Enabling a Voice Management System for Space Applications

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Abstract— **The sustainable missions beyond Low Earth Orbit (LEO) envisioned for NASA's Artemis program will require autonomous capabilities. Moreover, Artemis mission crews will need a means to efficiently interact with a spacecraft's autonomous systems. This interaction can be facilitated by voice and speech communications because voice-based controls enable users to interact hands- and eyes-free, allowing the user to better focus on critical tasks. The goal of our project was to explore the knowledge and technology needed to successfully design effective Voice User Interfaces (VUIs) for autonomous systems utilizing Human Centered Design (HCD) principles. The focus of the human factors' aspect of engineering, pays close attention to psychological and physiological principles in the development of autonomous crew operation systems. A main objective was to understand how a crew member, through voice interaction, could efficiently and intuitively communicate with a notional autonomous vehicle system manager. This project was a part of the NASA Moon to Mars eXploration Systems and Habitation (M2M X-Hab) 2020 Academic Innovation Challenge.**

The work from the BLiSS Team, at the University of Michigan, resulted in the design of a system persona, Diego, to which an astronaut may quickly build trust with autonomous systems, to alleviate known stressors on mental health expected during long duration space missions. Optimal software to facilitate integration of the system persona into a reference Lunar orbiting Gateway station was defined. Additionally, a Speech to Text (STT) system and a Graphical User Interface (GUI) that could be implemented in future missions was developed on an Internet of Things (IOT) platform.

The Voice User Interface (VUI) design for the M2M X-Hab 2020 project leveraged previous technology developed by the BLiSS team to incorporate a voice-based interface into NASA's Platform for Autonomous Systems (NPAS) software. This required technologies to convert voice to text, conduct semantic interpretations, and convert responses from the autonomous system to text and to speech; additionally, the spacecraft background noise environment was assessed, a noise mitigation technique was developed, and a relatable personality for the autonomous system was developed in order to to facilitate human-like conversations.

The success of our effort was largely due to the diversity of the team that included expertise in Space Systems Engineering, Human Computer Interaction, Aerospace Engineering, Computer Science, Biomedical Engineering, and Applied Physics. The diverse perspectives fostered elaborate discussions, resulting in the conception of three main subsystems: (1) User-System, (2) NPAS-System, and (3) Environment-System. The VUI was unique and had to be efficient and intuitive. For this project, 5 subteams were formed, each with a separate objective, Voice Design team, Background Noise Mitigation team, Software Integration team

and Graphical User Interface team. The BLiSS team crafted a personality for the VUI to enable human-like conversation and drive user adoption and trust. User surveys were completed and used to help determine the required VUI system personality traits by capturing perspectives and expectations of prospective "Artemis Generation Astronauts". To further simulate human-like conversations, the system had to be able to quickly interpret user speech and be able to integrate with NASA's NPAS platform for quick and reliable information transfer. The outcomes of our research were: (1) a working prototype user interface, that is compatible with NASA's NPAS platform; (2) software that demonstrates the ability of the VUI system to interpret user requests and respond appropriately; (3) the capability to implement fully expanded conversations between user and system using intuitive communication in four request categories; and (4) software and hardware recommendations that optimize the system's ability to operate in a noisy environment. Our research has laid the foundation for the development of VUI's for autonomy, and provides a baseline for future VUI developments.

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I. INTRODUCTION

As NASA prepares to extend and sustain a human presence beyond Low Earth Orbit (LEO), the role of crew support autonomy systems becomes increasingly important. Within the context of this paper, autonomy is defined as the degree to which crew members are free to make decisions and solve problems at their discretion [1], [2]. In order to achieve these goals, the new technologies must not only be simple to use, but also support crews in the planning and operations of missions autonomously without the need for dozens to perhaps even hundreds of flight controllers and subject matter experts which are currently running operations from the ground to provide real-time troubleshooting, just-in-time training, procedures, and system maintenance [3]– [6].

The technologies for the autonomy systems of future missions must be designed with focus on supporting the human users. As crews embark on missions that take them past LEO and beyond support from mission control, the technologies must be able to adapt, support, and implement many mission operations procedures – that previously were managed from the ground. These requirements stand in stark contrast to the brute-force autonomy associated with many commercial "smart" technologies [7]. One of the many challenges of designing autonomous systems is deciding what to automate. When design considerations are not centered around the human user, automation tends to promote boredom and disengagement [8], which in turn, can lead to an increase in human errors. Typically, these human errors are attributed to the end-user rather than the many humans who participated in the design and implementation of the system [9].

This paper describes the initial design process for generation of Diego, an anthropomorphic personality intended to promote user experience and trust in autonomy application developed using NPAS (NASA Platform for Autonomous Systems) [7], through voice interaction, and in support of advancing crew autonomy aboard a reference Lunar Gateway. Lessons learned and implications for human-centered design approaches in support of crew autonomy are also discussed. Integration into the NPAS autonomy platform is also discussed, which includes software recommendations that would facilities ease of use.

II. BACKGROUND

A. Voice management in space technology

Related work on voice assistance for spacecraft is discussed on a recent article titled "Development Considerations for Implementing a Voice Controlled Spacecraft System" from George Salazar [10]. In his paper, Salazar reviews many reports and presentations regarding the development and implementation of speech recognition technologies, while noting that the majority of this work has been on commercial, automotive, and aviation applications. Additionally, Salazar points out the lack of detail in NASA's guidance on voice-controlled spacecraft. Salazar highlights the need for Human-Centered Design (HCD) considerations for voice-controlled spacecraft systems, where he stresses the importance of the design process planning being led by a Human Systems Integration (HSI) practitioner to ensure that HCD activities are incorporated into all phases, including sufficient time for evaluations that lead to further design iterations and optimizations. However, there have only been a few attempts to implement voice control in space technology, which will be briefly reviewed next.

One of the first voice assistants implemented in space systems was developed to control the Space Shuttle's Closed-Circuit Television (CCTV) footage to gimbal the camera and reposition the frame [10]. The purpose of this effort was to study the effect of microgravity in relation to speech production and recognition. The next attempt at a voice control system was developed in partnership between NASA and Xerox for use on the International Space Station (ISS) was called, "Clarissa". The demonstration for a voice-operated computer system was showcased in 2005 at the University of Michigan during the Association for Computational Linguists 25th annual meeting [11]. Featured, was the ability of Clarissa to actively listen for questions and commands that the voice assistant was programmed to respond to. More recently, Airbus developed Cimon I (2016) and Cimon II (2018) for the German Aerospace Center Space Administration (DLR) [12]. The capabilities of this technology were also demonstrated in 2019 on the ISS. The free flying spherical system or the "flying brain", Cimon, was designed to fly autonomously and listen to voice-controlled navigation. It also had capabilities to take photos and videos on request. More impressively, Cimon-2 was designed to analyze emotion of the astronauts (on command) from their voice, and project empathy in response. NASA Stennis developed a Voice User Interface (VUI) system, the Autonomy Voice Assistant (AVA) prototype which was designed for voice interactions with NPAS including messaging capabilities [7]. The focus for the AVA design was to enhance the number of interactions a user could have with the system. Work for the AVA VUI project leverages previous contributions, and seeks to expand functionality while promoting human-centered design principles to support the development of a VUI for an autonomous system.

B. Human-centered computing and automation

Prior work on human-centered automation was first highlighted as an approach to promote decision making and replace the dominant, technology-driven processes within the context of cockpit design [13]–[16]. Brute Force Autonomy (BFA), highlights limitations in our ability to develop autonomous systems intelligent enough to mitigate every single risk required for complete crew autonomy [17], [18]. One of the many features that NPAS enables is that with NPAS autonomous systems can support the ability to approximate the thought process of a person, and in that way enable a more efficient and trusting interaction with crew. Evidence to date emphasizes factors which include but are not limited to gaps in users' mental models of how the automated systems work as well as the system's weak feedback, which was identified as being a primary contributor to automation surprises [19], [20].

NASA's Intelligent Systems Division emphasizes human-centered computing as a revolutionary approach to systems design, which is intended to foment an epoch of space exploration in which the systems of both humans and machines working together are optimized, freeing the humans to more actively engage in operations that require more cognitive awareness [21]. Ames Research Center and Johnson Space Center found that a human-centered strategy proved to be a more effective approach for collaborating on intelligent systems for both manned and unmanned missions [22]. While NASA has demonstrated an increased interest in standardizing human-centered processes and implementing them into the design of next-generation space technology, little work has been done to shed light on how these concepts are implemented in current space engineering projects. The research discussed in this paper, describes a process to help mitigate surprises observed during implementation of automation, while simultaneously promoting a positive user experience.

III. METHODOLOGY

A. Design of a systems persona

Human-Centered Design emphasizes the development of deep empathy for the people you are designing for. According to ISO 9241-210:2019 [23], the HCD approach improves the effectiveness of the system and efficiency of the development process through improved human well-being, user satisfaction, and counteracting possible adverse effects on human health, safety, and performance. Thus, psychological and physiological principles must be considered in the design of a VUI. When designing the VUI for a lunar gateway application, these principles were taken into consideration to reduce human error, increase productivity and focus on the interaction between user (human) and system.

Before attempting to understand how the system could attend to the psychological and physiological needs of the user, the user needed to be identified. In the case of this project, the user is defined as the "Artemis Generation Astronaut". This concept represented the user as an educated member (e.g., scientist, engineer, biologist) of the 21st century society. The Voice Design team went through an iterative process to develop an idea and examples of what various personas might look like. To broaden the capabilities and personality of the system beyond those identified from the Voice Design team, a survey was created that was intended to be sent to students, professionals and former astronauts however, due to COVID-19 setbacks, the survey was limited to the BLiSS members, n=15.

The first survey asked participants to select tasks, collected from prior brainstorming sessions on tasks that would be suitable for voice interaction. The results of this survey were used to create a prioritization matrix, which enabled the Voice Design team to converge on specific tasks to direct design towards and in alignment with which tasks the team collectively determined were both most impactful for the user, as well as easiest to develop. The top choice results from the survey are represented below in Figure 1.

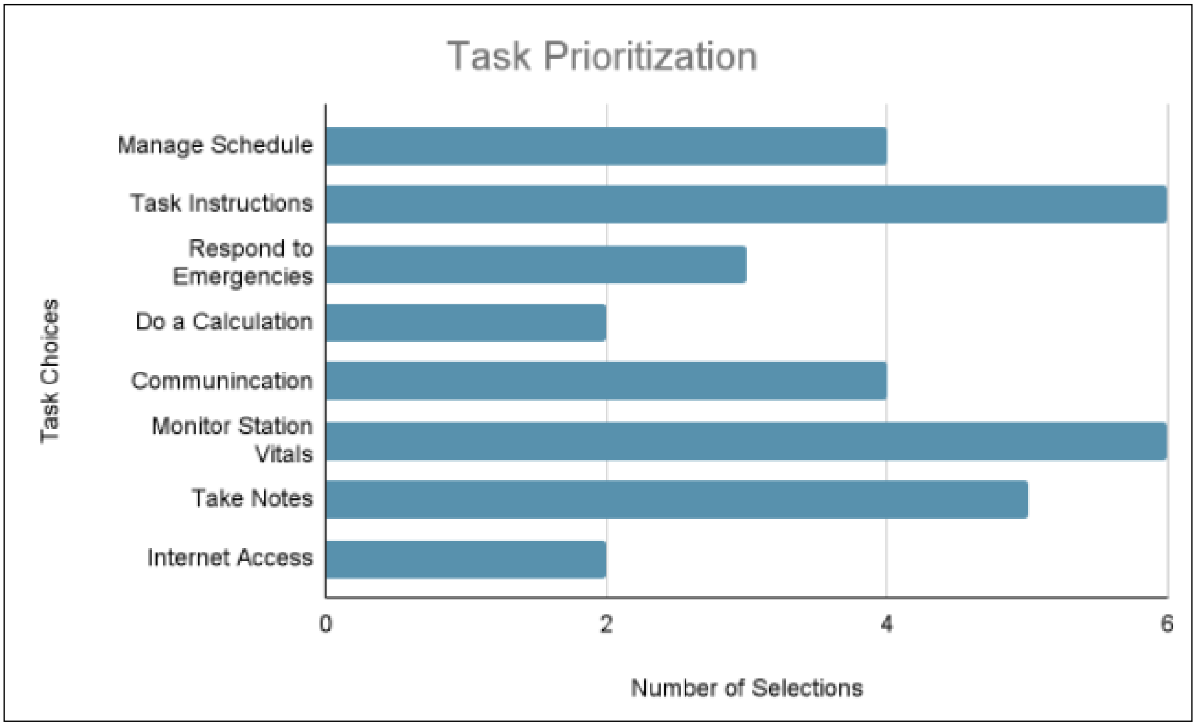


Figure 1: Results from survey on expected functions of the VUI

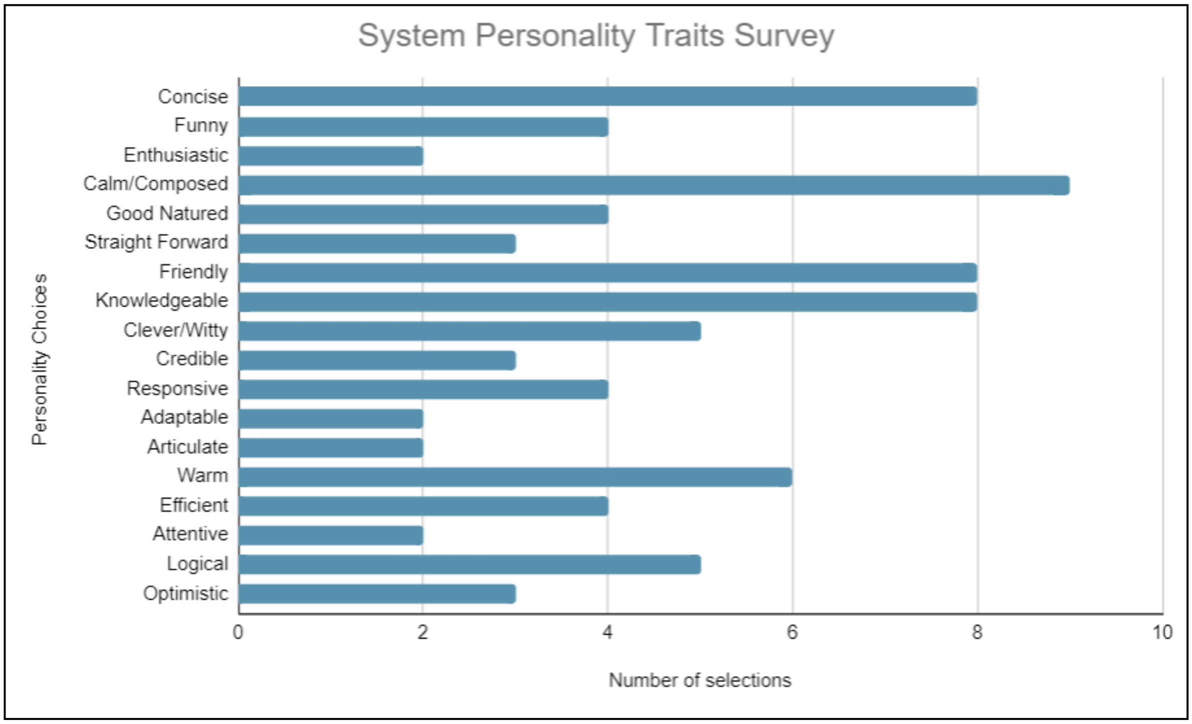


Figure 2: Results from survey on desired personality for the VUI

The results from this survey, helped the Voice Design team to narrow down the focus for VUI tasks. Top choices included, Managing Schedule, Task Instructions, Respond to Emergencies, Calculations, Communication, Monitor Station Vitals, Take Notes and Access the Internet. Taking notes and reading task instructions seem simpler than monitoring station vitals and communication which would require multiple connections with other systems. This functionality is more complex; however, it has become a focus for the VUI, and that for optimum assistance it should be fully integrated into the system of the spacecraft.

Further refinement of the developed persona's was made possible through a deeper comprehension of what functionalities the user expected and how the system could meet those expectations. After further refinement the best option for the voice and persona was defined as an educated individual who is organized and friendly. To verify this vein of thinking, a second survey was conducted. The question posed this time, gave the respondents 45 personality traits to choose from, directing them to select as many as desired to create their vision of the ideal personality for a Voice Management System. Figure 2 summarizes those results.

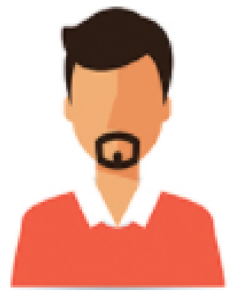
The results from survey 2 were somewhat similar to what was expected, descriptive words such as logical, efficient and articulate, mirrored the expectation that the user would want a well-versed persona for the VUI. The unanticipated result of this survey was the common requests for a VUI to be friendly, calm and warm. These descriptive terms are not often seen to describe the personality of Scientists, Engineers or Biologists. Studies have shown that during long missions, individuals may truly miss friends, family and home in general; being surrounded by their peers can still leave them feeling lonely [24]. The personality of the VUI in this sense, may be of assistance in alleviating the lack of these types of human connections.

Now that both the expectations of functionality of the system and desired personality were both understood, the Voice Design team brainstormed complementary personalities. Each member of the team created their own vision of what the systems persona could look like, resulting in the following personas.

System Persona 1

Name: Marie
Age: 53
Occupation: Retired USAF flight instructor, current Air Force Academy educator.
Hometown: Dayton, OH
Current residence: Colorado Springs
Education: B.S. Aerospace Eng., M.S. Ergonomics, M.S. Education
Hobbies: Building kit planes
Short Description: Marie joined the Air Force because she was always fascinated by the planes flying overhead when she was growing up. When she was in high school, she began taking flying lessons from a retired colonel who pushed her to push the boundaries with a plane. She loved the freedom flying gave her. After, 30 years as a pilot in the Air Force, she wanted to be able to pass her love of flying onto the "next generation" She retired and was offered a position as a flight instructor at the Air Force Academy. She often has to cut the BS that students give her and deflate the egos of those who are too full of themselves. But she also makes sure that the students get to learn to love flying as much as she does. **Voice:** A midwestern accent, penetrating, well-read but not pretentious, but gravelly (sounds a bit like a smoker).

System Persona 2



Name: Diego Sanchez
Age: 38
Occupation: Directorate Chief Scientist
Hometown: Santander, Spain
Current Residence: Long Beach, CA
Education: B.S. Physics, M.S. Applied Physics, M.S. Systems Eng., PhD Planetary Science.
Hobbies: Skiing, surfing, astronomy and volunteering.
Short Description: Diego is from the bustling city of Santander, which is right on Spain's north coast. Here he grew up to love the water, and developed a strong passion for astronomy during his star gazing nights with the family. Diego's family-owned farms and a specialty coffee shop where he learned how to interact well with customers, and the value of hard work. After high school, he attended the University of Bordeaux in France, where he met a few colleagues planning to work with NASA post-graduation and offered to set him up with one of the hiring managers. After graduating with his second MS degree, Diego returned home for a year to help with the family business and then set out to Pasadena, CA where he accepted his first position as a Research Space Scientist. Since then, he has worked hard to achieve his current position of Directorate Chief Scientist for NASA JPL. In Diego's free time, he enjoys vacations with his family, teaching his youngest daughter French, and surfing on the LA coast. **Voice:** Slight accent, warm and kind and easy to follow/respect.

System Persona 3

Name: Carl
Age: 57
Occupation: NYC Cabbie
Hometown: Queens
Current Residence: Queens
Education: Queens Technical Highschool
Hobbies: Ham radio, astronomy and chess in the park.

Short Description: "Carl" joined the Navy after HS and served in the Navy Meteorology and Oceanography Command at Stennis Space Center in Mississippi, and aboard the USS Independence as part of the lead battle group in Desert Storm. After honorable discharge, "Carl" moved back to his hometown and became an NYC cabbie because he likes meeting people, hearing their stories and telling them some of his own. He extends this passion to his hobby of ham radio, a world in which he is semi-famous for broadcasting "Cabbie tales from NYC" to 71 countries. In his spare time, he likes to play chess in the park with the other "old farts", and regularly travels up to the Catskills with his telescope to look at the stars. **Voice:** Probably synthesized (can we synthesize Ernest Borgnine?)

System Persona 4

Name: Jamie
Age: 36
Occupation: Bookstore Owner
Hometown: Portland, OR
Current Residence: Small town in New Mexico
Education: B.S. Math and Physics, M.S. Astrophysics
Hobbies: Reading, martial arts, ceramics.
Short Description: Raised by free-spirited parents, Jamie grew up with little structure and few rules. This led them towards more rigid hobbies and fields; they first turned to karate, where they earned their black belt before beginning to teach classes, which made them patient and calm, yet stern and disciplined. Seeking a more black and white, structured lifestyle, they completed a BS in math and physics. Still wanting more, they took to understanding the structure of the universe, and got a MS in astrophysics. After working as an astrophysicist with NASA for 10 years, Jamie realized this fixation on structure may have led them astray in life, and moved to New Mexico, where they opened a bookshop and spend their days reading on any and every subject, and conversing with the locals, sometimes leading discussions and educational events for the community. They also took up ceramics to unleash their creativity. **Voice:** synthesized, gender ambiguous, Orson Welles vibe?

The comparison of different personas between different perspectives played an important role in the overall design context. If only one group member had been tasked with the creation of the persona for the system, the construct might have been overly simplified with little context. It was important to give each fabrication a background story such as where they came from and base their personality on that fictional but believable background. Creating this amount of depth to the VUI construct helped to create a relatable personality for the user, one that they could facilitate building trust and adoption of use with, and could potentially help alleviate symptoms associated with isolation and lack of human relationships.

The personas were presented to the BLiSS group, who voted for their top choice; the team decided to move forward with the personality of Diego. Diego is intended to be intelligent, relatable, kind and composed; all-qualities that encompass most of the survey result requests for personality traits.

B. *Trust and adoption with astronaut users*

To achieve the VUI project goal, which is to promote user experience and trust in autonomy application developed using NPAS [7], the user needs to be willing to trust the technology and adopt the system into their daily routine. Without trust, there is risk that a VUI system would be marginalized, and without willingness to incorporate use in daily routines, such as to manage schedules and communicate with others, the VUI could be disregarded. Trust begins with familiarity; therefore, dialogues were written that mimicked natural conversations between humans, and a Natural Language Processor (NLP) was implemented to help to create a more human like system which would be more readily adoptable.

The surveys which related to the functionality and personality of the system were intended to optimize the use of the VUI and to simplify adoption. The expectation was that, if the system could be relatable then the user would feel comfort and be willing, if not eager, to engage in frequent interactions. Capabilities for the VUI system were chosen based on this principle and the results from the survey's; those ranked the highest were selected. This process was intended to increase the likelihood that the user would benefit from the intervention of the VUI system, and that use would be reinforced as a resource for astronauts. Additionally, the personality traits of Diego helped to create the perception that the system may possibly be capable of friendship. This is expected to help build deeper user confidence of the VUI system.

The Voice Design team worked together to write dialogues to outlines the dialogue between user and system, attempting to make them seem like the conversation is between human and human. If the conversation paths were similar to natural human language, the expectation would be that little thought would be needed for the user to interact with the system, thereby, promoting use. There is an option that was considered, whereby the user to ask the system to perform a simple function such as "turn of the light in module 2", and rather than having a nice response from Diego, the lights would just turn off. There seemed to be two different preferences here, and so the option for response or no response was made available in the conversation pathways. In this sense, Diego should be flexible and customizable to the user. The Voice Design team continued to develop paths for each system capability that varied the ways a user would ask for help and/or information and the responses that Diego could reply with. A sample conversation is shown below.

Task: Pulling up instructions

User: Hey Diego

System: Hello, how can I help?

User: Can you pull up instructions for "_____"? / Pull up instructions for "_____" / Could you pull up instructions for "____" (e.g. toilet repair, microgravity experiment, etc.)

System: Pulling up instructions for "_____" (repeat input) / Yes, pulling up now / Here are the instructions for "____"

User: Thank you. Can you go to section "__"? / Turn to page "__" / Diego, go to section "___" / Skip to section "___"

System: Here's section "__" / Turning to page "___"

With respect to preferences pertaining to response to commands, the Voice Design team determined it would be important to create different pathways for the same request. The user may ask Diego to turn off the lights for them, and if an answer is desired, it would be varied. In the example provided above, the user could frequently ask for Diego to pull up instructions for a task, and the response would be different each time as such: "Pulling up instructions for ____" "Yes pulling up now" or "Here are the instructions for ___". These different dialogues are created with intention to help the system appear more human like, to help further build user trust and adoption.

To supplement the dialogues and persona, Rasa was used which is an NLP software. Rasa is capable of extracting intent and/or meaning from text (more information is provided in the Software Integration section below). This enables the VUI to understand a user's request when phrased in several different ways so that the user doesn't have to memorize a specific way to ask for assistance. Over time, Diego's VUI will learn from iterations, and incorporate those lessons learned to improve communication with the user.

C. Behavioral health impact

Long duration space flight can be exhaustive both physically and mentally. An analysis on long duration spaceflight has revealed that there are many stressors that impact crew performance and physical and behavioral health [25]. The paper *Psychological and Human Factors in Long Duration Spaceflight* provides basic understanding of human-related stressors in the spaceflight environment and those effects on behavioral health. Astronauts deal with many psychological stressors including motivational decline, fatigue, somatic complaints (e.g., insomnia, headaches,), and social tensions between crewmates. Additionally, strained crew relations, heightened causes for friction, and social conflict are expected when dealing with the constraints associated with mission isolation and confinement. To help mitigate negative effects on behavioral health, implementing psychological selection, training and in-flight support can be beneficial. In-flight psychological support involves: 1) monitoring of the psychological, cognitive, and emotional state of crewmembers 2) the provision of entertainment (e.g., videos, books, games), and 3) providing opportunities to communicate with the others to compensate for the effects of missing family and friends at home on Earth.

A VUI system could provide in-flight support which could encourage positive mental health of the users (the astronauts). The main goal of the VUI system proposed is to promote crew health, productivity and overall mission success. By developing the VUI to have casual interactions with the astronauts including for example, telling jokes, fun facts in addition to building a relatable personality as described in the previous sections, the expectations are to provide a more interactive environment that increases emotional engagement throughout the time the astronauts would be in space. The VUI system could also be used, proactively, for example, by including positive affirmations and mindfulness activities that could help improve overall morale of the crew. The system could be developed to create interactions that would help the users deal with a variety of psychological stressors. These interactions would help prevent motivational decline and fatigue. The VUI system could also be used to monitor the psychological, cognitive, and emotional state of crewmembers by detecting and assessing the voices of the astronauts; this is similar to the intended work design of Cimon II [12]. A further use could include analyzing voice inflections, semantic density and coherence, and pitch and syntactic complexity of speech to help determine/assess feelings and then use this information to help combat any negative effects on their behavior and productivity during missions.

Astronauts also deal with heavy workloads, which can cause tremendous stress. Therefore, by integrating activities with the VUI system, the astronauts could potentially complete tasks faster, set reminders, and streamline scheduled activities. Working collaboratively with the VUI, and taking advantage of the fact that the VUI could quickly process voice commands from various locations, avoids the need to type out commands or move to a certain location to complete tasks. In this way, astronauts could utilize simple commands to complete tasks which can reduce additional stressors caused by limited crew and conducting work in confined space.

Stressors related to technology interface challenges and use of equipment in microgravity conditions also pose problems. The VUI system could provide support for these situations by enabling hands free technology interaction and a humanized interface experience. By using voice commands, the astronauts would be able to call out commands for support while completing tasks that require the use of both hands. In the work of Austerjost et al. [26] benefits of using voice interfaces to take notes during experiments were demonstrated. Included, was the expressed potential for interfaces to be incorporated via voice controlled and internet-connected devices to monitor and control experiments Austerjost explains that a VUI could also leverage a humanized interface to log information, make it easier to communicate with other crew members, communicate with ground and be able to connect to other interfaces like iPads and watches. The cross platform and multilingual capabilities provide support to deal with these communication stressors that are caused by limited forms of exchange in long duration space flight.

There are also other varieties of psychological stressors associated with exceptionally high-risk conditions including isolation, confinement, possibility of mission abort, rescue and loss of life during missions. Living with these constant fears for an extended period, even with help of psychological training, can still cause stress and deteriorate mental health. A VUI system could help reduce some of these stressors, for instance by providing mission danger alerts, using a calming voice to pacify astronauts rather than a loud alarm, while quickly and efficiently providing the instructions required to respond to the situation. Another example use case could include the VUI system being used to continuously check vital support conditions on a Gateway-like space station e.g., providing continuous status reports on CO2 and O2 levels. Astronauts like Scott Kelly have spoken out about the important of monitoring CO2 levels, because changes can significantly affect astronauts' capabilities to conduct mission activities. Here is a quote from Scott's book [27] summarizing his experiences in this topic:

"... I started to correlate the symptoms I was feeling to specific levels of CO2. ... At four (mL), my eyes burn and I can feel the cognitive effects. If I'm trying to do something complex, I actually start to feel stupid, which is a troubling way to feel on a space station." - Scott Kelly Endurance: A Year in Space, A Lifetime of Discovery.

By providing alerts, a VUI system could quickly notify astronauts about any changes in CO2 levels and with this information, help them understand the changes in how they are feeling and/or prevent any corresponding operational activity issues that could results from unrecognized cognitive side-effects.

Figure 3: Scott Kelly during his year in space. Image by NASA.

IV. INTEGRATION INTO THE SPACECRAFT

Proper integration of a VUI system into a space station, or spacecraft, is as important as the design of the persona, Diego. Functional integration would help optimize key features incorporated and help the user adjust and adopt the system more quickly. For example, if the user is unable to speak with Diego in a normal conversational tone and cadence, the illusion of camaraderie and familiarity is lost. For integration, two subgroups were formed, Background Noise Mitigation and Software Integration. The Background Noise team focused on approaches to reduce background noise on a spacecraft, so that the system could hear the user properly. The Software Integration team worked to select hardware and software to optimize successful integration with NPAS and a spacecraft.

A. Noise Reduction Hardware

On ISS, the Heating Ventilation and Air Conditioning (HVAC) system, as well as experiments running on board, produce a significant amount of noise, and would make a normal speaking tone difficult for Diego's microphones to hear and interpret. Without mitigating this issue, the user might have a difficult time accessing the VUIs capabilities and quickly lose trust and opportunity for adoption. VUIs work best when the background noise is roughly 15-20 decibels (dB) quieter than the speaker's voice. Normal conversation happens at about 60-65dB, which means that ambient background noise would ideally need to be between 45-50dB. The ambient noise level on the ISS is approximately 73dB [28] so for this project, the goal was to reduce the representative onboard station noise by at least 20dB to ensure that the VUI system would be able to properly understand the user commands. It is anticipated that a Gateway-like space station ambient noise similar to that of the ISS.

Table 1: Typical Speech Noise Level

Speech Level	Noise Level (dB)
Whisper	~30
Normal Speech	~60
Target Volume	~70
Yelling	90-95

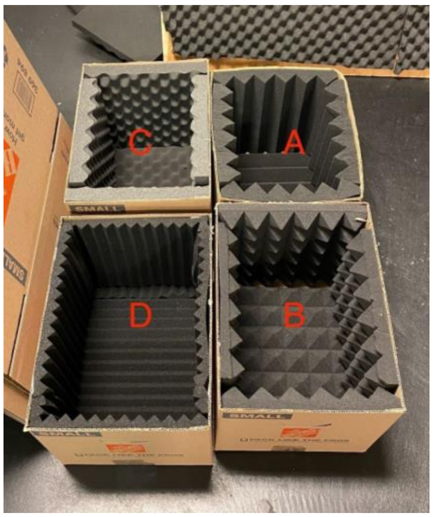


Figure 4: Passive Noise Cancellation tested consistency of various foam box samples. Sample A - 2” vertical cuts, Sample B - 2” diamond cuts, Sample C - 2” wave cuts, Sample D - 1” vertical cuts.

To reduce background noise, making the system more efficient at picking up user commands, both Passive Noise Cancellation (PNC) and Active Noise Cancellation (ANC) methods were utilized. PNC relies on soft materials to absorb sound waves, preventing them from being reflected by surfaces such as walls, floors, and ceilings. PNC is the most effective method for reducing higher frequency noises. The team assessed four sound booth grade PNC foam panels to determine overall effectiveness at noise reduction, as well as noise reduction at specific frequencies.

As shown in figure 9 all four foam samples effectively reduced noise levels by 20dB or even more at higher frequencies. Specifically, Sample C began reducing noise by 20dB or more at 4000Hz, the lowest frequency of all samples tested. Overall, all PNC’s tested helped reduce sound frequencies.

For ANC, a microphone and speaker were used to determine the incoming sound waves in the environment, then generate “anti-noise” signals which causes destructive interference, thereby reducing overall noise levels. ANC is most effective for lower frequency noises, and therefore when combined with PNC enables the effective noise reduction at a wide range of frequencies on a Gateway-like space station. The BLiSS Background Noise team assessed multiple open-source ANC algorithms to determine overall effectiveness.

The team determined that NVidia’s RTX software is the most robust commercially-available software among those tested. ANC combined with PNC could potentially be effective in reducing overall station noise by 20dB.

B. Integration Software

In addition to onboard noise reduction, the software and hardware used to implement Diego must be able to successfully incorporate design choices. The Cimon system currently onboard the ISS falls short in a few key areas, the most important being immediate accessibility for all users [29]. Simple accessibility to the VUI is crucial, and for that, Diego will incorporate multiple fixed microphones in each module of a space station, allowing the user to query and interact with the VUI at any location. Additional shortcomings with Cimon include the fact that it is not fully incorporated and connected into the ISS [30] which therefore limits its ability to aid astronauts in overall monitoring the ISS. The design plan for the Diego VUI is to make it an integral part of a space station design, and include a bridge to enable NASA’s Advanced Exploration Systems (AES) developed autonomy software NPAS, quick access for integration.

In order to create a human-centered, intuitive, and interactive experience with a Gateway-like space station, the focus for the BLiSS team was to deliver an out-of-the-box solution that is comprised of two modules: Speech-to-text (STT) and Natural Language Processing (NLP). By using both STT and NLP, an accurate and responsive command relay for daily routines on the space station through a robust voice-based interface could be developed.

The *STT* module handles the following tasks:

1.**Monitor** its surroundings and **Invoke** speech-to-text transcription service when “Hey Diego” is heard.

2.**Listen** and **Transcribe** audio into text until the current session has finished.

3.**Package** and **Deliver** transcribed text to NLP for user intent extraction.

4.Provide real-time voice user feedback.

The *NLP* module handles the following tasks:

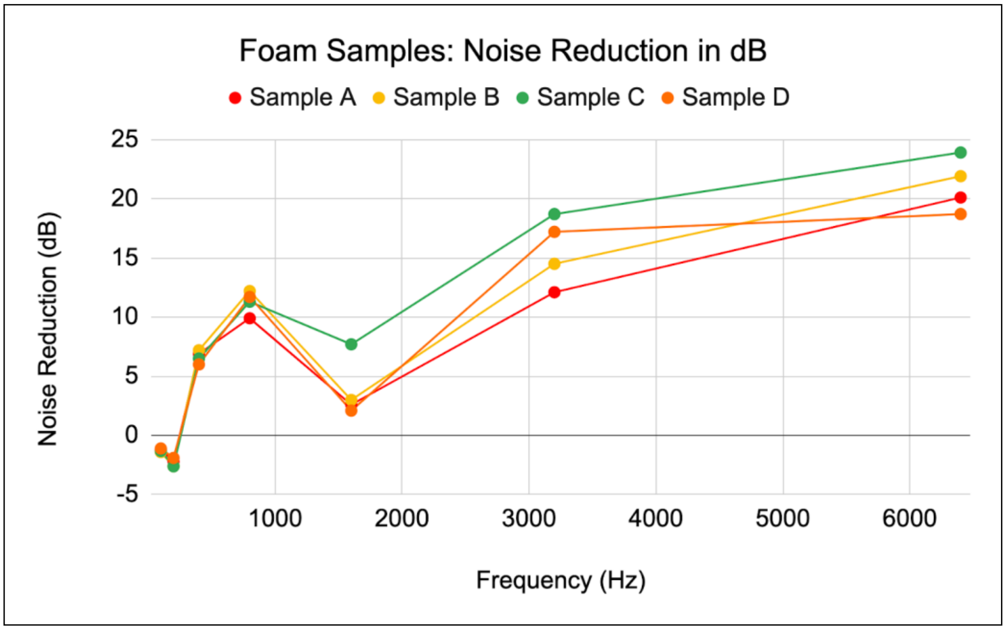


Figure 5: Foam sample test results indicating noise reduction levels

1.**Extract** user intents and categorize them on a set of pre-defined criteria.

2.**Generate** G2-compatible executable command sets.

To reiterate, the objective of these components is to emulate a personalized voice assistant that takes in audio inputs, parses inputs for executable intents, and provides real-time feedback to the current user to inform status or completion rate on demand. The NLP uses bridges (a G2 interface provided by NASA) for communication between NPAS and the VUI and astronauts onboard. The complete system architecture is shown below.

The complete VUI package is expected to run on a Portable Operating System Interface (POSIX) compliant operating system but is currently in development in Ubuntu 20.04 LTS (prior to migrating to two Raspberry Pi's running CentOS 7 for integration testing and workflow validation).

Speech-to-Text (STT) - The STT module was sourced to optimize ease-of-use, modularity, and compatibility. A requirement was that the STT had to be functional without an internet connection. This necessitates localized machine-learning and advanced neural networks that provide intuitive feedback as well as an acceptable level of transcription accuracy. In the preliminary study phase, the BLiSS team determined that modularity is at the core of an integrable and easy-to-use solution.

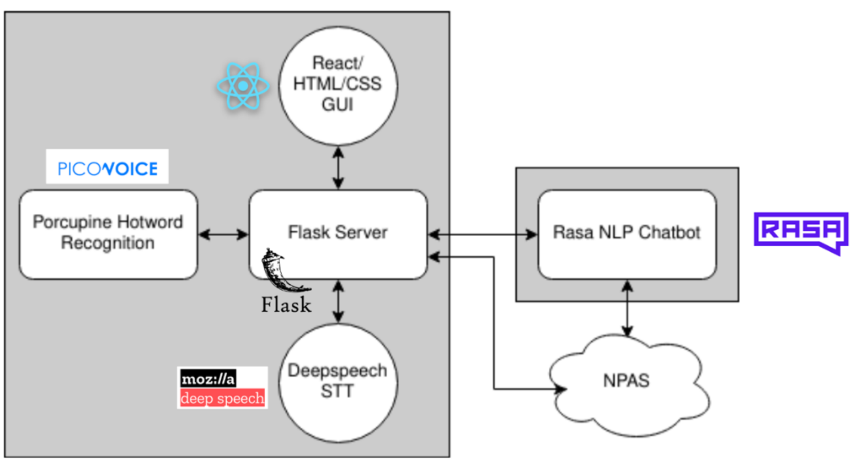


Figure 6: Visual showing how the modular VUI system can be integrated into NPAS applications efficiently.

Thus, the team proposed to proceed with three independent subcomponents that would accomplish STT as follows:

(1) Porcupine by Picovoice (Hot Word Recognition) - A hot word (as known as “wake word”) is a custom key phrase that triggers a sequence of pre-programmed events when heard. It serves as the only interactive entryway to a complete sequence run to its intended users. “Hey Diego” was selected as the hot word for this project’s implementation.

Porcupine (by Picovoice) was selected out of the three potential candidates for speech recognition (Porcupine, PocketSphinx, and Precise) due to the detailed documentation associated with it, and the ability to train models on Porcupine’s distributed server at no cost. Porcupine runs silently in the background as soon as the physical hardware on which it is being hosted powers on. Anything other than “Hey Diego” does not trigger the event sequence.

(2) DeepSpeech by Mozilla (Transcription) - DeepSpeech is an open-source speech-to-text transcriber based on Baidu’s years of research (arXiv:1412.5567v2) on relevant topics. DeepSpeech uses Google’s TensorFlow to facilitate ease of implementation. DeepSpeech is simple: it lets the user speak and uses a pre-trained model on a chosen target language to generate text.

(3) Coqui by Coqui.ai - Coqui is an advanced, embedded, and offline Text-to-Speech generator under a copyleft license. It leverages the latest research and offers a wide selection of pre-trained models for developers’ convenience. It takes a text input and articulates it back to you in a natural, human voice. This functionality is used throughout the VUI implementation to generate real-time voice feedback for the current user.

Natural Language Processing (NLP) - The NLP module is necessary so that the requests made by the user can be understood by extracting intents and entities. Intents are the desired results behind the user’s queries. Entities are important pieces of data within the queries that may be used as input data for the system. This module takes text requests from the STT module and interprets them to perform the action requested by the user.

The NLP module was selected based on ability to optimize ease-of-implementation and workflow fit. The NLP was also expected to be operable without internet connection. This requires machine learning and advanced neural networks to pre-train a language recognition model for intent recognition and entity extraction.

Various NLPs were assessed, and the Software Integration team determined that ease-of-implementation that included a good conversation design workflow fit would be optimal for implementing a solution efficiently with existing conversation data. Thus, the team proposed a chatbot-building framework to accomplish the task:

Rasa (NLP and Chatbot Framework) - Rasa Open Source is an open-source framework for building complex chatbots using NLP technology. RASA leverages various underlying technologies including machine learning framework Tensorflow for training, NLP framework spaCy for tokenization and language recognition, and Duckling for entity extraction. Rasa provides an all-in-one package, which simplifies chatbot creation by reducing training to a simple task of entering structured conversational data.

Rasa was chosen for several reasons, the most significant was the all-in-one packaging, which includes all the elements required to create a functional chatbot. Because of this ease of use, very little setup was necessary to get started with implementation. This helps reduce the amount of human effort needed to set up the system on the reference space station. Rasa also provides a built-in REST endpoint

to receive input from an external program or source, thus allowing simple integration with the STT module. The structure of Rasa’s training data aligned closely with conversation design, Diego, enabling an efficient transition between conversation design and chatbot training. While simplifying the chatbot creation process, Rasa still allows complex configuration and training via language processing pipeline modification and a built-in action server which runs Python code.

C. Graphical User Interface (GUI)

To improve efficiency of human-robotic interaction with the VUI, and to provide an additional way to access Diego, a complimentary Graphical User Interface (GUI) was designed. The GUI work was led by the Software Integration team, and included a relevant graphical interface for each command which serves to indicate that the command has been heard, registered and processed. Initially a study of the functions of current interfaces such as the Google or Apple interfaces was conducted. The Software Integration team determined that minimalism, flat design has the following features and advantages over skeuomorphism:

- Cleaner and enhanced visibility
- Simpler elements
- Clearer sense of hierarchy
- Pure color and better contrast
- Adaptable to different screen sizes and resolution
- Decreased design time.

From these findings, a list of functionalities to prioritize was

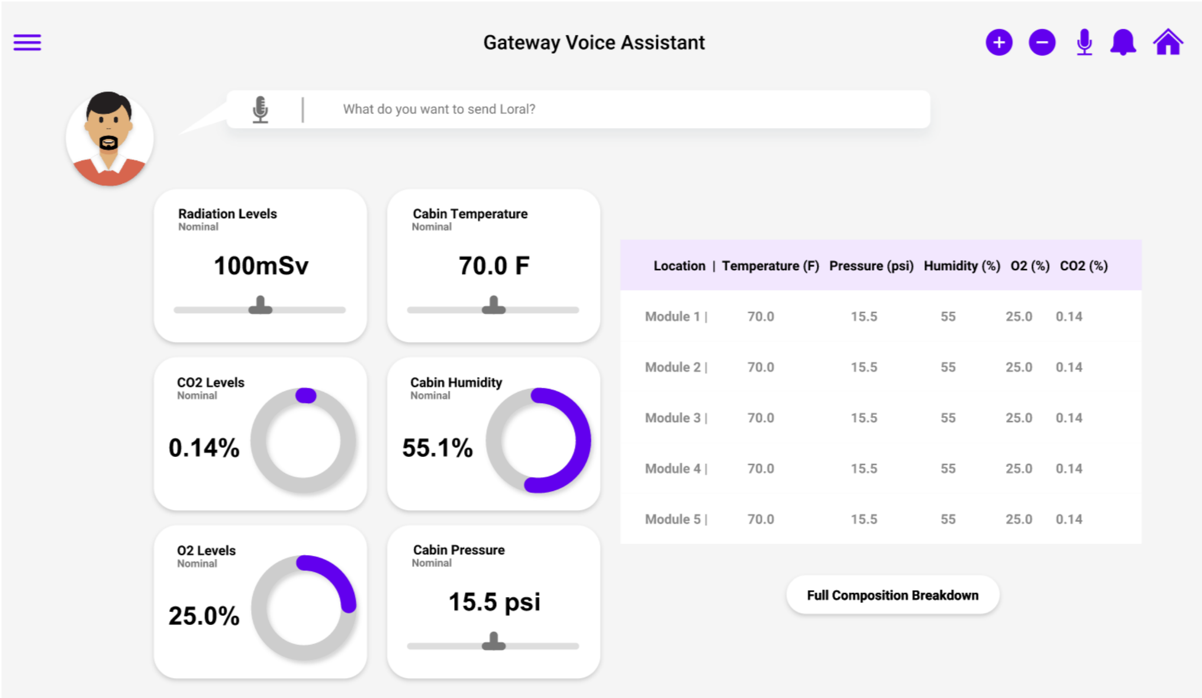


Figure 7: GUI Interface

created. The functionalities included were screen calling, page of commands, user schedules, notes page, messaging

screen, instructions page, pop up keyboard and station vitals visuals on the main page. Forming an understanding of the technologies available for the VUI, helped the team to design an intuitive interface and then set interactions which are meant to be utilized on a computer or tablet, for user preference and in the event that loud background noise interfere with the system's ability to hear voice commands.

Adobe XD was the interface design tool selected to create the GUI (because it was easy to use, visually stimulating and fit well with a design focused around human factors). Additional work was done in collaboration with the Voice Design team, who were responsible for providing the capabilities of the system, which were then integrated into the interface. The main functions for the GUI were as follows:

- Scheduling - asking about specific tasks, adding reminders for tasks.
- Communication - making a call, sending a text, sending a voice message.
- Station Vitals - query of a vital.
- Tasks - pull up instructions, read out step by step.

The main interface components of the GUI include a home screen, video call interface, messaging (with keyboard option), note taking/personal log screens, scheduling carrousel, station vital charts, and notification pop ups.

An additional expectation is that the GUI would be accessible via station computers, tablets and smart watches aboard a Gateway-like space station, for access. The intention would be to expand accessibility beyond voice commands, for example, in the event of preference of screen interaction, or that a voice command may not be heard.

Figure 11. represents the main screen of the GUI, where astronauts would have quick and easy access to other system users for quick communication. At the bottom there are options for checking station vitals which include real time data. A search bar is located at the top, which can direct the user to the different system functions and to request a command by voice rather than selecting the option manually, station vitals on the bottom with real time data and a search bar at. This GUI was designed with the two driving requirements in mind: existing technology and multiple access methods.

V. CONCLUSION

As NASA and others prepare to extend and sustain a human presence beyond Low Earth Orbit, supporting crew autonomy becomes increasingly important. A Voice Management System, designed to aid both daily operational activities and mental health, will be critical to extending missions. This study contributes to the literature available on system persona development, and overall VUI development and implementation strategies. Preliminary design considerations for a Voice Management Systems are provided which is based on Human Design Factors and the expectation of the "Artemis Generation Astronaut". The system developed is compatible with NASA developed technology, NPAS. Project goals were accomplished by focusing on the interaction between user and system, building familiarity, trust and adoption and completing multiple trade studies on which software packages may operate best on a Gateway-like space station.

After sourcing opinions and preferences from "Artemis Generation Astronauts", the BLiSS team determined that users want an autonomous system to manage simple daily tasks (such as scheduling tasks, communicating with others, or reading out work instructions). This was a good sign, since this represents the willingness to trust an autonomous operating system to assist in daily operations. In order to ensure that adoption, a good system personality is highly recommended. The results of a personality survey showed that users want systems to be kind, warm, knowledgeable and articulate; essentially, users wanted a friend. Using these traits i.e., conceiving the idea of a kind of personality which is kind yet logical, the personality of Diego was formed. Diego expresses his personality through his vocabulary, variations in response phrasing, and speaking voice. Jokes and humor should be added into his regular dialogue. Existing voice management technologies can feel cold, lifeless and often misinterpret user commands. The BLiSS team tackled those issues by creating conversational components that felt like natural conversation. Additionally, technologies that work efficiently with the onboard operating system were utilized and background noise was mitigated.

The findings from the Background Noise Mitigation team, lead to the selection of specific noise cancelling foams, which could be used to surround the speakers so Diego could hear the user commands properly without suffering from noise interference issues. Different ANC software's were assed and physically tested; the Background Noise Mitigation team suggests NVidia's RTX since in a noisy environment, it seemed to be the most robust. This software combined with the noise cancelling foam was found to be effective in reducing background noise by 20dB. Notionally, this combination should provide enough support to combat the noisy environment on a space station.

Additionally, this project determined the optimal combination of software for easy integration into a Gateway-like space station system, utilizing NASA Stennis's NPAS software. Speech to text software is also needed for the VUI system to integrate user commands and translate that into useable data. Porcupine, Coqui and DeepSpeech were determined to be the best combination of available software's that could be used. NLP software was also analyzed, to find the best option to extract user intents and categorize them. Findings from the research show that Rasa was the best option functioning as an all-in-one package to simplify both creation, as well as reduce training needs. These software suggestions should increase functionality of the VUI system and decrease initial set up time.

One limitation of this study, was lack of time for usability testing. For this work, the BLiSS team sought to provide a preliminary design direction that addresses how a VUI system could look, function and operate properly given the parameters but it cannot be said that the design is right. In order to claim that the design works, or would be effective, extensive usability testing is required. These findings are instead intended to aid in future finalized development of VUIs. Future work could be done to physically test the system, from a user perspective as well as from a system compatibility perspective. The expectation is that this would occur over the next few years as NASA gears up in preparation for the Artemis program, Lunar Gateway mission.

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Biographies

Tara Vega *is currently a Space Engineering Graduate student at the University of Michigan. She served as the Voice Design group lead with BLiSS for a portion of the 2020 VUI project, working to develop a surface Lunar habitat and Lunar Gateway environment with Voice Interface capabilities. She received a BS in Environmental Science, Minor in Biology, from Oakland University in 2018. Tara brings a unique perspective to BLiSS through her past 6 years of research in Bioinformatics, Astrobiology and Environmental Science. One day she plans to begin her own business, related to designing stainable homes on the surface of Mars.*

Ariana Bueno *is a NASA OSE Fellow researching rocket Plume Surface Interactions (PSI) on the Moon while pursuing a PhD in Applied Physics at the University of Michigan. She interned this summer at NASA Marshall with the PSI team and has previously interned with the Aerospace Corporation as the payload team lead for the Solar Gravity Lens project. She researched and identified the psychological benefits that a Voice User Interface has for crewed spaceflight. She sees her work advancing NASA's work on the Artemis program, both with the Lunar Gateway and future Lunar landers thus helping bring people back to the Moon. She plans to continue her research in the space industry after completing her doctorate and eventually conduct research on the Moon as a mission specialist astronaut.*

Chad Cerutti *served as co-lead for the BLiSS team and guided them through the completion of the Voice User Interface for NASA's 2020 Moon to Mars X-HAB Academic Innovation Challenge. He will be graduating with his Bachelors in Aerospace Engineering, minor in Business Administration from the University of Michigan in April, 2022. After graduation, he will join Lockheed Martin as a Systems Engineering Associate working on the operations of space hardware. His prior internships included additive manufacturing with startups and technical sales consulting at billion-dollar companies. He has a keen interest in supporting human spaceflight, hoping to one day set foot on the moon himself.*

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Matthew Garvin *received his BA in Anthropology from Wayne State University, and his MS in Information from the University of Michigan, where he is currently a PhD student. He has interned for NASA ExMC, where he worked to support the adoption of model-based systems engineering; and NASA CAS, where he investigated knowledge infrastructures for advanced urban air mobility. He currently works at the Generative Justice Laboratory, where his research focuses on Computer Supported Collaborative Work (CSCW), ethnocomputing, and emerging technologies to support circular economies.*

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Fernando Figueroa *received his BS Degree at the University of Hartford, CT (1983), and MS and Ph.D. Degrees at The Pennsylvania State University, PA (1984, 1988); all in Mechanical Engineering. He was faculty of Mechanical Engineering at Tulane University (New Orleans) for 10 years, and Associate Chair of Advanced Instrumentation and Control at The University of New Brunswick (Canada) for 2 years. He has been at NASA Stennis Space Center since 2000. He has lead multiple R&D projects in collaboration with academia, industry, government agencies, and other NASA centers. He is currently Lead for Autonomous Systems and Operations, working on projects funded by NASA Advanced Exploration Systems, Space Technology Mission Directorate, and NASA Stennis Space Center. His areas of interest include Autonomous Operations and Systems, Integrated System Health Management (ISHM), Intelligent Systems, Intelligent Sensors, Robotics, and Automatic Controls..*

Lauren Underwood *received her BS, MS and PhD Degrees in Biology (developmental neurobiology with focus in optics) from Tulane University, LA (1985, 1987 & 1991). Following graduation, she was awarded a National Institute of Health Training Grant Fellowship in Vision Research for post-doctoral studies (1991-1993). Dr. Underwood has been at NASA Stennis Space Center (SSC) since 2001, and has worked directly for the Office of the Chief Technologist (OCT), as well as supported activities associated with Science Mission Directorate, Science Technology Mission Directorate (STMD), DEVELOP and most recently works in the Test Technology Branch in the Engineering and Test Directorate at SSC. Currently, she serves as a SSC Project Manager, for NASA's Advance Exploration Systems (AES) autonomy software activities, as well as serves the Autonomous Systems Lab project manager for other related autonomy software infusion activities at SSC.*