Hibot
DeepStar® 2023
Robotic Intervention During Outages NUF
FINAL REPORT

DeepStar® Director: Shakir Shamshy
DeepStar Project Manager: Linehan Curtis

Project Champion(s):
Mauricio Calva - Chevron Corporation
Steven Trevino - Shell
Adedeji Ogunbela - ExxonMobil
Marcelo Goulart – Petrobras
Tadashi Sakurai - INPEX

Contractor:
Hibot Corp.
Watanabe Corp. Bldg. 4F
5-9-15 Kita Shinagawa, Shinagawa-ku
141-0001 Tokyo, Japan.

Principal Investigator: John O'Brien
itcSkills LLC jobrien@ircinspect.com

October 30th, 2024

Table of Contents

1 EXECUTIVE SUMMARY

Hibot was awarded the reference project as a Phase II study and the detailed project work was developed as outlined in this report a large portion of the targeted work has been completed by the data of this interim report and the balance of site testing of new developments shall occur in the remaining months. Some preliminary tests were carried out at the Shell Technology Center Houston in October 2023 and further validation at the ExxonMobil refinery in Fawley, United Kingdom in December 2023.

As indicated in the original submission hibot have engaged with itcSkills LLC for digital integration and project management services. In accordance with contractual requirements monthly reports have been delivered to DEEPSTAR and there have been regular at twice per month engagements with the project sponsors in addition to multiple one on one engagements.

The project was originally championed by Chevron but as the work progressed Exxon Mobil, Shell, Petrobras and INPEX have become significant contributors and the trial work scheduled for this year and for next year may encompass tests at Chevron, Exxon, Shell, Petrobras and INPEX facilities.

The aim of Phase II was to work on improvements points for the float arm system based on the successful evaluations that were carried out during phase I in 2022. The primary developmental task has been completed and engineered; only field testing remains.

The aim of Nippon Foundation Funding contains desires to not only expand the technology but also the commercial progression. This has and is occurring across a number of industry sectors including oil and gas, nuclear, aerospace and offshore wind energy. Participation at numerous industry events and exclusive demonstrations has increased commercial interest for the long term success of the project. The engagement with sponsors and potential commercial users has been particularly welcome as this drives our thinking and product development to ensure a product industry ‘needs’ and ‘wants’. These engagements have also allowed us to begin developing and implementing access solutions that will serve the method by which each industry will access the final products.

Hibot have also been developing use cases with add-on technologies driven by funding external to this project and those solutions have been shared with sponsors of this current work driving further potential use cases and interests from project champions. These peripheral developments have not utilized funds from this project but add into the overall investment in Flat Arm solutions.

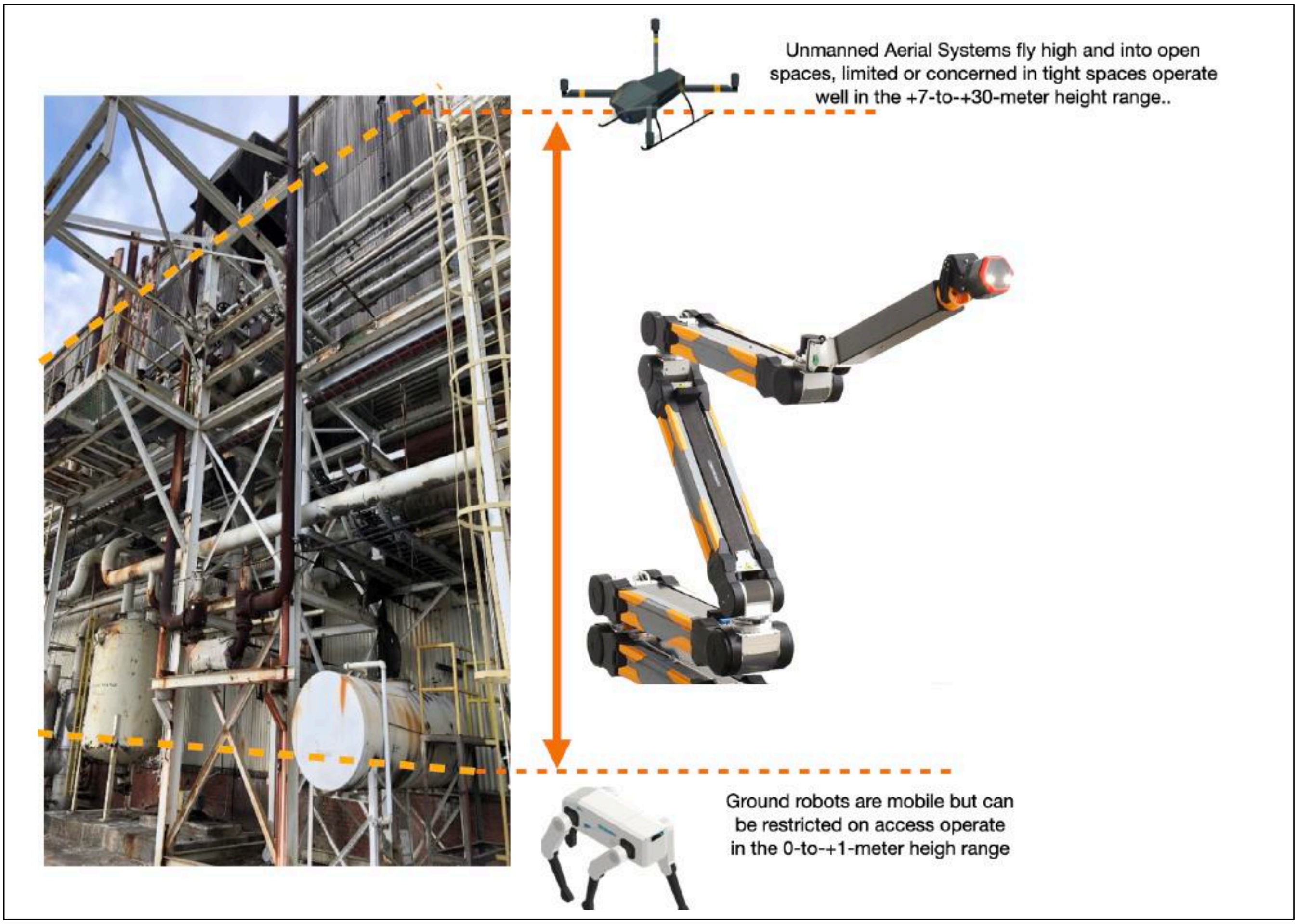
2 INTRODUCTION

2.1 SCOPE

This document outlines activities, past and planned, meant to explore and demonstrate the potential contribution of the Float Arm, a product by Hibot Corporation, towards meeting the objectives of the DeepStar consortium. In this respect, the Float Arm is currently being tested for its usability in the inspection of difficult to access parts or congested zones of offshore oil and gas facilities.

The potential areas of application (considering the currently available integrated sensors) of the Float Arm in offshore facilities include the following forms of remote inspection:
- Visual inspection of pipelines on floating facilities to determine corrosion and other damage.
- Determination of the wall thickness of pipelines on floating facilities.
- External visual inspection of tanks on floating facilities to determine corrosion and other damage.
- Determination of tank wall thickness at parts of the tanks that are difficult to access.
- Tank entrance and internal visual inspection of tanks in semi-autonomous mode.

Evaluation and test criteria are outlined for the evaluation of the Float Arm.
Future possible applications will target maintenance, such as coating, cleaning, blasting but also inspection with different type of sensors
The image below depicts the workspace that can be addressed by the float arm in comparison with other robotic solutions.



2.2 BACKGROUND

2.2.1 OFFSHORE INSPECTION: CURRENT PRACTICE

The future of NUF facilities (Normally Unattended Facilities), is to decrease the number of people and heavy machineries that are needed on site. Normally when operations of inspection and maintenance occurs, teams of 20~30 people are taken to offshore platforms with heavy machines.

Inspections must be carried out with precise and regular schedules. During these times human operators are requested to climb and move among difficult structures, to take pictures, using ultrasonic sensors to measure wall metal thickness and look at possible problems. In fact corrosions or cracks can cause issue in the offshore structure and even explosions.

The Float Arm is a long reach multi axis robot arm. To date it has been utilized to complete the following industrial inspections mainly at onshore locations:
The remote visual inspection of indoor and outdoor pipeline complexes at industrial complexes such as chemical plants, enabling high resolution imagery from elevated and difficult-to-access locations.
The remote measurement of pipe and tank wall thicknesses in industrial complexes such as chemical plants.

2.3 ABBREVIATIONS

Abbreviation	**Meaning**
CUI	Corrosion under insulation
NUF	Normally unattended Facilities
PEC	Pulsed Eddy Current
UT (sensor)	Ultrasonic sensor

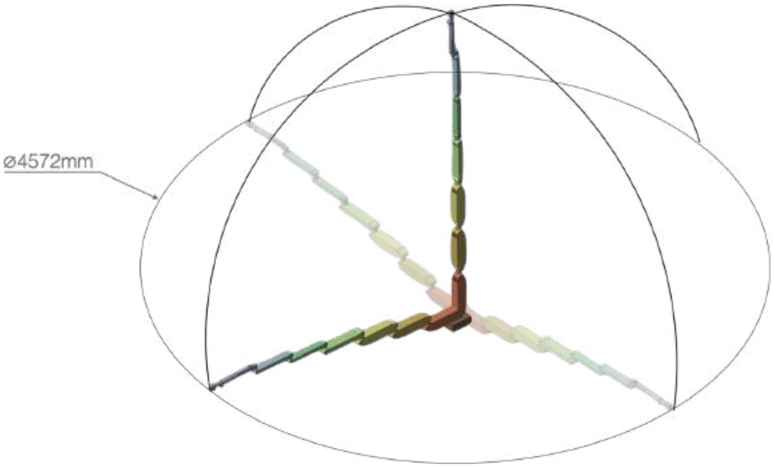
2.4 DETAILED OF WORK FOR PHASE II

Based on the results of the previous phase tests, it was decided to focus on the following major points of improvements:

- **Design of mechanical switch to allow downward motions**
- **Design of an easy portable base for deck to deck**
- **Integration of a gas sensor**
- **Improvement of software feature for faster and easier control**
- **Production of one set of float arm links from link n.6 to link n.1 (one unit)**

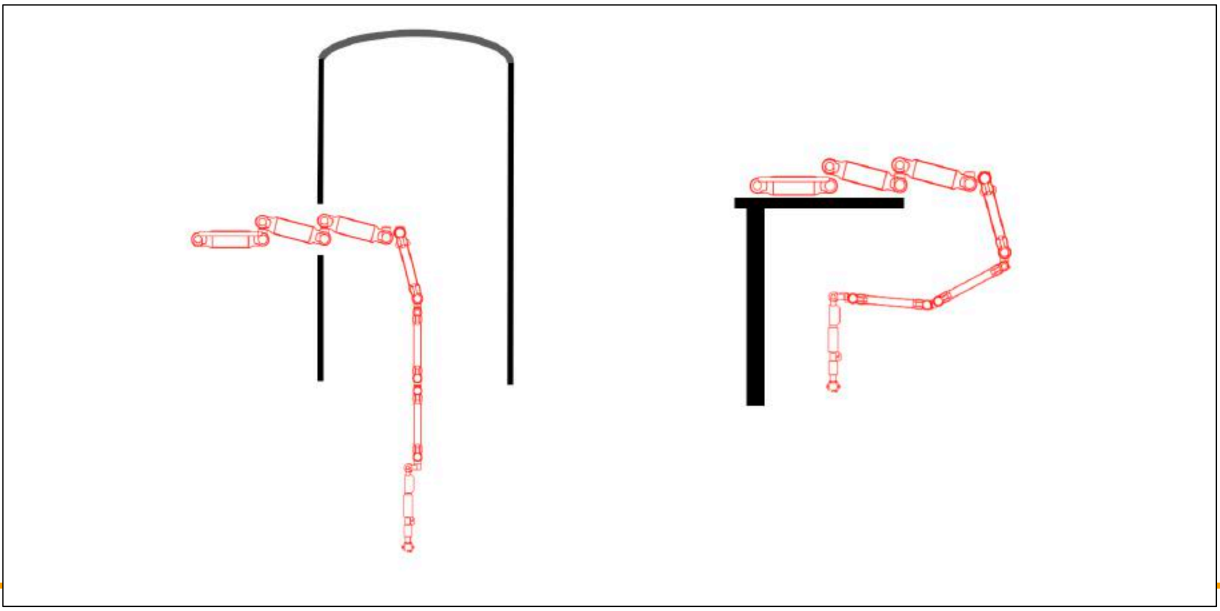
2.4.1 DESIGN OF MECHANICAL SWITCH TO ALLOW DOWNWARD MOTIONS

The workspace of the float arm consists, with its basic configuration, in a semispherical volume as shown in the following image.



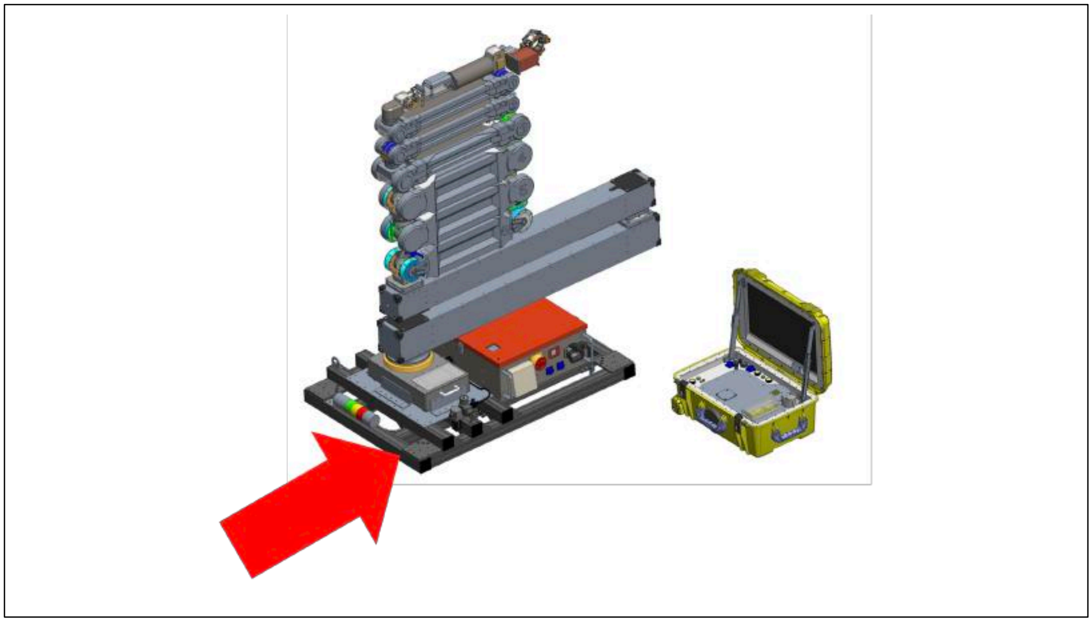
Arm workspace without the extension links

However, in several cases such as for inspections of vertical tanks with manways set in the middle of the asset or for under deck operations, the downward motion/workspace would be needed. For this option we proposed the development of a mechanical solution which could enable the upside workspace. By allowing the operator to select the mode of operation both workspaces might be enabled at least within the last four links of float arm. By enabling this option, the following two cases of operations would be possible:



2.4.2 DESIGN OF AN EASY PORTABLE BASE FOR DECK TO DECK

The following figure shows the actual base frame for the robot. It is used for stable motion and for hosting additional electronics such as the sub-box:



The base is at the moment heavy and sturdy to allow a simple setting of the float arm. Although during phase I, it was confirmed to be possible to be clamped on grating floors such the ones on off-shore platforms, sometimes the space for movement is minimum and it might be necessary to move it between different decks of the FPSO. For this reason, we will be working on a more compact and easier to move around FPSO and congested areas, base frame.

2.4.3 INTEGRATION OF A GAS SENSOR

Due to the type of explosive areas in off-shore platforms, in order to mitigate the non-ATEX configuration of the robot, we will be integrating a compact gas sensor which will allow to completely shut down the electric system of the robot in case of ELI gas detections.

2.4.4 IMPROVEMENT OF SOFTWARE FEATURE FOR FASTER AND EASIER CONTROL

For this development we will be working on motions that will further facilitate the utilization of the robot, features such as: click and go, collision avoidance and snake like motion will be integrated in the control system of the robot.

3 EVALUATION AND TEST CRITERIA

3.1 OVERVIEW OF EVALUATION

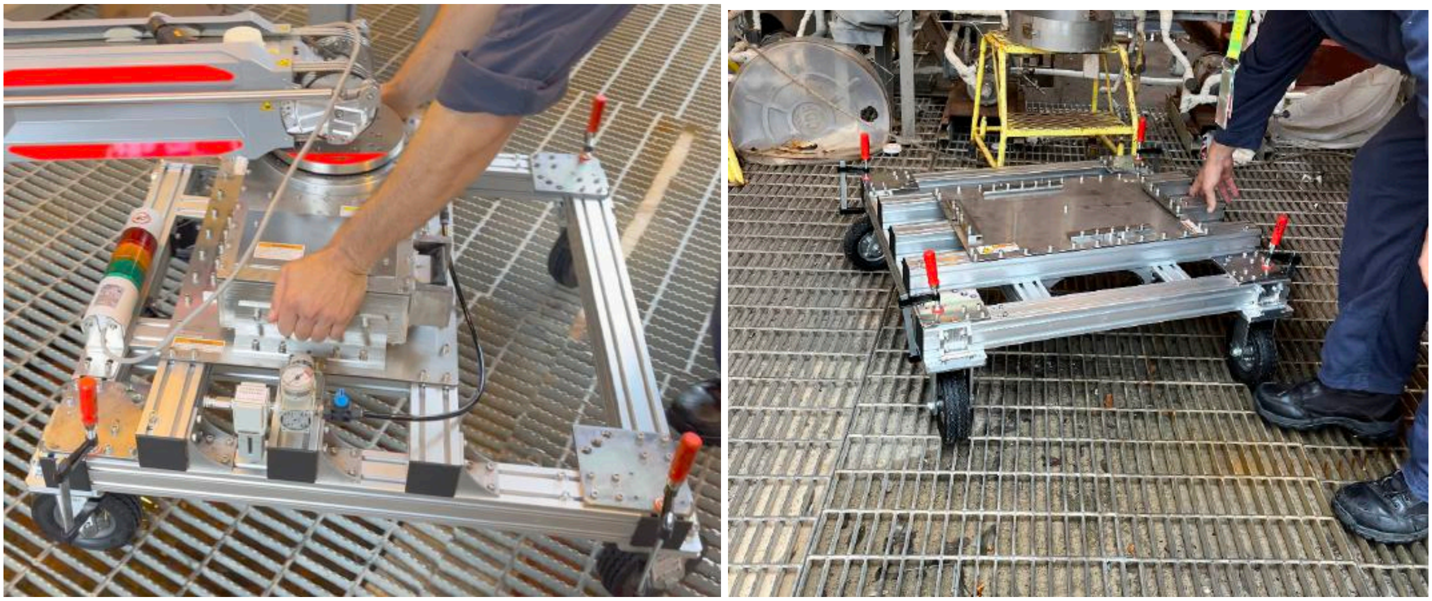
The project champions will design a test package to confirm and evaluate the targeted development for this phase II. As the development is still on going, the package will be presented with the completion of the project.

4 PRELIMINARY TESTS AND EVALATION AT HOUSTON SHELL TECHNOLOGY CENTER AND DEVELOPMENT STATUS UPDATE

On October 4,5 the robot was taken from Japan to Houston to be tested with a first new base frame concept and to verify the capability of the robot to avoid collision with the environment.
The tests were carried out in Shell Technology Center in Houston within the skid mockup.

Motions at heights, tank entrance and UT measurements were also carried out.

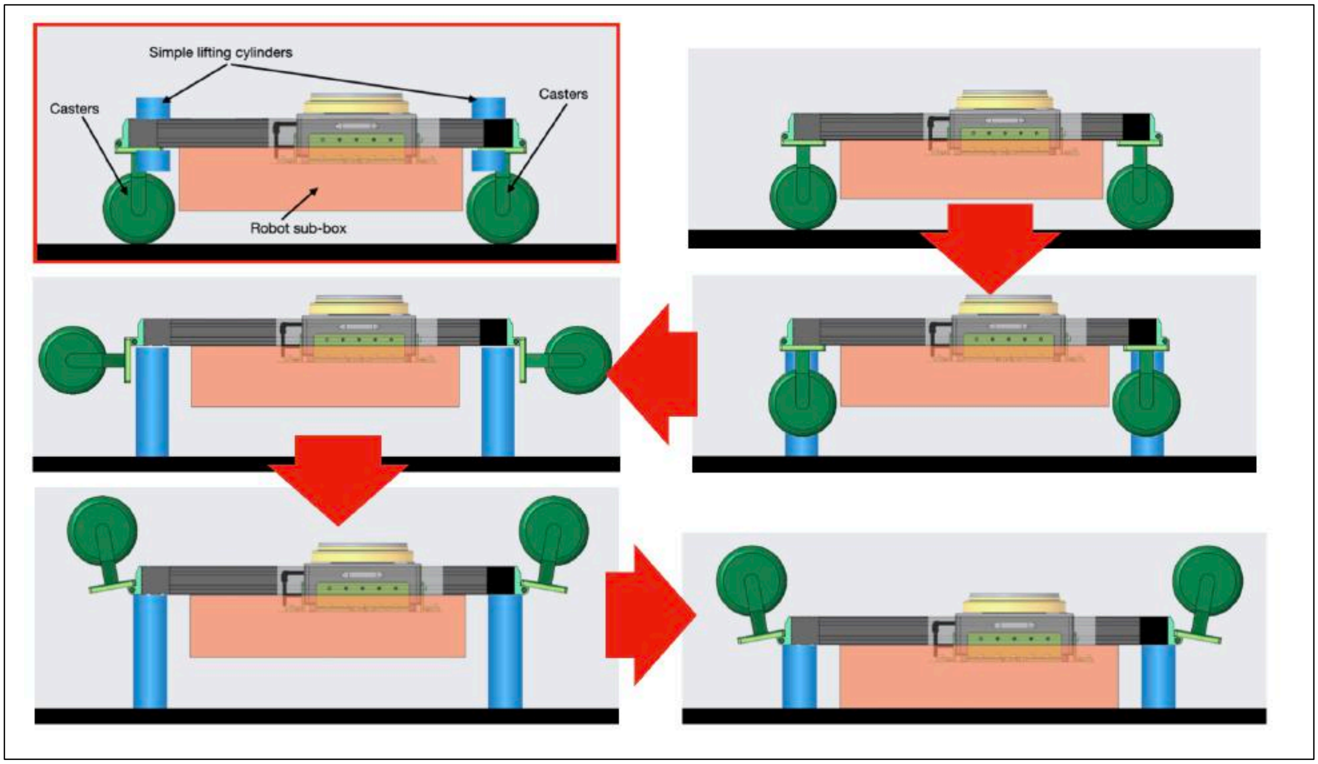
The base frame was changed from its original dimensions 80cmx120cm to 80cmx80cm with an additional caster added under the base to allow the base frame to be moved around on gratings and in narrow passages.
The following figure show the modified base frame that was tested.



The use of large casters under the frame was confirmed to be effective in moving the base around the skid mockup, bringing the time to move the robot to different locations from 40’ to 10’~15’ minutes in time.
The casters consist of a simple mechanism which allow them to be eventually flipped upside to allow a firm clamping of the base frame to the gratings or possible lifting mechanisms.
In the following photos, both configurations are shown.

As shown in the left figure, the casters during this highly congested access, were set upside to allow a firm and more stable base for the arm.

The tests allowed us to confirm what sort of final design the frame should be consisting of. Having the possibility to host the sub box electronic device under the base is an important feature, as well as the possibility to lift the base frame and finally to have also hooking points in case the base frame might be moved using the FPSO crane.

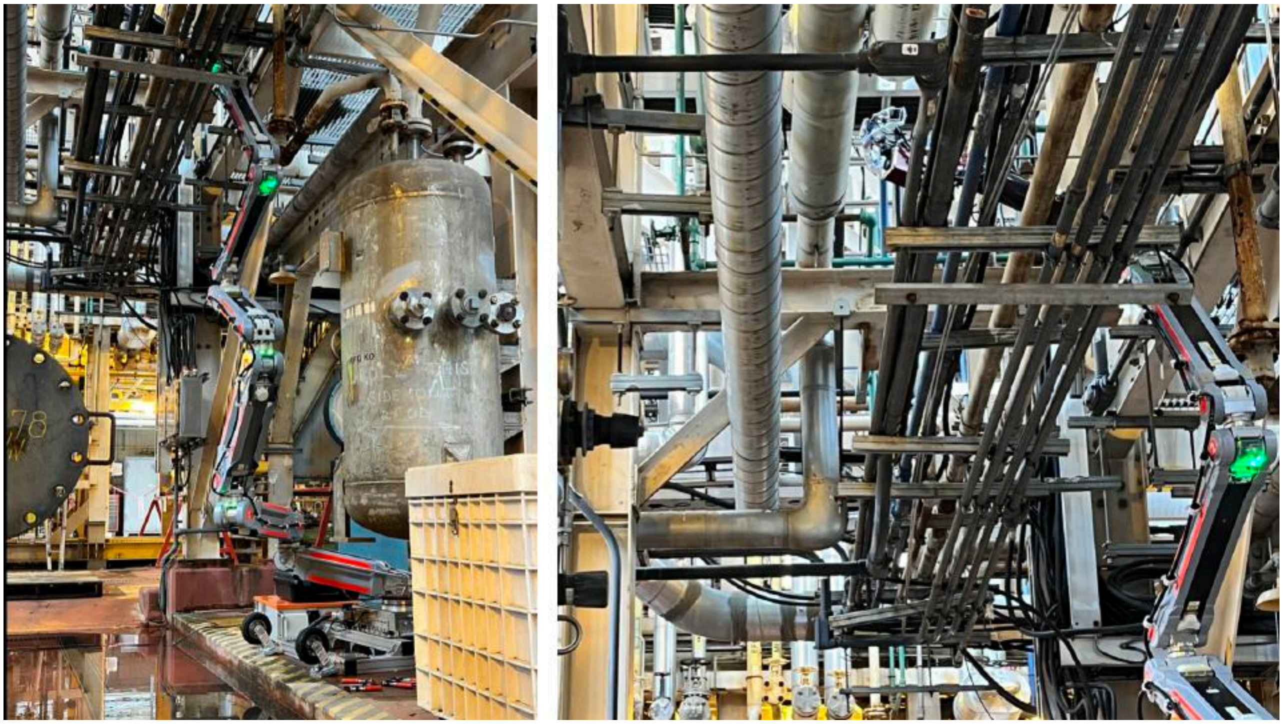


The figures above show the concept of the new base being designed and the sequence of motions that will allow an "easy set and move" of the float arm.

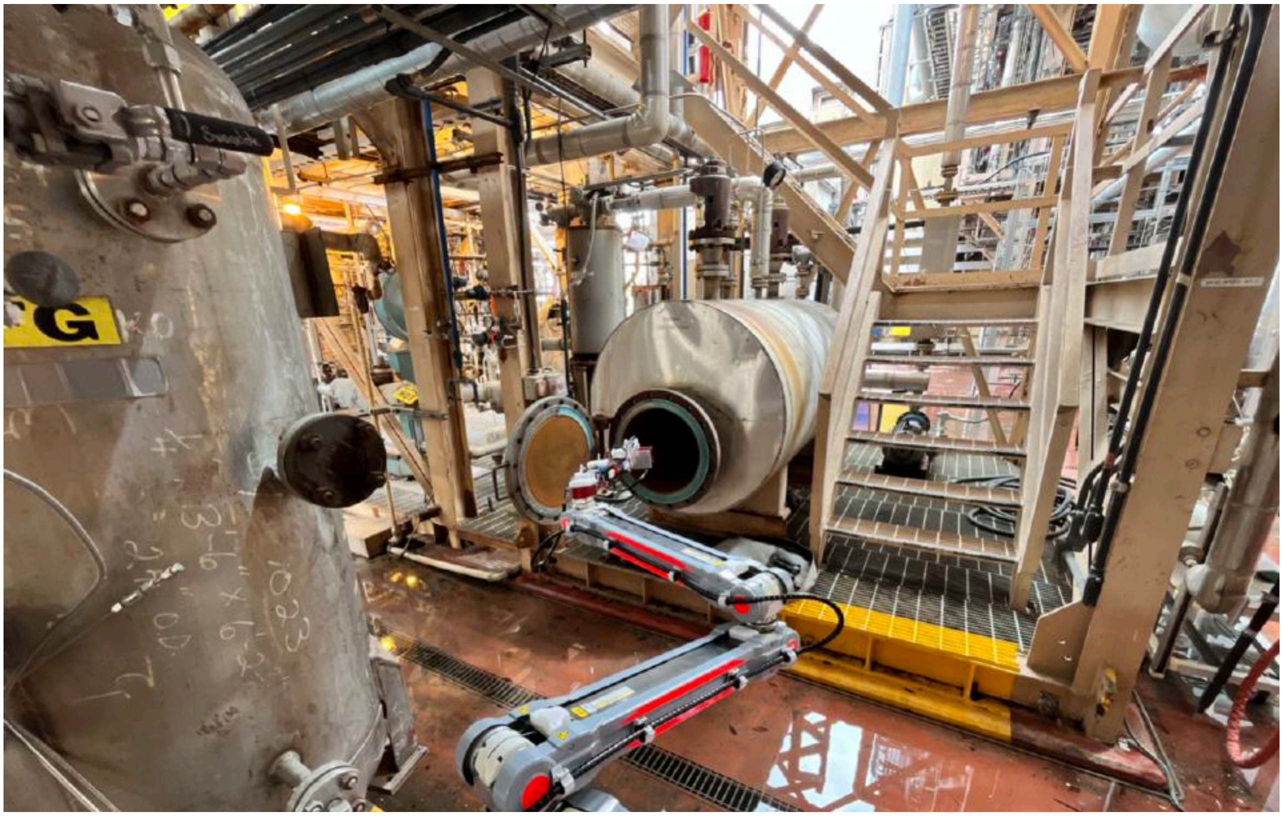
During the two days of testing the float arm features (visual inspection, UT and 3D data collection) were also tested and proven especially in the congested area offered within the skid mockup.

Tank entrance was also evaluated. As shown in the following figure, although the tank had internals, the arm performed well and could collected valuable information of the inside.

The performance of the collision avoidance was also confirmed. By setting a distance from all point of the point cloud it is possible to set, from the user interface, a safety zone. In case the robot might get in collision, the specific link will stop moving and start blinking in yellow, informing the operator of the possible collision.



Testing inspection on a height and with congested conditions



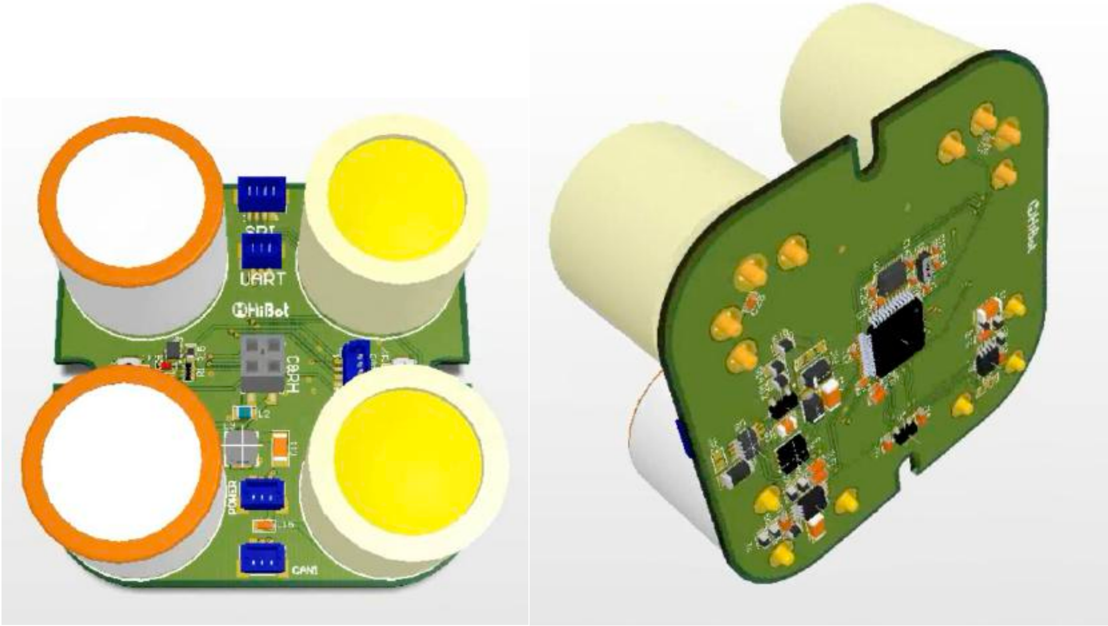
The arm is inserted in the vessel tank while avoiding the vertical internals standing in front of the manway

Data interface of the robot while inspecting the vessel tank

Measurements of wall metal thickness with spot UT sensors

4.1 GAS SENSOR

The following figure shows the actual design of the gas sensor board that will be integrated within the end effector (last link) of the arm.



The board is very compact in dimensions (45mm L x 45mm W x 30mm H) and offer the possibility to install up to 4 sensor modules. A microprocessor evaluates the signals and sends all detected levels to the main control board of the robot. In the user interface there will be the possibility to set the minim levels that eventually would trigger a hard stop of the power distributed to the robot through the main electric line.

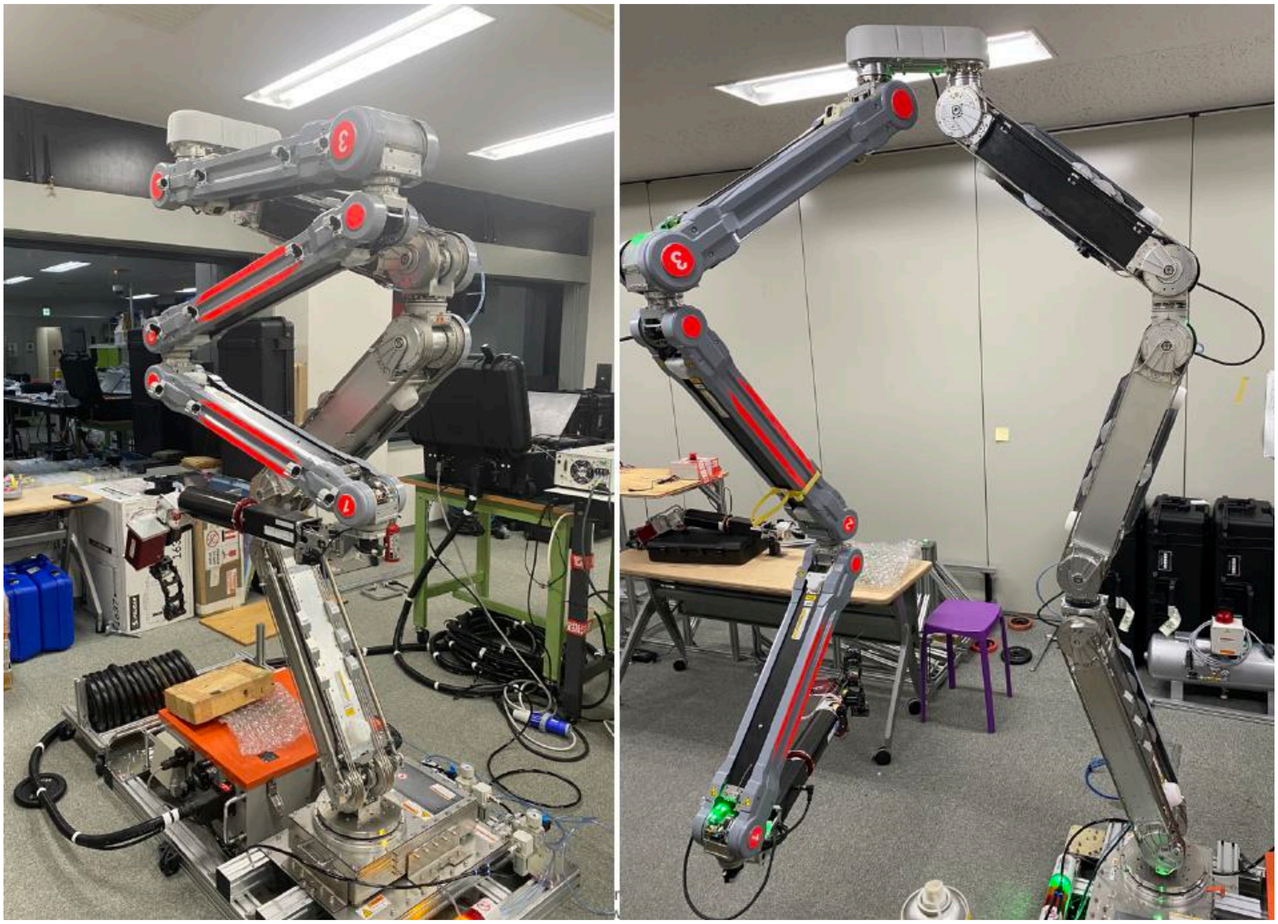
At the moment some of the sensor that have been tested are capable to detect the following gasses

O2, H2S, Pentane, Methane, CO2 , temperature and humidity.

4.2 DESIGN OF MECHANICAL SWITCH TO ALLOW DOWNWARD MOTIONS

The design of the mechanical feature allowing the downward motion have been completed and first three links have were assembled.

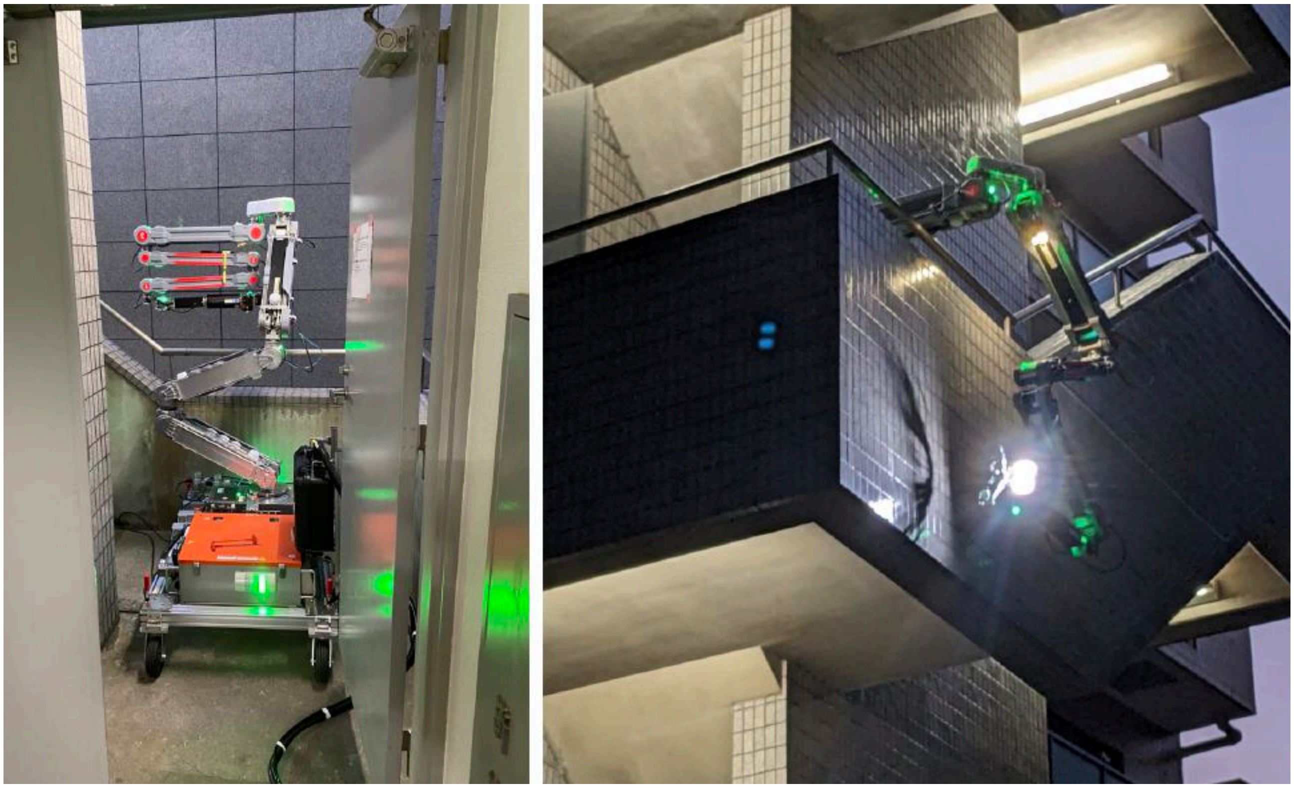
The respective software control on the user interface have been also modified to accommodate an automatic detection of the new configuration thus allowing new motions toward downward direction.



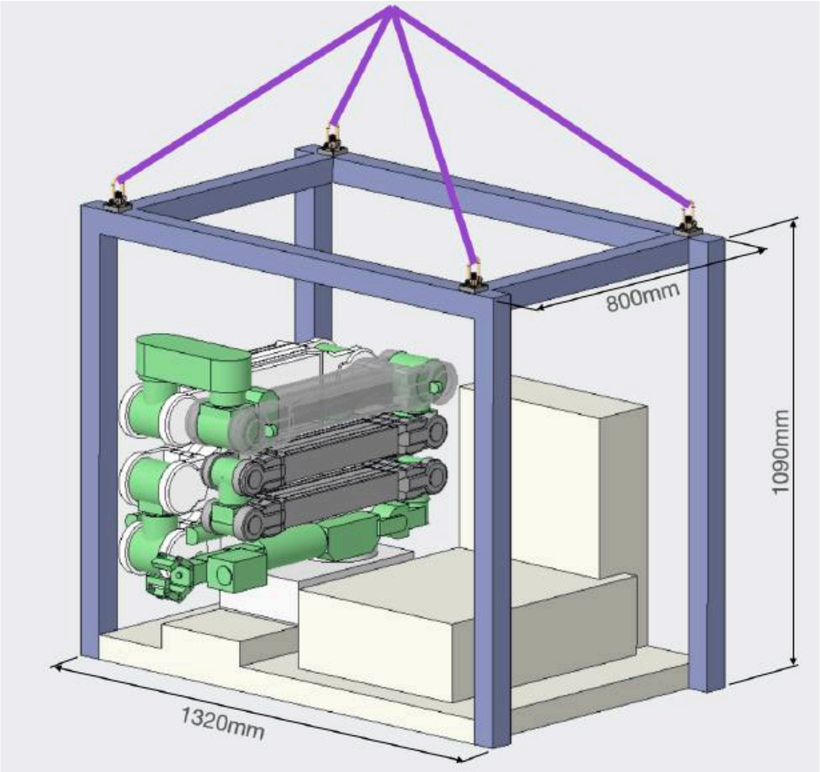
The figure above shows the first assembly of the links in downward motion and of the UD link, a part that connects the two arms.

The arm was also tested in outdoor condition and utilized already in an inspection of tanks housed in bunkers inside a nuclear facility in Belgium. The robot was deployed using a very compact cage which was delivered using a crane. This proved to be a very effective way of deployment which might be considered on FPSO when using the central main crane.

The arm with the downward configuration in its home location. The system can be very compact allowing the deployment in very narrow conditions.



Initial test of the arm in outdoor using the first prototype of the base frame



The new cage and base frame utilized to deploy the robot in downward motion within the nuclear facility

5 NEXT STEPS

We continue in our development according to our timeline as planned within the phase II. There has been a great support from all champions in setting up opportunities to test the system in different locations. Below we show some of the possible field trials that will occur throughout the rest of this development:

- SHELL supported for the Houston test (carried out in October 2023)
- ExxonMobil organizing a demo at Fawley (UK) refinery (carried out on 18th December 2023)
- Chevron exploring use for Europe and US use (Q1 2024)
- INPEX facilitating the testing on an off-shore platform in Abudabi and Japan (Q1~ 2024)
- Petrobras hoping to get opportunity for testing in Brasil and/or Singapore

6 SECOND TERM OF PHASE2 REPORTING

With the results obtained during tests and demonstrations in different regions, the following modifications were carried out to the system:

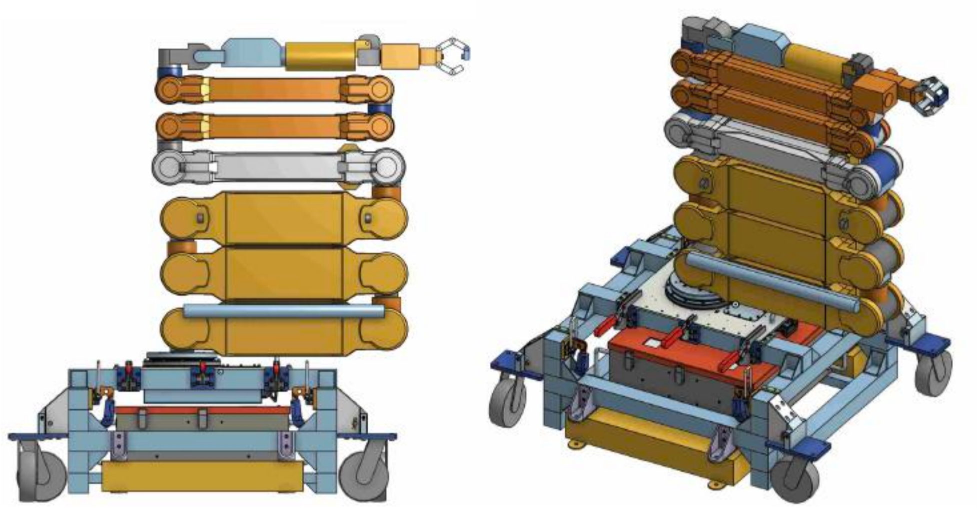
- Redesign of the base unit of the arm with allowing the installation by simple clamps vs the tithing of 20 bolts. This modification resulted in a decrease of the weight for the base unit of 7kg and a decrease in the time of installation from 10’ to 1’
- Redesign of casters wheels with removable parts so that the base could be fixed to the ground or a fork lifter.
- Redesign of the base frame with allowing the use of pneumatic pistons to allow the easy insertion and removal of the casters.
- Assembly of the gas sensor and its electronic/wiring
- Production of a set from 1 to 6 links for one float arm unit.

7 FINAL TESTING AND CONFIRMATION IN THE UNITED STATES

On May 2024, another mission in the United States was performed, the plan had the hibot team carrying out a demonstration at the OTC2024 conference, followed by a live demonstration at the Chevron building within the Technology event of Deepstar. Finally, one day of test was carried out at the SHELL facility where all new modification and features were tested and confirmed, with a last day of trial within the ballast tank challenge of the Sprint Robotics.

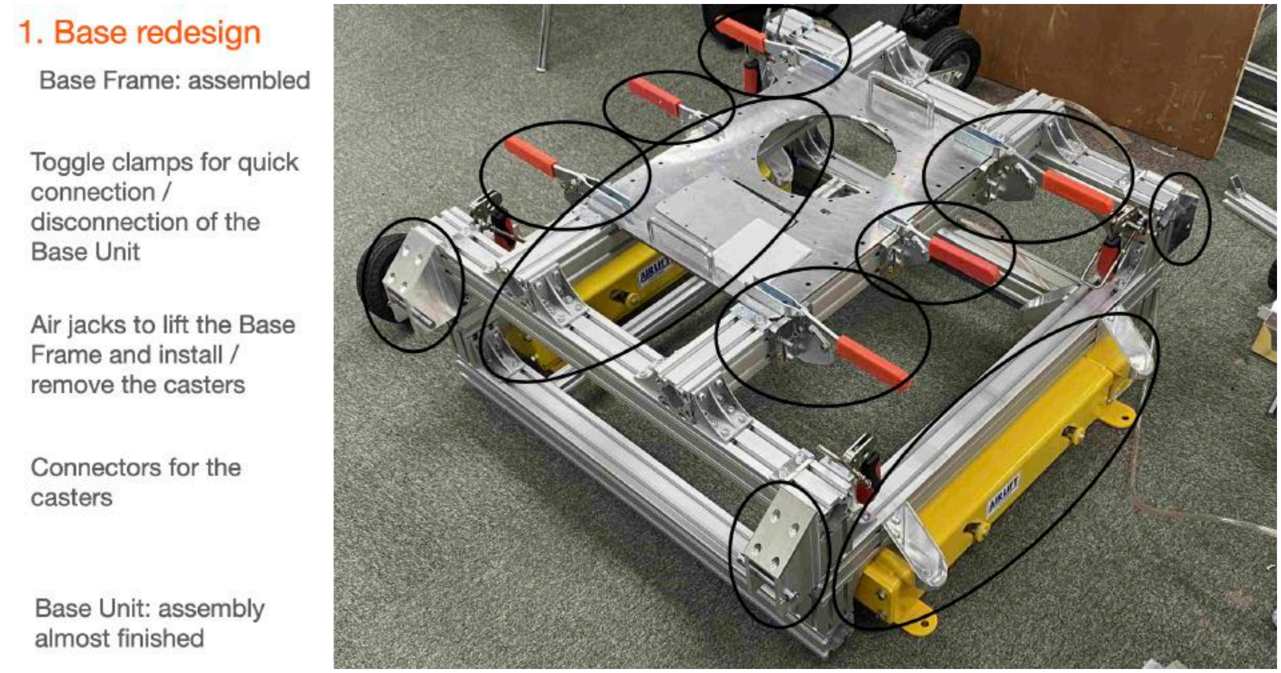
7.1 MECHANICAL DESIGN CHANGES FOR THE BASE FRAME AND UNIT

The following figure shows the new design that was confirmed with the deepstar members before production.



Design modification to the base – Clamps for the base unit and new pistons and caster modules

In the next set of figures the real modification are depicted and demonstrated



1. Base redesign

Base Frame: assembled

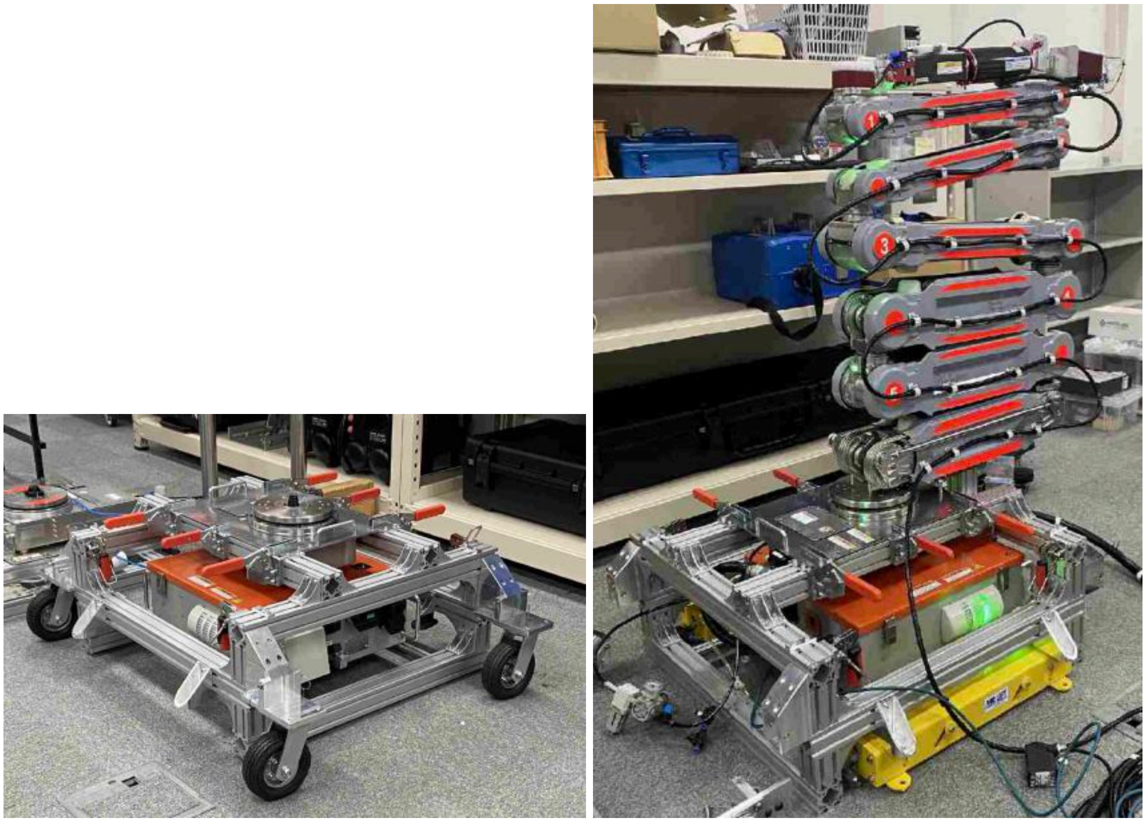
Toggle clamps for quick connection / disconnection of the Base Unit

Air jacks to lift the Base Frame and install / remove the casters

Connectors for the casters

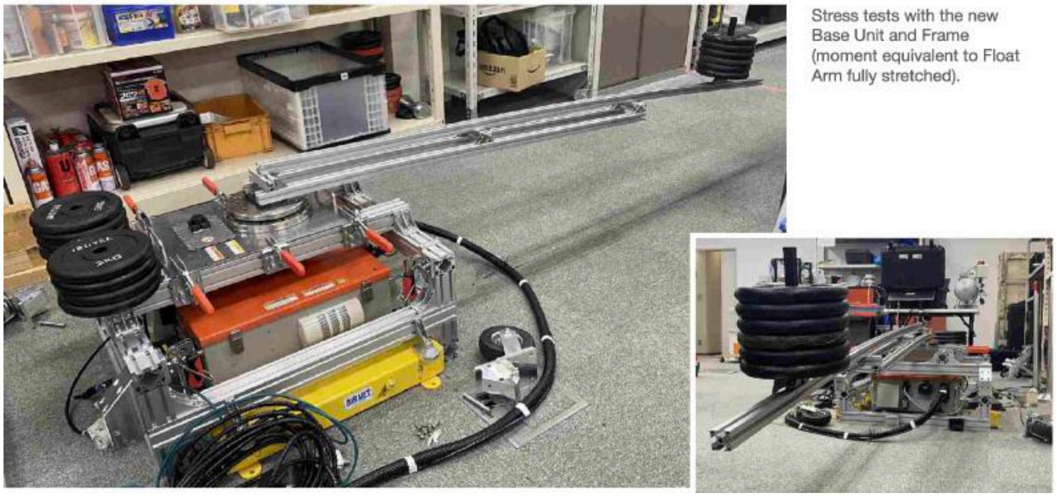
Base Unit: assembly almost finished

Finally the new assembly was presented:

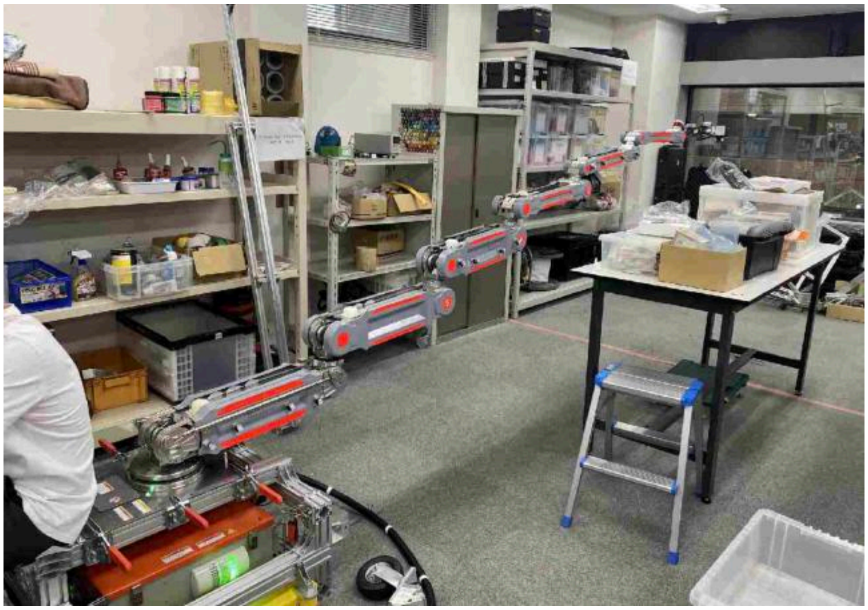


New casters modules with clamp mechanism and full machine assembled

The new design of the base unit was also tested with different weight conditions to simulate the momentum generated by the arm in a fully stretched configuration:



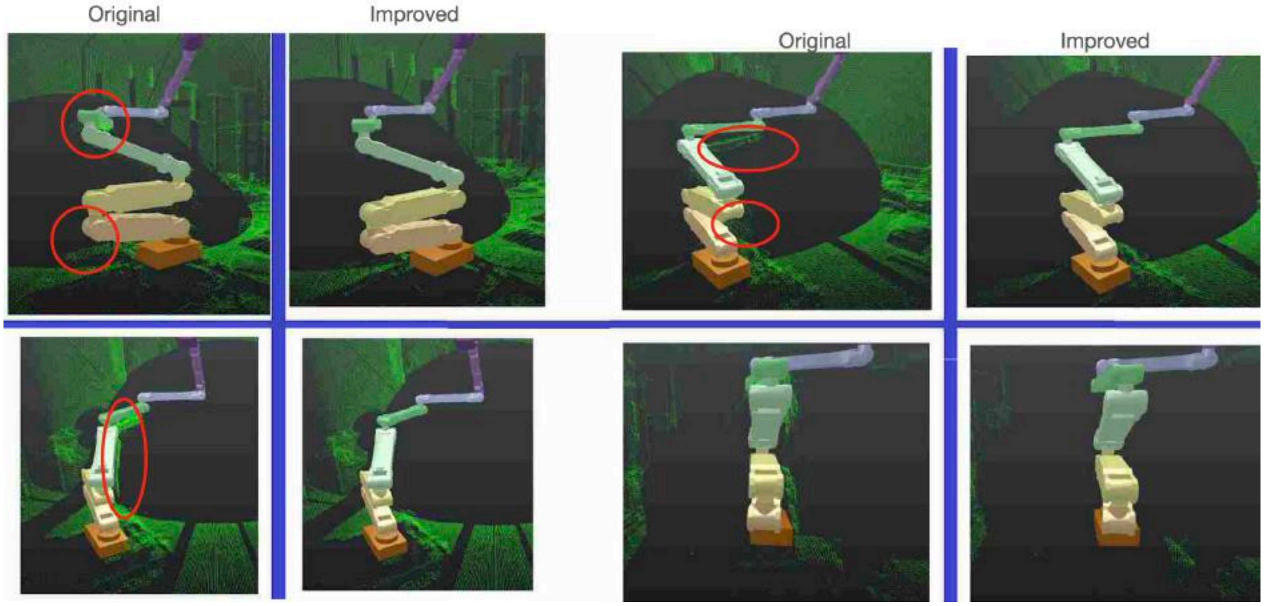
Stress tests with the new Base Unit and Frame (moment equivalent to Float Arm fully stretched).



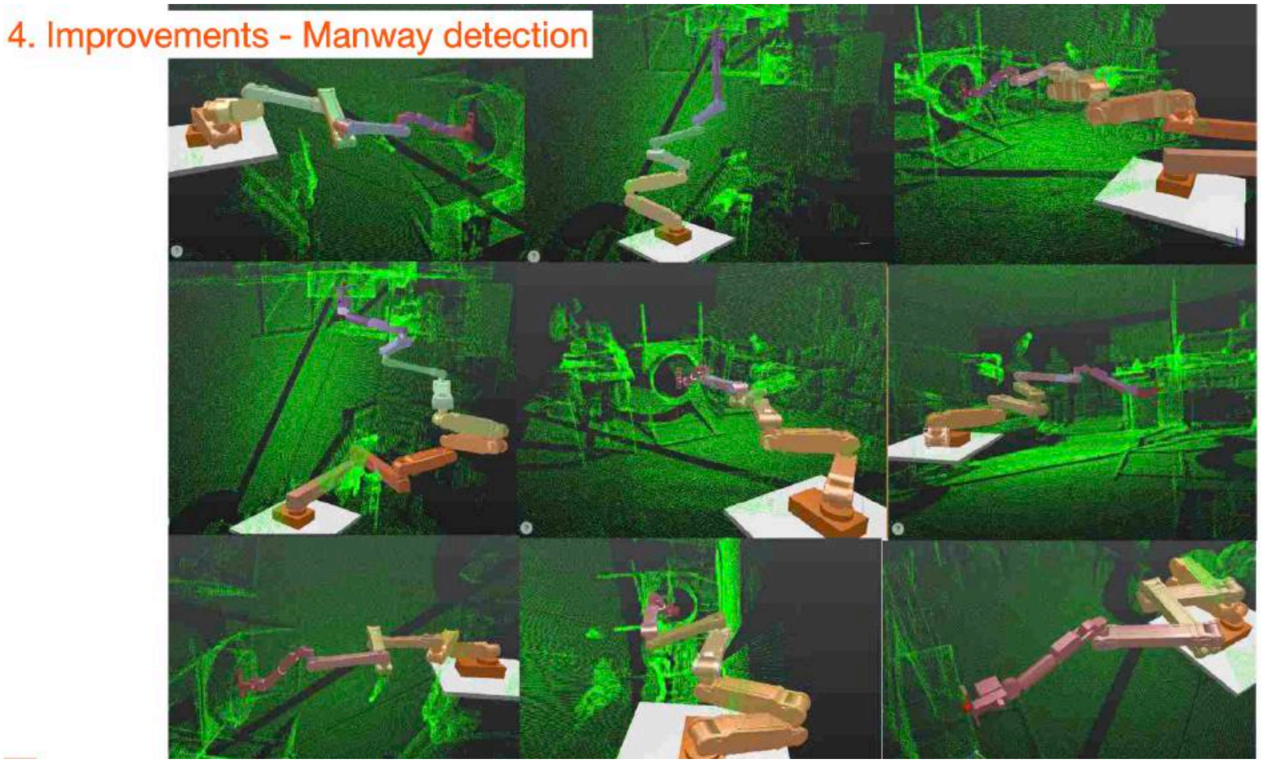
Stress test with the arm completely stretched

7.2 SOFTWARE IMPROVEMENT AND DEVELOPMENT

Strong of the results of the tests carried out in May modification were carried out on the point cloud software control. Points unwanted such as the detection of the arm itself are now automatically removed making the operation faster as shown in the following figure



Also a new software for the manway entry was developed as shown in the following images



4. Improvements - Manway detection

Capability of the software control to adapt to different configuration for the automatic trajectory definition toward manway entry

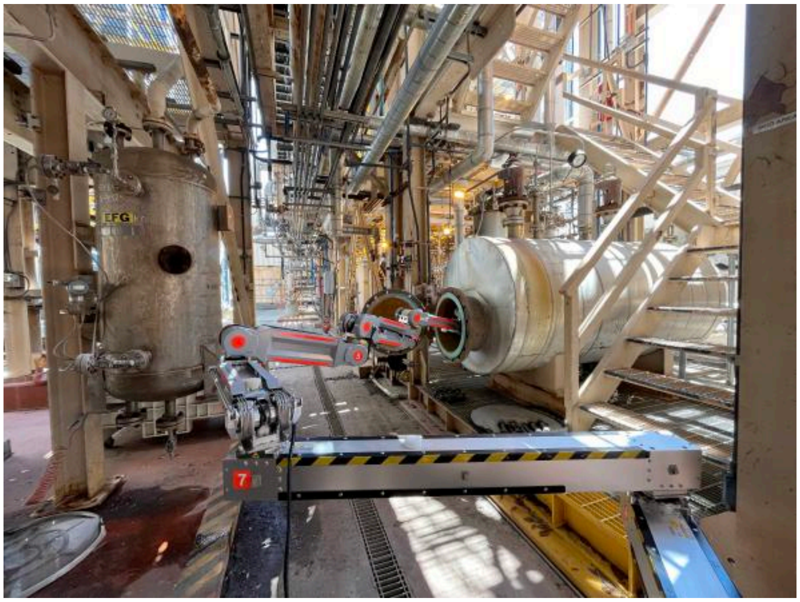
8 FINAL TESTS AT SHELL FACILITY

The above modifications and improvements were then confirmed at the SHELL Technology center, the following set of images show the confirmation of the different functionalities.

Testing the mobility of the new base frame

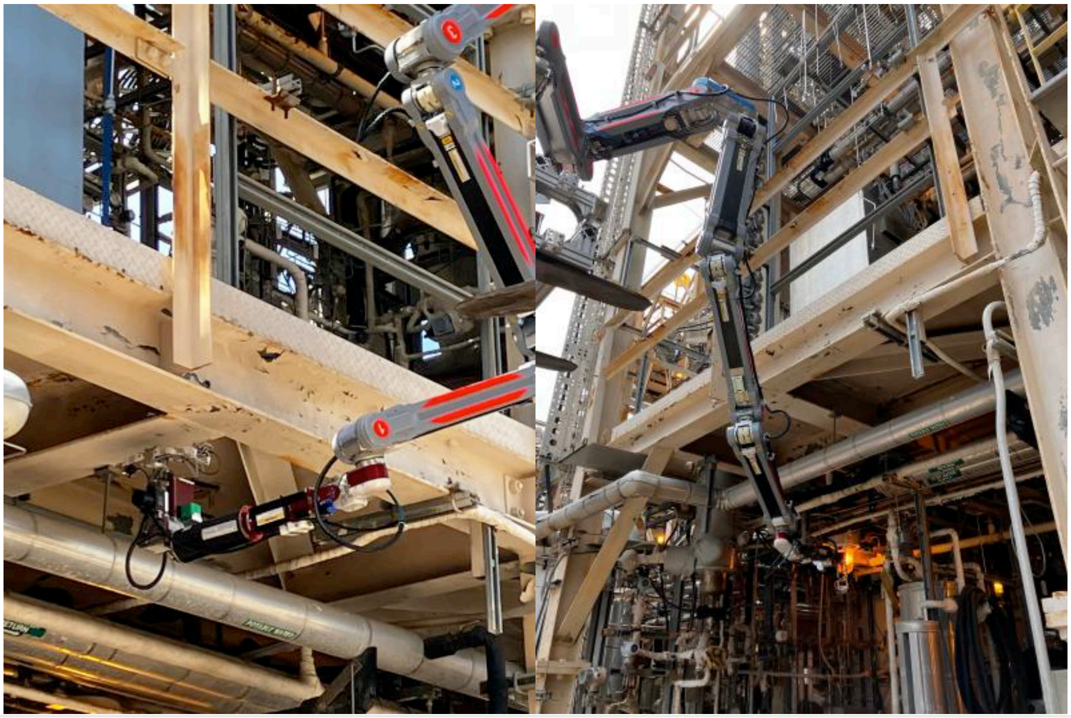
The new mobile frame proved to be effective in moving the whole system assembled without the need to disassemble the robot links. The whole robot was easily moved in different inspection location through narrow corridors without problems.

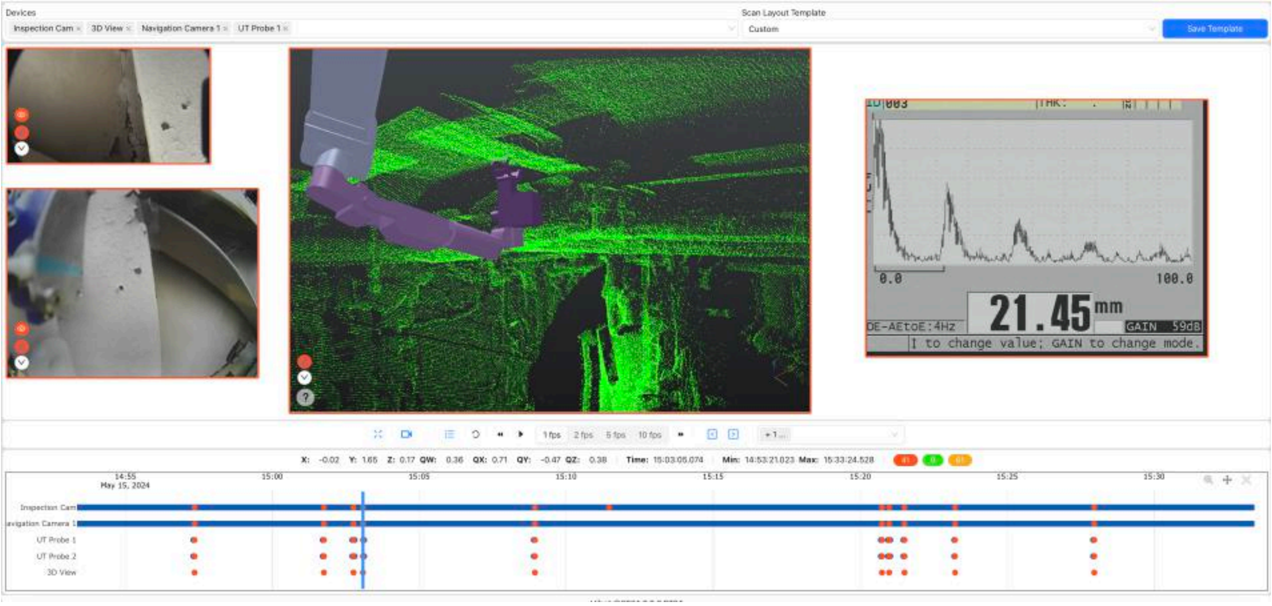
Also the new software modules used for manway adaptation were confirmed within the small tank available at the test facility



Testing vessel tank entrance software

Finally, also the downward motion was confirmed. The base frame was set at a forklift and the validation of the downward motion was performed simulating an under-deck inspection with having the whole robot lifted to the first level floor of the mockup facility.





Devices: Inspection Cam, 3D View, Navigation Camera 1, UT Probe 1

Scan Layout Template: Custom

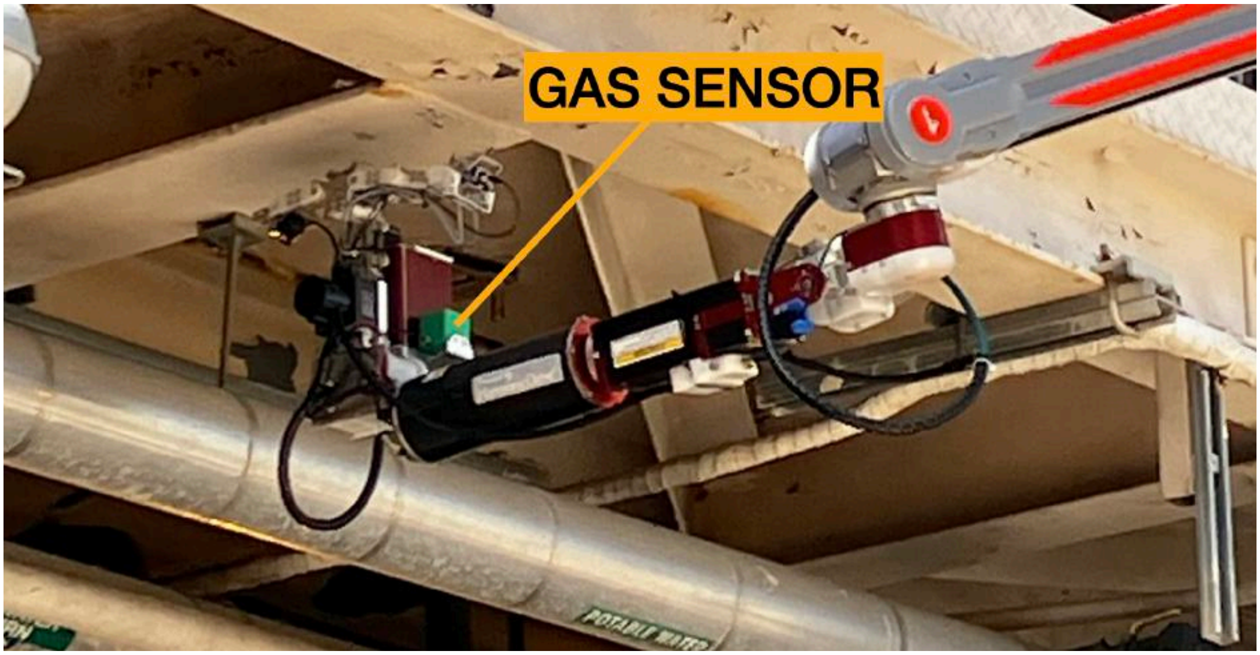
ID 003 THK: 21.45 mm
DE-AEtoE:4Hz GAIN 59dB
↕ to change value; GAIN to change mode.

X: -0.02 Y: 1.65 Z: 0.17 QW: 0.36 QX: 0.71 QY: -0.47 QZ: 0.38 Time: 15:03:05.074 Min: 14:53:21.023 Max: 15:33:24.528

Downward confirmation and hibox interface showing the results of measurements carried out under the floor

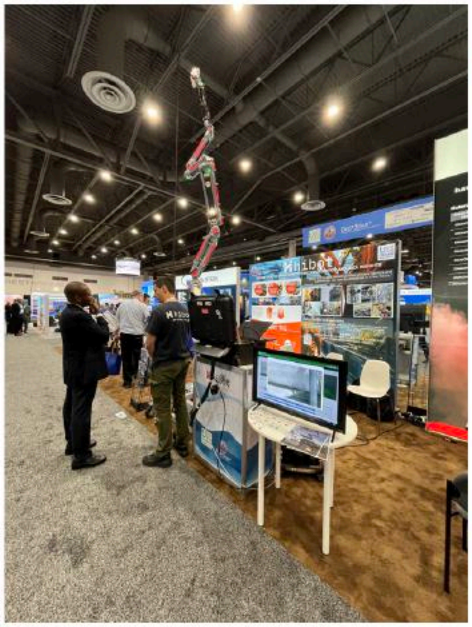
At last also the gas sensor was confirmed. In the following figure it is shown at the tip of the end effector. It was not possible to prepare an environment with real ELI gasses within the testing facility, however it was confirmed to have both functionalities working as follows:

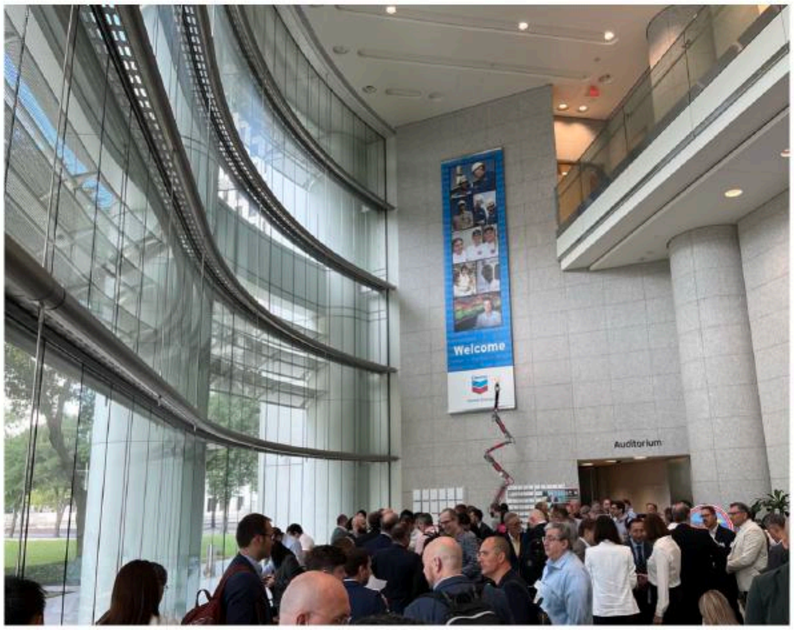
- Shutdown of electric power in the system automatically after reaching a minimum gas level set on the user interface
- Display of warning message on the user interface without automatic shutdown of the power



Forklift keeping the robot at the height of the first floor of the testing facility

The following images show moments respectively of the OTC2024 presentation within the NipponFoundation pavilion and of the ballast tank challenge of the SprintRobotics





Left: OTC2024 exhibition Right: Chevron headquarter demonstration day

Ballast Tank Challenge of Sprint robotics