

Collaborating with Autonomous Agents

“I’m a Doctor, Jim. Not an Engineer!” – Dr. Leonard McCoy,
Star Trek: “Mirror, Mirror”

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With the anticipated increase of small unmanned aircraft systems (sUAS) entering into the National Airspace System, it is highly likely that vehicle operators will be teaming with fleets of small autonomous vehicles. The small vehicles may consist of sUAS, which are 55 pounds or less that typically will fly at altitudes 400 feet and below, and small ground vehicles typically operating in buildings or defined small campuses. Typically, the vehicle operators are not concerned with manual control of the vehicle; instead they are concerned with the overall mission. In order for this vision of high-level mission operators working with fleets of vehicles to come to fruition, many human factors related challenges must be investigated and solved. First, the interface between the human operator and the autonomous agent must be at a level that the operator needs and the agents can understand. This paper details the natural language human factors efforts that NASA Langley’s Autonomy Incubator is focusing on. In particular these efforts focus on allowing the operator to interact with the system using speech and gestures rather than a mouse and keyboard. With this ability of the system to understand both speech and gestures, operators not familiar with the vehicle dynamics will be able to easily plan, initiate, and change missions using a language familiar to them rather than having to learn and converse in the vehicle’s language. This will foster better teaming between the operator and the autonomous agent which will help lower workload, increase situation awareness, and improve performance of the system as a whole.

Nomenclature

UxV	Unmanned Vehicle
GCS	Ground Control Station
NL	Natural Language
SAR	Search and Rescue
sUAS	Small Unmanned Aerial System
sUAV	Small Unmanned Aerial Vehicle

I. Introduction

SMALL unmanned aerial vehicles (sUAV) are starting to become ubiquitous because they are relatively cheap and are fairly easy to fly while the potential immediate productivity gain is large for applications such as photography and inspection. As more people find innovative ways to employ sUAVs¹ – such as crop monitoring,² photography³ and filming,⁴ package delivery,⁵ pipeline inspection,⁶ search and rescue⁷ (SAR),

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and fire monitoring⁷ just to name a few – the way humans interact with them will become critical. Current interaction methods typically include manual controllers,^{8,9} smartphones¹⁰ and tablets,¹¹ or graphical ground control stations (GCS). For the graphical GCSs that allow waypoint navigation,^{12,13} several freeware versions are available (*e.g.*, Mission Planner, APM Planner 2, MAVProxy, Tower (DroidPlanner 3), AndroPilot, MAVPilot, iDroneCtrl, and QGroundControl).¹⁴ Interacting, though, with all these types of controllers requires the operator to learn and understand the sUAV dynamic behavior rather than having a more natural and teaming relationship. A lack of teaming typically results in increased workload, decreased situation awareness, and trust issues among all active agents. However, with the possibility of communicating with various types of unmanned vehicles (UxVs) by more natural language (NL) methods, such as speech and gestures, the teaming aspect may come to full fruition.

The capabilities of not only small unmanned aerial systems (sUAS) but also the systems for all UxVs, be it a more sophisticated sensor suite, awareness of internal state and surrounding environment, decision making under increasing uncertainty, are rapidly advancing. In order to make the most effective and efficient use of these advances, true human-machine teaming is necessary. If architectures and requirements are developed from the start with teaming as a goal, increasing autonomous vehicle system capabilities, including sUAS capabilities, would naturally integrate with the human operator.

This paper will detail the considerations of operators, who may not fully understand the dynamics of the sUAVs under their control, interacting with autonomous agents using NL in order to increase teaming between them and the sUAVs. Possible solutions will then be discussed. Lastly, this research is part of a corpus of work NASA Langley Research Center’s Autonomy Incubator¹⁵ which includes an architectural backbone¹⁶ that is able to seamlessly encompass machine learning^{17,18} and decision making¹⁹ besides this natural language work while ensuring safe flight within an organic environment.^{20,21}

II. Problem Setting

For UxVs and possibly for personnel air vehicles, the operator may be partially or completely unaware of the dynamics of the vehicle and its environment. For example, a user controlling a sUAV may not fully understand traditional stick and rudder concepts nor have a basic understanding of aerodynamics such as how stalls occur. Furthermore, the operator may understand that certain expanses need to be searched for a SAR mission; not how to develop the optimal routing for the vehicle or how to maintain the flight path and sUAV attitude. For operational safety, the vehicles and operators should have certain characteristics and capabilities²² and the interface between the two should also have certain characteristics and capabilities.

A. UxV Operators

As mentioned above, operators may not fully understand the dynamics of the vehicles they are managing. Instead, they may be experts in the overall mission, such as how best to conduct a SAR or inspection mission, or dispatching UxVs for package delivery. As UxVs become more autonomous, the relationship between the operators and the vehicles will change from them behaving as managers to becoming more team members with the autonomous vehicles.²³

1. Current Interaction with sUAVs

The current interactions of operators with sUAVs typically have them in the role of the pilot where they have direct input to the attitude of the sUAV. Their interactions, though, have steadily moved from single- to multi-loop control (comprised of inner- and outer-loop controllers). For basic inner-loop control of the sUAV, operators must have a better understanding of the dynamics of their vehicles and they fly using more traditional stick and rudder controllers (Fig. 1). In fact, the GCS may be comprised solely of this type of controller.

However, with operators becoming more of mission managers or team members with other autonomous agents, they no longer are concerned about actively maintaining the attitude of the sUAV. Instead, their primary concern isare what the vehicle is doing in



Figure 1. Typical sUAV manual controller. The sUAV operator directly controls the rudder, throttle, elevator, and aileron.

relationship to the overall mission. As such, most sUAVs now have automatic stabilization and several are able to do waypoint navigation^{12,13} using graphical user interfaces¹⁴ (Fig. 2). Even with the advent of more sophisticated autopilots, the operator is still tasked with maintaining basic flight of the sUAV through waypoint setting and constant monitoring.

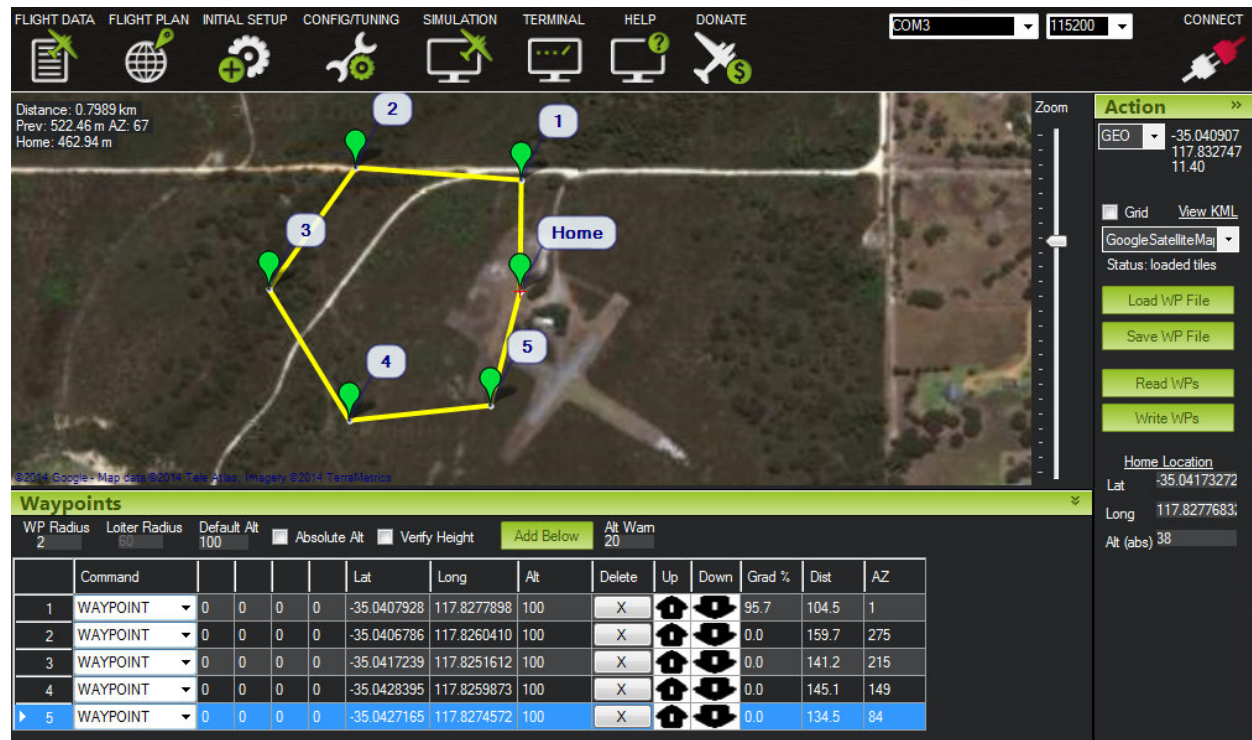


Figure 2. Typical graphical GCS to plan and control a sUAV mission via waypoints. Figure is the Mission Planner interface from <http://planner.ardupilot.com/wp-content/uploads/sites/5/2014/04/MP-FP-Screen.jpg>.

2. Teaming

As UxVs become more autonomous, the UxV operator's role will become that of a mission manager and an active team member with the autonomous UxV. As mission managers, the operators must understand the goals and subgoals of the mission and how to accomplish those within the confines of their knowledge and the interface (*i.e.*, the GCS) between them and the vehicle. These mission goals must be clearly communicated to the vehicle by the operator. Mutual understanding of the mission goals is a requirement for the operators to become participating team members with the autonomous agents under their control.

Other requirements to be a successful team member besides understanding the mission goals include communication and trust among all team members. To facilitate trust, a shared understanding and situation awareness among all parties is a must. With the goal of autonomy, these characteristics must now also be inherent in the autonomous UxVs for optimal performance of the team.

B. Missions

Three classes of missions that incorporate several capabilities the system (humans + GCS + autonomous agents) must possess to perform optimally are SAR and inspection missions, data sampling operations, and delivering packages. This section will describe requirements for the operator interface to the autonomous agents in order to define and manage these classes of missions.

1. Search and Rescue and Inspection

SAR and inspection missions are very similar. Inspection missions include inspecting power lines,²⁴ pipelines,⁶ oil rigs, buildings, etc. Both these types of mission have a defined volume of interest, particular patterns the UxV needs to follow, and objects of interest. The volume of interest may be very confined, such as inside

a transformer station, or very large, such as a mountain range, but there is a definable area of interest. sUAVs are well suited for many of these missions and the patterns the sUAV needs to fly are typically well defined. These patterns consist of following a trail, road, or power- or pipe-line, and grid or circular patterns typically used in SAR.²⁵ Lastly, the objects of interest are known and may be a lost hiker, a downed wire, etc. Therefore, to conduct these types of missions, the operator must define the search or inspection volume, the pattern to be followed, and ensure the sensors required to look for the signals of interest are available on the UxV. The operator's input of the area of interest and the flight path typically involves manual entry into the GCS which usually requires the operator to define each waypoint along the path.

Tactical changes to these types of missions may be cumbersome with the traditional manual controller or GCS. Tactical changes will usually arise from either changing the pattern between the grid and concentric circle patterns, or wanting to hover or circle around an object of interest.

2. Data Sampling

Data sampling consists of missions where the sUAV is collecting samples along its flight path. An example mission would be coordinating several sUAVs to take CO₂ air samples continuously in a coordinated pattern of concentric circles while increasing altitude at a particular rate (Fig. 3).^{26,27} As with SAR and inspection missions, these types of operations require defining a volume of interest and flight patterns. Some of the desired flight patterns would require the manual input of several waypoints to fully define the path. The operator would also have to input other parameters such as required UxV coordination and UxV vehicle speeds.

Tactical changes to data sampling missions may be driven by the desire to follow an object of interest (*e.g.*, a smoke plume). For this type of change, easily restricting the sUAV operating bounds through the traditional GCS may be cumbersome.

3. Package Delivery

Defining a package delivery mission is substantially different from specifying the previous missions described. Typically, this type of mission requires starting, drop off, and return (if different from the starting) locations for the sUAV, a delivery time, and the possibility of exclusion areas, such as schools. Of these requirements, exclusion areas may be the most difficult to input using the traditional GCS.

Package delivery mission tactical changes will often involve changes in the delivery location due to receiver preferences (*e.g.*, the back door rather than the front stoop) or unavailability to the original drop-off location due to unexpected and mobile obstacles like pets or vehicles. Once again, either manually controlling the UxV (if it is a point-to-point delivery system that starts in a warehouse with the delivery point as an office) in real time to affect these changes, or trying to define new waypoints or drop off locations in real time may be cumbersome with the traditional GCS.

III. Approach: Natural Language Interaction to Facilitate Teaming

In addition to increasing the autonomy on the vehicle to plan new trajectories^{28,29} and avoid obstacles,³⁰ improving the user interface will facilitate the communication of any changes to both the operator and the other autonomous agents. This improved communication amongst all agents will benefit transparency and predictability. This, in turn, will promote the sense of all agents as being part of a team.

With communication among all autonomous entities facilitating teaming, a shared perception among all agents will enable the operator to more readily trust the autonomous UxVs;³¹ to achieve this, the operator must understand what each vehicle is doing and why it is doing it (*i.e.*, intent). Possible methods to show the operator the decision state of the autonomous vehicle includes directed graphs and augmented reality.³²⁻³⁴

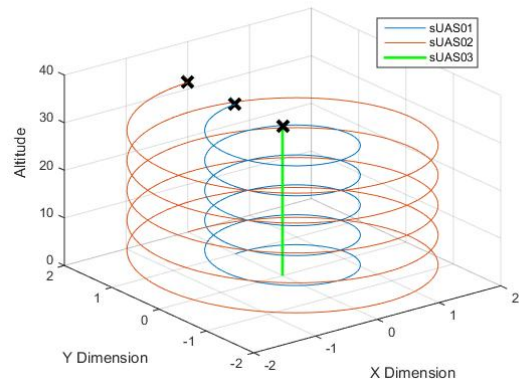


Figure 3. Example sUAV coordinated helix flight pattern for an air data sampling mission.

More streamlined means of the operator communicating with the vehicles include speech and gestures. Using these methods, which are natural to the operator, will decrease workload, increase situation awareness, and increase communication to the autonomous agents. This allows the operator to focus on mission execution (rather than the minutiae of changes) which, by extension, will increase teaming and trust in the system.

A. Speech Recognition

Using speech recognition to give commands is becoming pervasive, especially as speech commands move from controlled to natural language. Many people are now comfortable with speech commands beyond the primitive phone tree systems, such as Apple's SIRI, Microsoft's speech recognition system, and Google's Now. Great progress has been made in these systems to understand human speech without training.^{35–38} However, the word error rate is still rather high for typical conversational speech recognition especially in noisy environments.³⁹ Various methods to improve on this have been implemented (for example, see McMillian and Gilbert (2008)⁴⁰) but have only been partially successful.

The use of speech recognition systems to control UxVs would allow operators to more naturally communicate missions to the system. Even under current NL instantiations, effective mission directions for UxVs are likely possible. The environments these operators would be working in would likely be relatively quiet or the operator may have the ability to filter out some external noise by going into an enclosed space (for example a car). Furthermore, the commands given to the system would typically fall within a certain vocabulary scheme – a controlled language. Incorporating speech commands rather than using the more traditional mouse and keyboard entry methods may increase the speed of response, which is critical for SAR missions, and subsequently decrease operator stress levels.

For SAR and inspection missions, typical commands would encompass the pattern to follow such as a grid or concentric circles. The mission operator would also define starting and end points, especially for pipe- or power-line inspection, and the sUAV's altitude. Lastly, the operator would define the overlap required to ensure full coverage.²⁵ See Table 1 on the next page for suggested voice commands for SAR and inspection missions. Of course, for this mode to be more natural to the operator, the commands could be given in any order; for example^a,

Fly a **GRID** pattern at **400 FEET** with **30% OVERLAP**.
START at your **CURRENT LOCATION** and fly a **PATTERN LENGTH** of **100 YARDS** before turning around.
END and **RETURN** once you have flown out **400 YARDS**.

Similar verbal commands could be seen for other missions. For example, atmospheric data sampling mission commands could be (see Fig. 3 on the previous page for an example graphical representation)

With three drones, fly **CONCENTRIC HELIX** patterns **FROM THE GROUND** up **TO 400 FEET** with the **SAME HEADINGS**.
START at your **CURRENT LOCATION** and the **FIRST DRONE** should fly **STRAIGHT UP**.
The **SECOND UAV** should fly a helix with a **5 FOOT RADIUS**.
And the **LAST DRONE** should use a **RADIUS** of **10 FEET**.
GO UP at **2 FEET PER SECOND**.

A package delivery verbal mission definition should encompass which package to deliver and the drop off location rather than the flight pattern. An example package delivery verbal mission definition could be

Deliver **PACKAGE 3U56TS** from the **DISTRIBUTION CENTER TO BUILDING 2101 NOW** and **RETURN**.

Work in NASA Langley's Autonomy Incubator is incorporating speech commands to both control a sUAV and to initially define and strategically change its mission. Currently, the Autonomy Incubator can use speech commands to takeoff, return, and land a sUAS. Additional work in this area includes broadening the range of commands the sUAV understands and using speech to define the initial parameters for SAR and package delivery missions. Subsequent work in this area may include incorporating speech generation from UxVs to the human team members to further increase the NL capabilities.

^a**CAPITALIZED RED** text indicates key words. See Table 1 on the following page for example key words.

Table 1. Possible SAR and Inspection Speech Commands

Category	Command	Options	Example
Pattern	Grid		
	Concentric Circles		
	Hover		
	Circle		
Area to be covered	Start/Begin	Current location	start at current location
		Latitude and longitude	start at 42.3598° N, 71.0921° W
		Named waypoint	begin at BARN
	Pattern length	x feet or yards	pattern length of 400 yards
		Latitude and longitude	end at 42.3598° N, 71.0921° W
		Named waypoint	finish at BARN
	Return	Distance	end 400 yards out
		End point	do not return
		Named waypoint	return to BARN
		Starting point	return
Altitude	At	x feet	return to starting point at 400 feet
Amount of overlap	Overlap	$x\%$	at 400 feet altitude overlap 30%
		x feet	overlap 5 feet

B. Gesture Recognition

People naturally communicate using gestures such as pointing or indicating the size of an object. Tablet and smartphone users are becoming more comfortable with interacting with computers using gestures because of the touchscreens used on most of these devices. Users can now quickly activate a device by swiping the screen, and increase or decrease the image size on the screen with pinching actions. Gestures are a natural way for humans to communicate and the vast majority of gestures contain useful information.⁴¹

More free form gestures produced out in space rather than directly touching a screen are starting to be recognized and interpreted. Examples are Microsoft's Kinect, Leap Motion Controller, and Intel's RealSense. These technologies are rapidly improving^{42–44} and being used in a variety of settings in addition to gaming.^{45–47}

The types of gestures for mission management would be emblematic, iconic, and deictic gestures. As with speech recognition systems, gesture recognition systems could easily allow operators to define start and end locations (deictic gestures), and patterns to fly (both an emblematic and iconic gesture). Rather than having the operator tediously enter waypoints for an atmospheric data sampling mission, the operator could use gestures to indicate the pattern to be flown and if the underlying algorithms understood the environmental factors such as the location and volume boundaries, the system could translate the gestures to a flight path in the predefined volume. For example, the mission operator could gesture a helix pattern and the system could translate that into a flight path. For a SAR or inspection mission, the operator could gesture a grid pattern and the system could translate that into waypoints.

While the optimal gesture recognition system would be external to the operators, thus leaving them unencumbered, some type of tactile feedback may be of benefit. For example, if a gesture in free space was to pan a map or flip a switch, some tactile feedback to indicate that the map or switch was grabbed rather than just visual feedback may enhance the NL aspects of the GCS.

Current work in the Autonomy Incubator is incorporating gesture recognition with tactile feedback to interact with displays in the GCS. Furthermore, for more tactical changes in the vehicle path that may require manual marking of local object interest, previous work by the author indicated that controlling a vehicle using hand motions is feasible.⁴⁸ This work will eventually be incorporated into the GCS to allow

for real-time tactical changes during SAR and package delivery missions where the operator may control the sUAV to more closely look at an object of interest or control the sUAV during the “last 50 feet” of package delivery respectively.

C. Natural Interaction (Speech and Gestures)

The most natural way for people to communicate is with both speech and gestures;⁴⁹ in fact, a person may even gesture while speaking even if the receiver can not see the gestures (*e.g.*, talking with someone on the phone). This concept started to take root with Bolt’s seminal paper “Put-That-There.”⁵⁰ With the improvements in speech and gesture recognition systems, many are looking to combine both into a multimodal system³⁹ in order to improve efficiency^{51–53} and decrease workload.

With the increasing use of NL to define and control missions, the degree of true teaming may increase because the operator may feel more in touch with the autonomous agents. Furthermore, if the autonomous agents communicate back to the operator their understanding of the command, similar to what pilots do with air traffic control commands, the level of trust among all agents should increase due to increase transparency of the system.

With this in mind, an example multimodal command for the SAR mission described above (Section III A on page 5) might be^b

Fly THIS [GESTURES A GRID PATTERN] at 400 FEET with 30% OVERLAP.
 START here [POINTS TO A LOCATION] and fly this far out [GESTURES TO A POINT IN THE DISTANCE]
 before turning around.
 END here [POINTS TO A LOCATION] and RETURN once you have flown out
 to there [GESTURES AT A LOCATION].

IV. Conclusion

Humans naturally communicate with one another using both speech and gestures. In order to fully realize the benefits of working with autonomous agents such as sUAVs, these autonomous agents should understand the operator’s multimodal input. With such multimodal communication will come better teaming among all agents and if aided with transparency, will decrease workload, increase situation awareness, and increase efficiency and trust throughout the system.

NASA LaRC’s Autonomy Incubator is currently working on incorporating voice and gesture commands in the GCS in order to control various UxVs. This research is initially focused on strategic mission definition and eventually real-time tactical changes to the mission. The first missions considered include SAR, atmospheric data sampling, and package delivery since these tasks encompass commands common to various other missions (such as crop and wildlife monitoring, and aerial photography). The Autonomy Incubator’s goal is to combine the NL mission definition with appropriate feedback to enable trust in the system as a whole, with work encompassing algorithms to plan coordinated flight paths and real-time obstacle avoidance. With this integration, a mission manager will feel more like a leader of a team of agents, rather than a lone individual, with all involved striving to reach the same goal in a multi-task mission.

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^bCAPITALIZED GREEN text indicates gestures.

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