Operational Testing of Drone Tracking and Obstacle Avoidance in Simulated Martian Environments

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Abstract

NASA's Ingenuity helicopter proved the feasibility of aerial mobility on Mars, inspiring this study on the role of small uncrewed aerial systems (sUAS) in supporting astronaut extravehicular activities (EVAs). Using a DJI Mini 4 Pro, we evaluated autonomous astronaut tracking and obstacle avoidance during two Mars analog missions: the Space Analog for the Moon and Mars (SAM) in Oracle, Arizona, and the Integrated Lunar-Mars Analog Habitat (ILMAH) at the University of North Dakota campus in Grand Forks, North Dakota.

At SAM, the drone tracked astronauts reliably in open terrain but lost lock near rock walls and the tunnel, with collisions against thin obstacles. Performance degradation was potentially caused by the infrared sensor's limitations on uneven surfaces. At ILMAH, the drone required manual initiation; once engaged, the "Blueberry" suit, with visor cover and contrast markings, was tracked successfully, while the "Cherry" suit suffered inconsistent recognition.

These findings highlight the promise of sUAS for EVA support and the need for improved algorithms, LiDAR sensing, and EVA suit adaptations.

Keywords: sUAS, Drone autonomy, Obstacle avoidance, Exravehicular Activity, Ingenuity, Analog Astronaut, Martian mission

Pruebas operativas de seguimiento de drones y evitación de obstáculos en entornos marcianos simulados

Resumen

El helicóptero Ingenuity de la NASA demostró la viabilidad de la movilidad aérea en Marte, lo que inspiró este estudio sobre el papel de los pequeños sistemas aéreos no tripulados (sUAS) en el apoyo

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a las actividades extravehiculares (EVA) de los astronautas. Con un DJI Mini 4 Pro, evaluamos el seguimiento autónomo de astronautas y la evasión de obstáculos durante dos misiones análogas a Marte: el Análogo Espacial para la Luna y Marte (SAM) en Oracle, Arizona, y el Hábitat Análogo Integrado Luna-Marte (ILMAH) en el campus de la Universidad de Dakota del Norte en Grand Forks, Dakota del Norte.

En SAM, el dron rastreó a los astronautas con fiabilidad en terreno abierto, pero perdió la sincronización cerca de las paredes rocosas y el túnel, con colisiones contra obstáculos delgados. La degradación del rendimiento se debió posiblemente a las limitaciones del sensor infrarrojo en superficies irregulares. En ILMAH, el dron requirió activación manual; una vez activado, el traje "Blueberry", con visor y marcas de contraste, fue rastreado correctamente, mientras que el traje "Cherry" tuvo un reconocimiento inconsistente.

Estos hallazgos resaltan la promesa de los sUAS para el apoyo a las actividades EVA y la necesidad de mejorar los algoritmos, la detección LiDAR y las adaptaciones de los trajes EVA.

Palabras clave: sUAS, autonomía de drones, evitación de obstáculos, actividad extravehicular, ingenio, astronauta analógico, misión marciana

在模拟火星环境下对无人机跟踪和避障进行运行测试

摘要

NASA的“机智号”直升机证明了在火星上进行空中机动的可行性，这启发了我们开展关于小型无人机系统(sUAS)在支持宇航员舱外活动(EVA)中作用的研究。我们使用DJI Mini 4 Pro无人机，在两项火星模拟任务中评估了自主宇航员跟踪和避障能力：一项是位于亚利桑那州奥拉克的月球和火星空间模拟任务(SAM)，另一项是位于北达科他州大福克斯市北达科他大学校园的综合月球-火星模拟栖息地(ILMAH)。

在SAM任务中，无人机在开阔地形中能够可靠地跟踪宇航员，但在岩壁和隧道附近会失去锁定，并撞到一些细小的障碍物。性能下降可能是由于红外传感器在不平坦表面上的局限性造成的。在ILMAH任务中，无人机需要手动启动；启动后，带有面罩和对比标记的“蓝莓”宇航服能够被成功跟踪，而“樱桃”宇航服的识别则不稳定。

这些发现强调了小型无人机系统在舱外活动支持方面的潜力，以及“改进算法、激光雷达传感和舱外活动服适配性”的必要性。

关键词：小型无人机系统(sUAS)，无人机自主性，避障，舱外活动，机智号，模拟宇航员，火星任务

Purpose

The purpose of this research was to evaluate whether a consumer-grade sUAS, the DJI Mini 4 Pro, could reliably identify, track, and follow astronauts in analog EVA suits while autonomously avoiding obstacles in both natural and constructed analog environments, and to identify gaps that would need to be addressed before real-world execution.

Methods

This research was conducted across two high-fidelity analog environments: the Space Analog for the Moon and Mars (SAM) at Biosphere 2 in Oracle, Arizona, and the Integrated Lunar-Mars Analog Habitat (ILMAH) at the University of North Dakota in Grand Forks, North Dakota. At SAM, the drone was tested in a warehouse-sized Mars Yard with carved rock walls, uneven terrain, and a lava tube. At ILMAH, the drone was tested in an open field with natural obstacles such as trees.

For each trial, EVA-suited astronauts deployed the drone from a marked takeoff zone. The drone was elevated to a height of 15 feet, and ActiveTrack 360° mode was engaged to allow the drone to follow the astronaut autonomously. Three primary scenarios were tested: open terrain tracking, perimeter navigation along walls or trees, and occlusion response when the astronaut moved behind an obstacle. Performance data were collected through 4K onboard video footage, flight logs, and observer notes.

Results

At SAM, the drone demonstrated reliable tracking in open terrain but exhibited significant failures when astronauts approached or moved behind rock walls. Tracking failed 50% of the time when astronauts walked directly toward a rock wall and 100% of the time when moving behind walls or into a tunnel. The drone also experienced two collisions: one with an angle-iron crossbar and one with a suspended rope, both thin obstacles that the visual and infrared sensors failed to detect. Infrared-based obstacle avoidance also appeared to degrade in uneven terrain, where inconsistent light reflection likely reduced sensor performance.

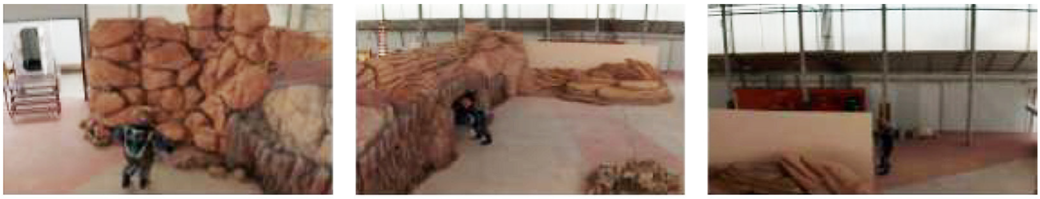
At ILMAH, the drone was unable to auto-recognize astronauts from behind and required the astronaut to face the drone to initiate ActiveTrack 360°. Once engaged, performance varied by suit. The "Blueberry" suit, with a visor cover and contrasting markings, achieved consistent and accurate tracking even through tree occlusions. In contrast, the "Cherry" suit, which appeared visually headless and had minimal markings, experienced up to 80% tracking failures during occlusions and sharp turns.

Facility/Suit	Acquiring Active Track 360 on the Astronaut's back	Losing an Astronaut in the open (>5 ft from any structure)	Losing the Astronaut during a direct approach to a wall or obstacle	Losing the Astronaut while walking near a wall or obstacle (within 5 ft)	Losing the Astronaut behind an obstacle	Collision with an obstacle
SAM suit	0 fails / 5 attempts **(0% failure)**	0 fails / 3 attempts **(0% failure)**	3 fails / 6 attempts **(50% failure)**	0 fails / 2 attempts **(0% failure)**	2 fails / 2 attempts into the tunnel 3 fails / 3 attempts behind the wall **(100% failure)**	1 collision with an angle-iron support 1 collision with a rope hanging from the ceiling
ILMAH "Blueberry" suit	6 fails / 6 attempts **(100% failure)**	0 fails / 6 attempts **(0% failure)**	Not applicable	1 fail / 13 attempts around trees **(7.6% failure)**	0 fails / 6 attempts through trees **(0% failure)**	None
ILMAH "Cherry" suit	6 fails / 6 attempts **(100% failure)**	1 fail / 6 attempts **(16.6% failure)**	Not applicable	2 fails / 12 attempts around trees **(16.6% failure)**	4 fails / 5 attempts through trees **(80% failure)**	None

Figure 1. *A Table of Attempts and Fails Across Various Categories*

Discussion

These results highlight both the promise and limitations of consumer-grade sUAS in planetary analog environments. While effective in open terrain, the Mini 4 Pro struggled in complex environments with occlusions and thin obstacles. This limitation is linked to its reliance on visual and infrared sensors. Other DJI models feature LiDAR-based sensing that could improve detection, but such hardware increases weight and reduces battery life. For planetary missions, this trade-off between capability and endurance is a significant design challenge.



Note: (Left image) The rock wall with a 50% failure rate. (Middle image) The tunnel with a 100% failure rate. (Right image) The wall with a 100% failure rate.

Figure 2. *Images of Failure Locations at SAM*

The study also revealed the importance of EVA suit design in sUAS recognition. Blueberry's visor cover and contrasting markings enabled more reliable tracking, while Cherry's lack of contrast and visible head structure reduced recognition accuracy. These findings suggest that suit adaptations, such as adding reflective surfaces, contrast markings, or integrated radio beacons, could complement hardware and software improvements to create a more robust system.

Note: The Blueberry suit (left 3 images) at ILMAH utilizes a visor cover along with two flashlights compared to the Cherry suit (right 3 images).

Figure 3. *Images of the EVA Suits at ILMAH*

Conclusion

Small uncrewed aerial systems have the potential to enhance EVA safety and situational awareness by providing real-time tracking and reconnaissance. However, current vision-based algorithms and lightweight sensor packages are not yet sufficient for complex planetary environments. Future research should investigate custom tracking algorithms, improved hardware solutions, and EVA suit adaptations. A combined systems approach will be necessary to make drones a reliable asset for planetary exploration.

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Limitations and Bias

This study was limited by a small sample size and reliance on a consumer-grade drone not optimized for analog conditions. Results may not generalize to actual Martian environments, where lighting, gravity, and atmospheric differences could alter performance. Suit differences introduced confounding factors. Findings represent exploratory observations rather than statistically validated results.

Conflicts of Interest

This research was funded through the APUS Faculty Research Grant. The author declares no competing financial or personal conflicts of interest. Portions of this work were previously presented in poster form.

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