Effective Autonomous Sterilization in Space Travel and Planetary Missions

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ABSTRACT

COVID-19 changed the world in many ways. It brought about many new inventions which have in a way prepared us for any future outbreaks which we would be able to tackle more effectively. Initially where frontline workers were cautious of treating even after wearing personal protective equipment were still at risk of exposure. Space technology often paves way for existing challenges on Earth. NASA's spinoff technologies have contributed extensively to various problems. We sent probes to the moon, Mars, and beyond because putting the most fragile element of any mission i.e humans were too risky or the technology for such missions was not in place. This led to the development of the Medical Assistant Robot to perform several tasks that a nurse/doctor would do with minimal contact, remotely and autonomously.

1 INTRODUCTION

Having previously built rovers for NASA's Human Exploration Rover Challenge being held in Huntsville Alabama and working on a robotic probe for disaster management on MARS, the idea for life detection and life sustainability has been highly ambitious research to attain maturity. We built first of its kind Medical Assistance robots with remote patient testing and UV/Disinfectant sterilization to fight the pandemic deploying nearly a dozen such bots in various hospitals in Mumbai. How can this model be replicated for sterilization in space travel and life on Mars/Europa?

2 BACKGROUND

2.1 COVID-19

The spread of the novel coronavirus was alarming in COVID Care Centers. Sterilization requires disinfectant to be sprayed every few hours. To reduce the exposure of a human disinfecting such a high-risk area, I developed a remotely operated medical assistance device with a UV/disinfecting sprayer as a part of the bot. The bot itself is one of its kind for the integration of medical platforms for remote vitals monitoring, disinfection, food/medicine delivery, and two-way interaction. It is semi-autonomous with line tracking autonomy, with a new combination of wheels with mecanum and heavy-duty regular wheels providing agility to spot turn reducing vibrations of mecanum wheels by 50%. This enables the bot to carry food for up to 120 patients at once. It is complemented by a one of its kind portable and mobile ECG/PPG monitoring system with 2 touch probes which makes quick and instantaneous measurements possible. This effectively reduces expendables such as PPE, Chemicals, masks while reducing the risk of infection.

Figure 1. Ignite Labs Robot with UV for COVID

2.2 Efficacy of UV

UVC and far UVC both have shown promising results in deactivating the majority of the pathogens, bacteria, and viruses. Firms such as UVD Robots, etc had deployed UV based robots in various hospitals to stem the transfer of infection during hospitalization. Boeing unveiled the self-cleaning lavatories in the 787 with the use of far UV light. The cleaning cycle takes just 3 seconds. This not only takes care of hygiene but also reduces expendables such as soap, water, tissue paper, etc. In response to the COVID outbreak and the stemmed aviation industry, for effective and quick sterilization Boeing designed a UV for with a 222nm wavelength to disinfect airplanes with an efficacy enough to inactivate SARS-COV-2. This also reduces the expendables such as electrostatic chemicals, etc. UV filters are used in water purifiers to purify the water post reverse osmosis for a long time. It does not leave any debris nor requires maintenance unless the light itself gets damaged/non-functional.

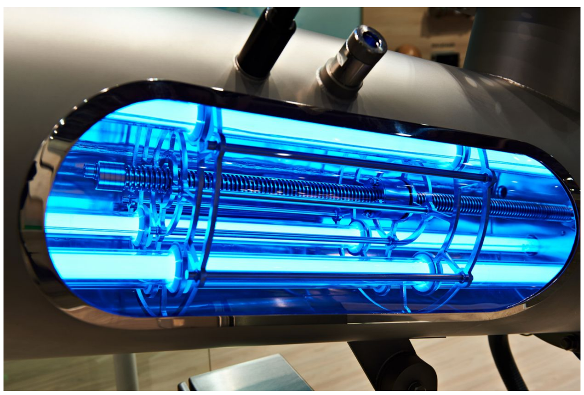

Figure 2. Actual UV Filter

3 HARDWARE CONFIGURATION

3.1 Mechanical structure design

Stainless Steel 304 grade is used to create the skeleton of the bot in 10 mm pipes. Initially, 3mm Acrylic fittings were laser cut to make up the body which later was changed to Mild Steel 0.5mm sheets for the side fittings and 1mm for the rest powder-coated. The motor mounts initially fabricated from mild steel with 1.5mm plates failed the load stress testing due to excessive shear load on the front end due to the mechanum configuration and shear load of up to 20kgs on each mount leading to bending. These mounts were upgraded to SS304 3mm plates now rated to up to 50kgs of load each. The structure is analyzed via AnSys to sustain a load of up to 120kgs with a factor of safety 1.75.

3.2 Mobility

Industrial Grade Planetary Gear motors each delivering a torque of 20kg-cm at 24 volts and 4 amps totaling to 80kg-cm. The motors are rated for 300 rpm enabling the robot to attain a top speed of 20kmph while moving along the long passageways. The bot's gross weight ideally at 25 kilograms and with a food load of up to 30kgs the motors are well below rated torque and much below the stall torque of 55kg-cm per motor. Initially, 4 regular Heavy-duty wheels were coupled with the motors which applied excessive shear load towards the center of the platform and the wheels itself causing excessive wear and horizontal vibrations with a displacement greater than 50mm. The hospital environment requires an extremely narrow wheelbase and turning radius. 4 mechanum wheels solved this problem with increased vibrations not within the accepted 3mm of displacement vertically along with the noise. Replacing the rear wheels with heavy-duty wheels reduces the vibrations to half while still maintaining its agility to turn within the front half which reduces the vibrations by 50% and less than 2mm only on the front end.This particular configuration reduces wheelslip, and the loss due to angular force while maintaining its rotational agility.

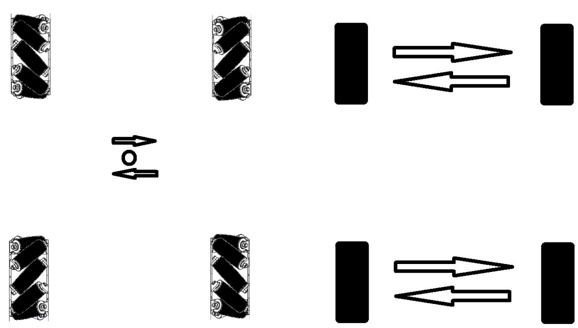

Figure 3. Regular Mechanum and Heavy Duty Wheel Setup

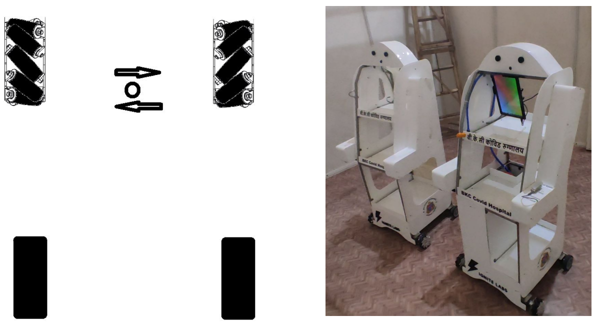

Figure 4. Chosen Setup

3.3 Power

A 22000 mah 6-cell Lithium Polymer battery pack powers the bot with instant blow fuse and short circuit protection. Step down converters power the microprocessor, the sensors, lidar, cameras. At full load and maximum speed the system utilises 484watts of power. However in most of the ideal conditions the system averages to 60 watts giving a battery backup of about 10 hrs with the 550 watt battery. A custom designed integrated power supply and quick charger recharges the battery at 390 watts within 90 minutes.

3.4 Sensors

The bot utiliss pure infrared distance sensors, 2-D lidar, stereo cam, pulse oximeter probe, ECG/PPG breakout board, thermal imaging array and the bot health/stats sensors including voltage, current, imu sensors. Its utilisation is for autonomy, robot stats and patient vitals.

4 Software

4.1 WiFi/ IOT based system.

The software part of the robot consists of 5 different platforms combined to function Linux based Raspian, shell/bash scripts, python, html/css, C++. Linux based Raspian runs the operating system onboard which links the html based web. The bash/shell commands execute the motion via PWM to the motor drivers after taking inputs from the obstacle avoiding sensors. The vitals monitoring system uses microcontrollers interfaced to the microprocessor via serial communication and python processes the data to the web based monitoring/logging.

4.2 Pure RF based system

The hardware for this system is similar just that there are additional control/video transmitters and receivers. Centers which lack the resources of WiFi are installed with a low frequency pure RF based control system. This uses a 100-200 Mhz communication protocol for command and operation in dense areas with multiple concrete walls. In case of a make-shift hospital, higher frequencies of 1.3ghz for video and 2.4ghz for control are utilised. The control box sends commands to the XBEE communication module which is interpreted by the microprocessor which computes the equivalent pwm and situation from the sensors to drive the motors.

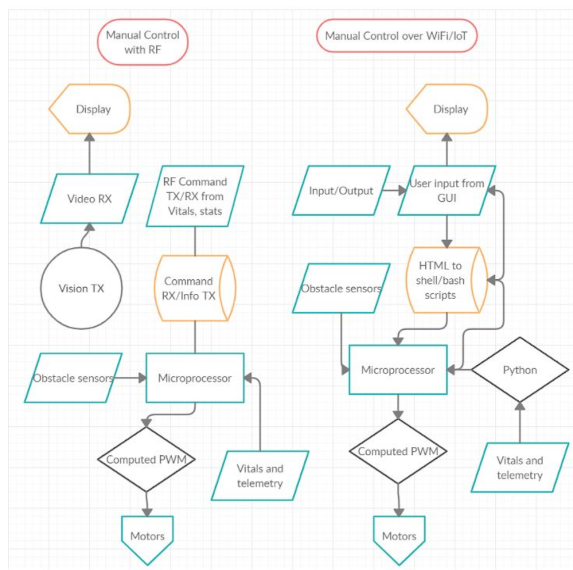

Figure 5. System data flow

5 Operation

5.1 Manual Operating mode

The operator has 2 GUIS one for robot operation and the other for vitals testing. Sensor and computer override is on a higher priority to avoid any collisions. The patient's vitals are stored in the hospital database and when the vitals are being tested, the admin sends an API request to fill in the patient vitals directly and that is processed to the microprocessor which logs in the data directly and without a manual trigger from the operator side. The advantage of operation in this mode is the speed of maneuverability given the makeshift hospital contains 1000 beds spread over a 200 metre long passage. Consistency of Wi-Fi signal is a necessity for manual mode. However due to hardware limitations, the system retains the previous channel of the same network until it drops completely. To overcome this, a python based script which auto switches the channel when a higher signal strength is available was created to make the video and control feed seamless and reliable with a latency of less than 100 ms.

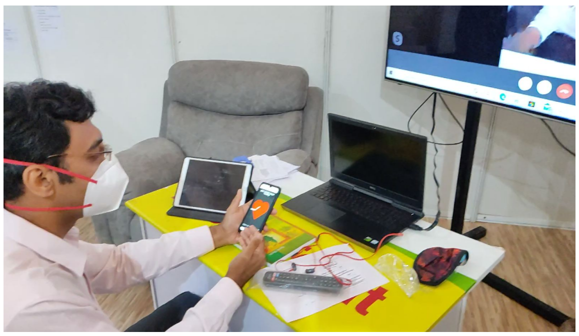

Figure 6. Remote vitals in safe zone

Figure 7. Direct access to critical patients

5.2 Autonomy in operation.

When in an autonomous mode of motion, there are 2 modes available. In the first mode a track following mode is used to assist the operator and maneuver through the dedicated wards and navigate through the wards. In this semi autonomous mode the commands are received from the user operating from a safe(non COVID) area. The track following sensors complemented by the stereo vision from opencv combine and assist the operator to reach a certain location swiftly. Currently the fully autonomous mode is based on stereo camera based navigation. This is specifically utilised to track vitals of patients with a fever. A model is trained with the path inside a ward and fed in the system to replicate against all wards. All wards have the same layout which makes the operation seamless and reliable for autonomy. While inside a ward, the bot clicks a thermal image and sends it to the doctors control room for each ward. The limit for fever is set at 99 degrees F.

Using open source human identification library and open cv combined with the thermal image the location of the suspect is identified and the bot moves as close as possible to the suspect patient using its vision and obstacle avoidance system(lidars/infrared sensors).Once it arrives near the patient the patient put his/her finger in the pulse oximeter probe and the tablet onboard display the self diagnostic report and monitored via the doctors room. if any anomalies are found in the values of temperature(greater than 99F), pulse rate(outside 60-100)or oxygen saturation(less than 91), the doctors room is alerted and the ECG of the patient is tested via 2 single touch probes. On obtaining the ECG/PPG graph a decision is made by the doctors. This leads to a quick response/action when the condition of a patient is deteriorating.

Currently the normal PPG/ECG graphs of healthy patients are being modelled for an AI model to detect anomalies in ECG without the need of a nurse/ doctor.

Figure 8. 2 probe ECG/PPG testing

Figure 9. 2 probe ECG/PPG sensor

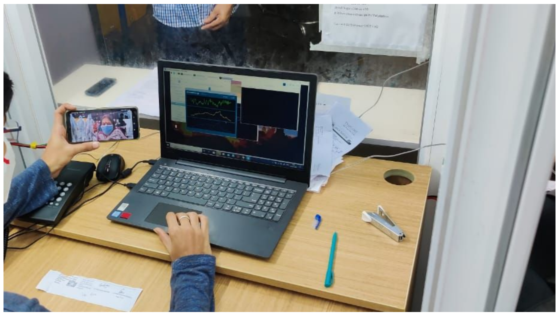

Figure 10. Remote ECG/PPG graphs

Figure 11.Thermal Array cam feed for fever tracking

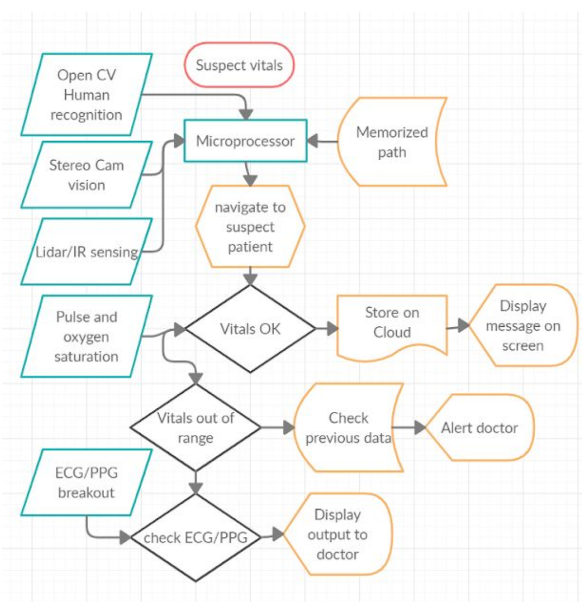

Figure 12. Autonomy Data flow

Figure 13. Instant vitals diagnosis on display of the bot

5.3 FAR UV vs 285nm UVC sterilization

Optionally the robot also features a combined sterilization using a combined 222nm and 285 nm UV Led strip for disinfection. A 285 nm UVC poses a skin cancer/ cataract risk to humans. The same vision system used to detect humans switches the disinfection mode from 285nm to 222nm UV source to eliminate the risk of exposure. In the newer models purely 222nm light sources are used to disinfect passage ways, tables, beds and frequently contacted surfaces. Two linear actuators with a 600mm stroke house the 500 watt UVC with a wavelength of 222nm making it safe for operation around humans.

5.4 Potential future upgrades

Currently at a makeshift hospital with 1000 bed facility, average 350 ppes are utilised on a daily basis. One of these robots has shown potential to reduce the staff by 5 nurses/wardboys. The utilisation of ppes can be greatly reduced if this bot is upgraded to do swab test, mobilize samples,etc and greatly reduce the workload on an already overloaded medical staff. A fully autonomous system is currently being tested which continuously monitors patients, suspects the potentially worsening cases by an AI algorithm merged with patient x-rays from the cloud and keeps on checking vitals of such patients. The facilities lack vitals monitoring equipment and the whole system is under stress where only one or two nurses/ward boys attend over 50 people. The fever tracking algorithm takes care of vitals of those having a fever. However if the Oxygen saturation values are stored and accessed back for those with marginal values, it can frequently check patients with low SpO2 fully autonomously. For a new concept portable ICU unit that caters COVID-19 patients on ventilator/critical care, a low key and small UVC based bot is in development with similar navigation profile. This is particularly to reduce viral load in these containers as exposure to medical staff is relatively higher in these situations. Modifications are in development to add a drop and place equipment for food/supplies.

6 UV Based Air Filtration System

6.1 Existing Methods of Sterilization

Current air filtration systems at the ISS use an expendable/replaceable HEPA filtration system that provides clean/microbe-free air for respiration and other activities. However, there have been instances of contamination at the ISS due to these filters. Dry Heating i.e heating the spacecraft/payload for prolonged periods is one of the methods of killing microbial contaminants before a spacecraft is launched. It still carries the atmospheric contaminants into space

Contaminants generated aboard crewed spacecraft by diverse sources consist of both gaseous chemical contaminants and particulate matter. Both HEPA media filters and packed beds of granular material, such as activated carbon, which are both commonly employed for cabin atmosphere purification purposes have efficacy for removing nanoparticulate contaminants from the cabin atmosphere. The phenomena associated with particulate matter removal by HEPA media filters and packed beds of granular material are reviewed relative to their efficacy for removing fine (less than 2.5 micrometers) and ultrafine (less than 0.01 micrometers) sized particulate matter. Considerations are discussed for using these methods in an appropriate configuration to provide the most effective performance for a broad range of particle sizes including nanoparticulates[1].

6.2 Proposed UV filtration system

A UV filter will reduce the expendables and increase the efficiency of the air filtration system. The main advantage of a UV filter against HEPA filters is its one-time installation cost against the recurring cost of HEPA filters. Also, the efficacy of HEPA filters reduces with time. HEPA filters are expendable while the UV Filtration system is not. For Space travel to mars and beyond, replacing HEPA filters would lead to additional payload and space utilization which can be replaced by a more effective and

Airlocks act as an active interface for the transfer of bacteria/microbes in/out of the spacecraft/potential habitat on mars. Airlocks often could become the medium of transmission of contaminants. There have been at least a dozen incidents of contaminants being present in cleans rooms which can be stemmed by UV sterilization. Just as the airlock system, the entry/exit points of the ISS and the vehicles can be fitted with a UV sterilizer to sterilize the contaminants moving in/out of the entity of concern. Clean rooms have been found to have a substantial bacterial load at multiple instances. The efficacy of the UV system relies on the power and dosage of UV light on the infected area/contaminants present. Using AI the dosage of UV during the onward and return trip can be adjusted to suitably kill probable microbes/contaminants. These can simply be integrated with the air circulation system replacing traditional HEPA filters. A close examination of the filter thickness used in space applications and the equivalent dosage via UVC would reduce the size of the filter by one half. This would use barely 5-7volts and less than 3watts of power.

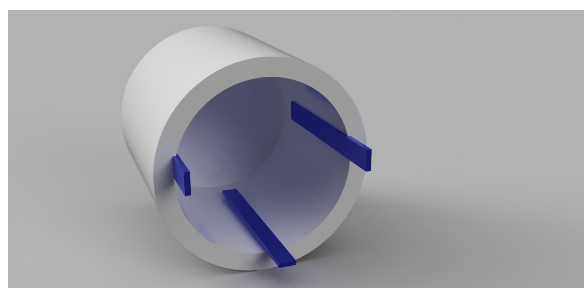

Figure 14. Cross Section of Air Lock with UV

6.3 Working of the filtration system

The air after being scrubbed for absorbing CO2,etc is passed through the UV filtration system instead of HEPA filters. At 50mw of intensity and at a distance of 3 cm from the light source, the air is purified within 5 seconds and processed for Ozone detection.

UV at times reacts with Oxygen to produce Ozone. A 185 nm UV begins to produce Ozone when reacting with Oxygen. UV light in the range from 160 nm – 240 nm creates ozone by the photolysis of the oxygen molecule. This disintegrates into valent oxygen atom (O) that combines with any individual oxygen

molecule O2 to form ozone O3. A dual ozone detection system is integrated to avoid being pumped back to the supply of filtered air. Ozone detectors in the filtration system will redirect the flow to an ozone reduction chamber. This chamber will incorporate the ozone module and reduce it to 2 Oxygen modules.
The flow detector will further detect for ozone and if not present will recirculate back into the module. However, if further ozone is detected which is possible even in ambient situations without a UV based filtration system, it will be redirected to a PECO Filter at the end of the system. This can also be swapped with Silica for ozone absorption.

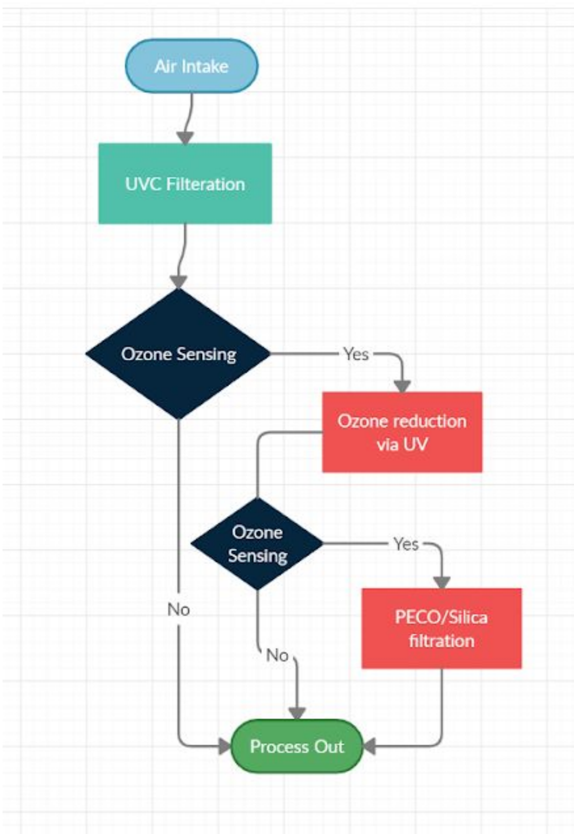

Figure 15. System flow

6.4 Potential Integration with MOXIE

MOXIE(Mars Oxygen In Situ Resource Utilization Experiment) is headed to the red planet on MARS 2020 which will produce oxygen from Martian carbon dioxide. According to JPL, NASA plans to send a larger version of MOXIE to mars by 2030. When utilizing for respiration and other activities in the hab on mars, the air could be directed into a UV based filtration system slightly modified than the ones on spacecraft/space stations. Ozone generated can be released back into the martian atmosphere. Rather than using scrubbing for CO2, the air can be recirculated directly to MOXIE and then in the loop of filtration.

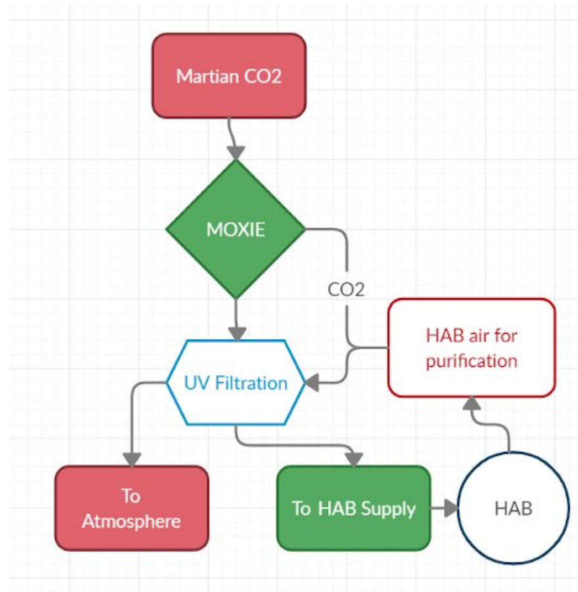

Figure 16. System Integration with MOXIE

6.5 Development towards the future

For deploying far UVC for complete sterilization of ICU units, my robot is currently been modified with inputs and testing by the NIV (National Institute of Virology, Pune) for efficacy of various frequency and power of UVC, Ozone detection to develop a more robust system for existing infectious diseases such tuberculosis, HIV, etc. Findings related to Ozone detection would propel the idea of a UV Filtration system in space and its inducibility and reliability. A small experiment based on a UV filtration system can possibly be launched to the ISS to test its efficacy and shortcomings. A miniature model of the filtration system can be induced and via air quality and Oxygen level sensors the data can be analyzed for feasibility in longer spaceflights.

7 CONCLUSION

Another Space spinoff technology which makes medical staff on the frontline of COVID19 centers less exposed to the infection and significantly reducing their workload for treating patients with mild to moderate symptoms was a result of 5000 plus lines of programming, 9 different hardware and software platforms and a contribution to the medical warriors. A technology used for numerous COVID applications i.e UVC and far UVC has potential in existing space applications such as air filtration and future space flights and space habitats on Mars. Upon further testing and results obtained with NIV research, a potential application could be tested in a Space environment, possibly an experiment in the ISS.

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