessitated changes to resolve questions such as:

- Can relaunching be simplified by creating easily swapped cartridges?
- Could the interface be moved to a phone or tablet rather than a computer?

Finally, at a team level there are questions about:

- What training will be necessary to allow current firefighters to use this technology?
- Will practitioners see the technologies more as remote presence capabilities or taskable agents?
- How will the redefined roles change the overall processes, and what impact will this have on current methods of communication?
- How will the vehicle communicate to the people around it about its current and future states?

Next Steps

Prior to the burn season in March 2017, we are working on increasing the range and payload through testing new, larger UAS platforms. This should allow a more direct comparison to current techniques and allow us to work with practitioners to answer both the process and platform questions while removing the cartridge design question. We are also developing a tablet based interface with a smaller computer to run ROS, while allowing greater mobility for the end-user.

We have also been working on surveying more stakeholders at all levels and planning focus groups to understand practitioner opinions and concerns to begin addressing them early in the design process.

Discussion

The application of robots to a dangerous, dynamic domain such as that of prescribed fires generates many questions about integration within a team and mitigation of disruptions or distractions which can lead to injuries or accidents. This paper proposes an initial set of questions raised by both the practitioners and development team after two demonstrations of the UAS-RX in field tests.

Of most importance to the current workshop are the team questions, which examine how the users will employ the technologies, what barriers they have to adoption, how this will change the current team processes, and what amount of communication ability will be required of the vehicle. Each of these questions are expected to be addressed within the next two years as the technology is developed and readied for transfer to the practitioners for use. In the next year, more field demonstrations are planned wherein the UAS-RX will be compared directly with drip torch fire lines to compare granularity and speed, but also to understand how the system may begin to move these practitioners to the exterior of the burn. With these anticipated process changes, the impact on the workflow will have to be modeled and assessed to ensure that the personnel being moved have the capacity to undertake their new processes. Additionally, since the users will now be expected to perform a more cognitively demanding task (though from a safer distance), it will be important to understand the impact on their ability to perform other functions (such as communications tasks which were previously performed on a radio). Finally, it is anticipated that few of the users will be able to look at an interface while in the field, and those who can will also have to divide their attention between the interface and the dangerous environment, which can lead to important messages from the vehicle being missed.

Due to the consideration about missing messages from the vehicle, it is important to investigate how the vehicle might communicate to people in its close proximity through communicative flight paths. These paths would need to be employed in such a way that they do not needlessly distract from the task at hand, but that they garner attention when important information needs to be conveyed. This information could be that the vehicle is about to begin dropping ignition spheres (of general interest to bystanders), that there is a cold area in the middle of the field (indicating ignition failure, also of interest to the team), or that there is an onboard error (only interesting to the operator).

Conclusion

In order to develop a new capability for prescribed fires to be ignited by a sUAS, important questions must be answered about how this technology will be integrated into existing team processes and how this technology will impact the team communication protocols. Two field demonstrations were described, which produced a set of questions focused on four areas: process, platform, system, and team. These questions will be further refined through surveys and focus groups before being addressed and tested in further field trials over the next two years.

Acknowledgements

Thanks to the NRI team: Carrick Detweiler, Sebastian Elbaum, Dirac Twidwell, Lisa Pytlik Zillig, Justin Bradley, and Craig Allen. The students involved in the field experiments: Evan Beachly, James Higgins, Christian Laney, and Becca Hozewski. As well as the partners in the Loess Canyon Rangeland Alliance and Department of Interior. This work was supported by a grant from NSF (#NRI-1638099).

REFERENCES

1. Evan Beachly, James Higgins, Christian Laney, Sebastian Elbaum, Carrick Detweiler, Craig Allen, and Dirac Twidwell. 2016. A micro-UAS to Start Prescribed Fires. In *International Symposium on Experimental Robotics*.

2. Dirac Twidwell, Craig R Allen, Carrick Detweiler, James Higgins, Christian Laney, and Sebastian Elbaum. 2016. Smokey comes of age: unmanned aerial systems for fire management. *Frontiers in Ecology and the Environment* 14, 6 (2016), 333–339. DOI: http://dx.doi.org/10.1002/fee.1299