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HIL Simulation Towards Autonomous Manipulation of an Underwater Panel in a Permanent Observatory

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***Abstract*— This paper explains how the autonomous grasp of a valve situated in a permanent underwater observatory is performed, using camera and laser sensors. The experiment has been performed within the benchmarking UWSim Underwater Simulator [1][4], which makes it possible to test the hardware ROS (Robot Operating System) interfaces in a simulated environment, which can be directly applied to the real robot later on. This architecture enables the design of Hardware-In-the-Loop (HIL) experiments, which has been shown to be very useful, especially when integrating components of several partners in complex research projects.**

Keywords—underwater intervention; autonomous manipulation; laser reconstruction; 3D simulation; Hardware-In-the-Loop (HIL)

I. INTRODUCTION

Endowing an Intervention Autonomous Underwater Vehicle (I-AUV) with the ability to manipulate an underwater panel in a permanent observatory is one of the challenges of the GRASPER project. GRASPER ("Autonomous Manipulation", under responsibility of the Jaume I University, UJI) represents only a sub-project inside a Spanish Coordinated Project, entitled: TRITON, "*Multisensory Based Underwater Intervention through Cooperative Marine Robots*", which includes two other sub-projects: COMAROB ("Cooperative Robotics", Univ. of Girona, UdG), and VISUAL2 ("Multisensorial Perception", Univ. of Balearic Islands, UIB).

The TRITON marine robotics research project is focused on the development of autonomous intervention technologies really close to the real needs of the final user and, as such, it can facilitate the potential technological transfer of its results. The project proposes two scenarios as a proof of concept to demonstrate the developed capabilities: (1) the search and recovery of an object of interest (e.g. a "black-box mockup" of a crashed airplane), and (2) the intervention on an underwater panel in a permanent observatory. In the area of search and recovery, previous projects like SAUVIM [3], RAUVI [7] and more recently TRIDENT [8], have become milestone projects, progressively decreasing the operational costs and increasing the degree of autonomy. With respect to the intervention on an underwater panel, the ALIVE project [2] demonstrated the capability of an underwater vehicle to dock autonomously with a ROV-friendly panel by using hydraulic grabs. Nevertheless, unlike in TRITON, a very simple automata-based manipulation strategy was used to open/close a valve.

In this paper, recent progress towards autonomous underwater manipulation using UWSim as 3D simulation tool, and new algorithms for grasping approach and execution are presented and discussed. The validation scenario will be the intervention of an underwater panel in a permanent observatory, the second scenario proposed by TRITON.

II. EXPERIMENTAL ARRANGEMENT

To deal with the challenge proposed in the second scenario of TRITON, a virtual model of the underwater panel in a permanent observatory and the autonomous intervention vehicle have been loaded into the simulator (see Fig.1). Moreover, to allow the system to reproduce the experiments with real hardware (HIL), the same real scenario has been prepared in a water tank, including an underwater manipulator (see Fig. 2) attached to a fixed platform, representing the robot at the docking position.

The intervention mission begins with the approaching movement of the I-AUV to the intervention panel. Then, when visual contact with the objective is established, the I-AUV will locate the panel using visual servoing techniques. The final part of the docking operation will involve a mechanism which attaches the vehicle firmly to the panel. After this, the manipulation will take place, and will consist of the opening/closing of a valve and pushing several buttons installed on the panel.

Fig. 1. UWSim visualization of the underwater considered scenario with the I-AUV docked in the intervention panel designed by UdG.

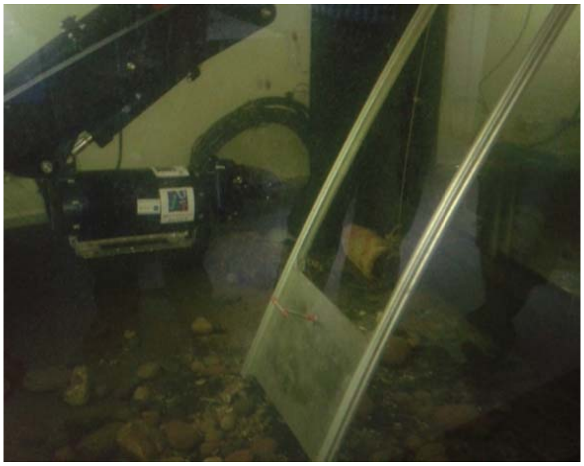

Fig. 2. Real GRASPER scenario in the water tank, for autonomous manipulation experiments.

III. THE APPROACH TO FOLLOW

A. HIL simulations with UWSim

UWSim [4] is an UnderWater SIMulator for marine robotics research and development, started with the RAUVI [7] and TRIDENT [8] research projects. It is conceived as a tool for testing and integrating perception and control algorithms before running them on the real robots, allowing Hardware-In-the-Loop (HIL) simulations (see Fig. 2 and 3) as well as benchmarking. It is available on-line (http://www.irs.uji.es/uwsim) as an open source software.

UWSim visualizes an underwater virtual scenario that can be configured using standard modelling software. UWSim is currently being used by different ongoing projects funded by European Commission (MORPH and PANDORA) in order to perform HIL experiments and to reproduce real missions from the captured logs. This paper describes several new functions recently included in UWSim such as physical-dynamic interactions, 3D laser reconstruction (see Fig. 3 bottom) and force/torque sensors, in order to cope with the mission scenario under consideration.

B. Manipulation Architecture

Further progress in the robustness and the reliability of the system, to improve its autonomy and also to increase the manipulation capacity, will allow the operation of off-shore panels, pick up biological or geological samples, locate shipwrecks or parts of crashed airplanes, etc. All of these are real intervention missions whose interest is not only economic or scientific but also humanitarian or even cultural. The previous know-how developed through different autonomous manipulation contexts [5][6] is now applied to the context of the underwater intervention panels (Fig. 3). The manipulation architecture has been improved and adapted in order to deal with this new, specific mission scenario.

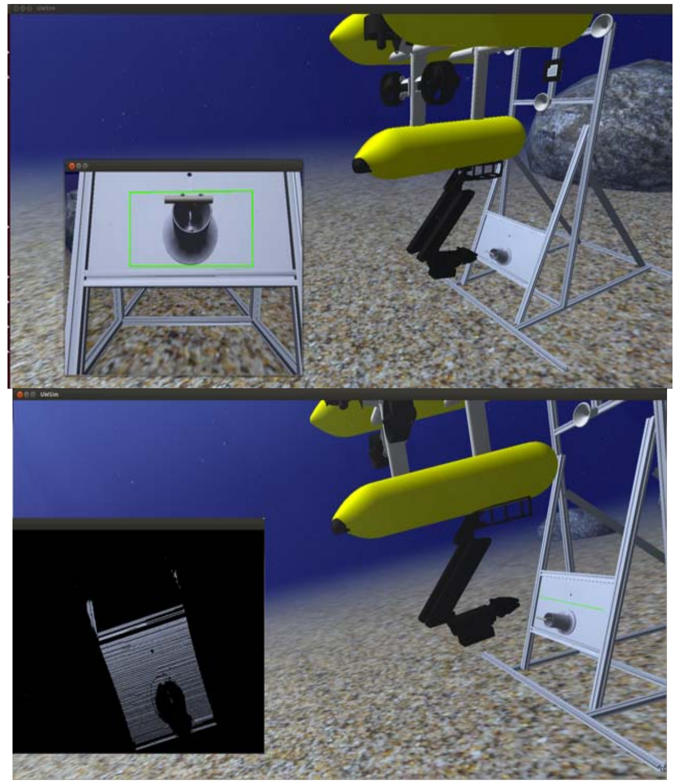

Fig. 3. UWSim simulation of a manipulation intervention (top). Point cloud data obtained from a laser 3D reconstruction for target manipulation (bottom).

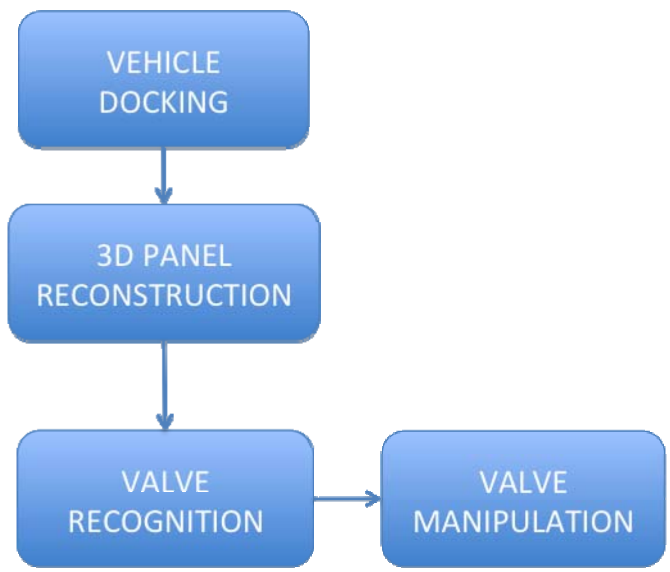

Fig. 4. Underwater panel autonomous manipulation architecture

As can be seen in Fig. 4, the experiment manipulation architecture has four main parts, which will be explained in more detail later on. First of all, the vehicle performs a visual servoing docking with the underwater panel, by using a procedure provided by UdG. Once the vehicle is attached to the structure, the arm uses the laser and the camera to provide a 3D reconstruction of the scene, recognizing the valve base as the main point of reference for the manipulation task. Then, once the valve has been related to the 3D scene, the manipulation task can be performed accordingly.

IV. UWSIM: FORCE FEEDBACK AND STRUCTURED LIGHT LASER SIMULATION

A. *Force feedback and dynamics simulation*

To perform the autonomous manipulation and the docking of the vehicle within the panel, two new functions have been included to the UWSim, force feedback and structured light laser simulations.

First of all, the mobile vehicle includes a dynamics module, which have been integrated into the simulation, allowing real physical interaction between the vehicle and the environment (see Fig. 5).

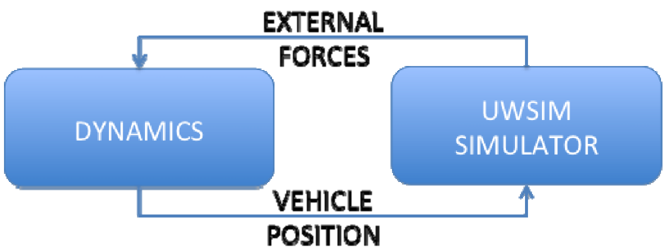

Fig. 5. Force feedback and dynamics calculation in UWSim

The UWSim calculates the reaction forces once a collision has occurred. For this, it processes the contact information provided by the Bullet physics module[1], getting the collision point and vector. With this, the system calculates the forces that will have to be applied to the vehicle to get a proportional deceleration to the linear moments of the colliding objects.

For simplicity, the collisions between the vehicle and the fixed building structures (e.g. walls) have been modelled, considering its mass as infinite and that the collision is not elastic, getting then a final zero velocity of the vehicle. Moreover, the model can be extended to elastic and non elastic objects, after knowing their intrinsic physical parameters.

Once the final and initial velocities of the vehicle are obtained, it is necessary to include the period of time where the force will be applied. For this, the dynamics internal tick has been used. The applied force is then,

$$F = m\,(dv)/t \qquad (1)$$

where F is the force, m is the mass of the object, dv the velocity variation, and t the collision time.

It is important to remark that the described calculations can be used to model a force/torque sensor, in this case, for the center of mass of the vehicle.

B. *Structured Light through laser*

Secondly, another new function included into the simulator is the projection of structured light through a laser, that can, for example, be added to the arm of the vehicle, to obtain a 3D representation of the scene before manipulating the environment.

This feature enables the projection of a given pattern over the scene, being quite simple to experiment with different parterns, such as circular lines, parallel straight ones, etc. (see Fig. 6 and 8).

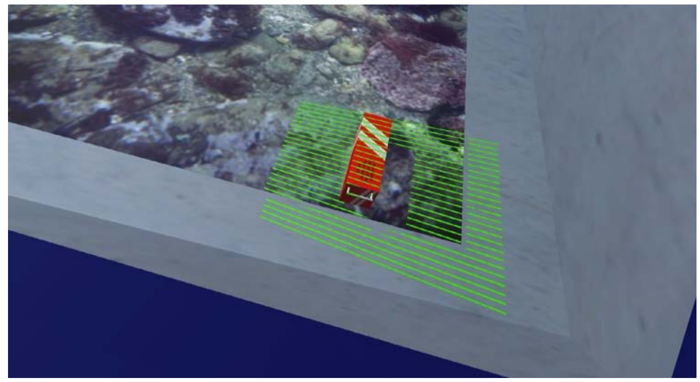

Fig. 6. Structured light through laser calculation in UWSim, for recognizing a black box in the sea bed

To calculate the shadows produced by the objects when using the laser reconstruction, the *shadow mapping* techniques are used [9], which calculates the distances from the laser to the objects by implementing a z-buffer algorithm.

There are many variations from this previous work such as [10], [11] o [12]. However, some of these extensions cannot be applied to this particular application, because their purpose is to create a more realistic shadow while we are avoiding light pattern projection through objects. One issue of this technique is that the quality of the shadows depends enormously on the available memory used for the textures, producing a phenoma known as aliasing. This can be an improvement for further work (see Fig. 7).

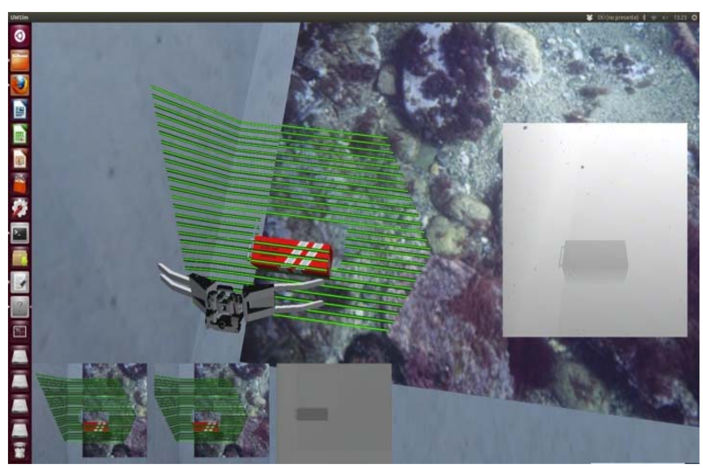

Fig. 7. Non-binary texture projection over a black box in the pool creating errors in the laser color

To get a more realistic laser representation, binary textures are used, which makes it possible to distinguish whether a

[1] Coumans, E. Bullet physics library (2009). Available online: (http://bulletphysics.org)

point belongs to the pattern or not. This means that the laser projections have the same color as the emitted light, making the scene more realistic.

Moreover, the simulator makes it possible to use different binary patterns, permitting the comparison of results using other kinds of laser projections, such as circles, squares, lines, etc.

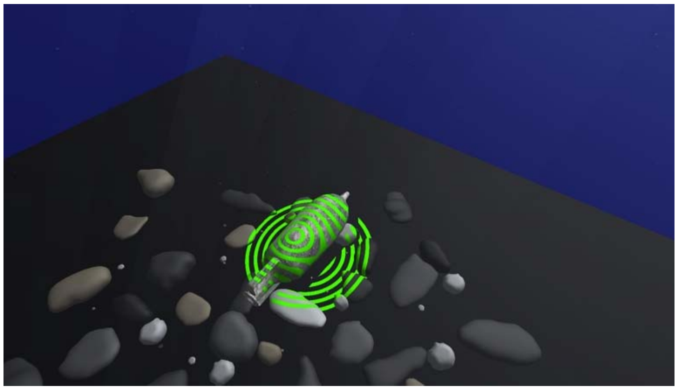

Fig. 8. Circular structured light pattern for autonomous manipulation of an amphora.

V. PANEL AUTONOMOUS GRASPING SIMULATION

In this section the 3D laser scanning and autonomus manipulation of a valve in the underwater panel is explained.

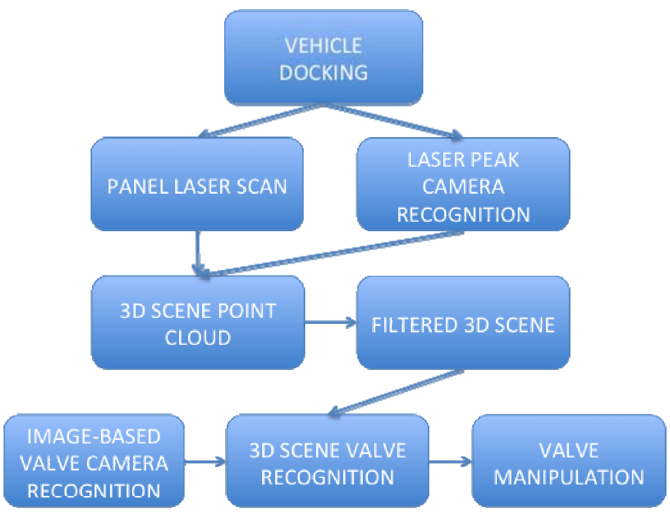

Fig. 9. Detailed architecture for the autonomous manipulation

As shown in Fig. 9, the first step is to perform the vehicle docking. As this procedure belongs to another sub-project, it will not be explained in this article, as we are focusing on the manipulation part.

As explained in [13], the TRITON vehicle has a 4 degrees of freedom arm attached to its base (i.e. CSIP Light-weight) having a gripper in the final effector. One laser emitter is attached to the forearm, and a camera is located at the base of the arm.

The handle is located in the upper part of the panel. Its size is known and it has a marker in the point that joins the panel to the valve, which permits the recognition of this point from the camera sensor. The valve is perpendicularly attached to the panel.

Once the scene recognition begins, the arm moves from top to bottom to perform a panel laser scan, and a laser peak camera recognition, which gives a 3D point cloud of the whole scene as output. As the handle is thin, using only the point cloud to get the grasping point is not sufficient (see Fig. 3 bottom), so the next step is to recognize the base of the handle by using the camera, and relate this to the 3D scene point cloud, once it has been filtered accordingly, so that the points to the base plane of the panel can be associated. The UIB is working on the 3D recognition of the panel using stereo cameras, which is an alternative when the images are well textured and the visibility is good.

The last step is the manipulation of the handle, once its position from the robot base has been obtained from the robot kinematics.

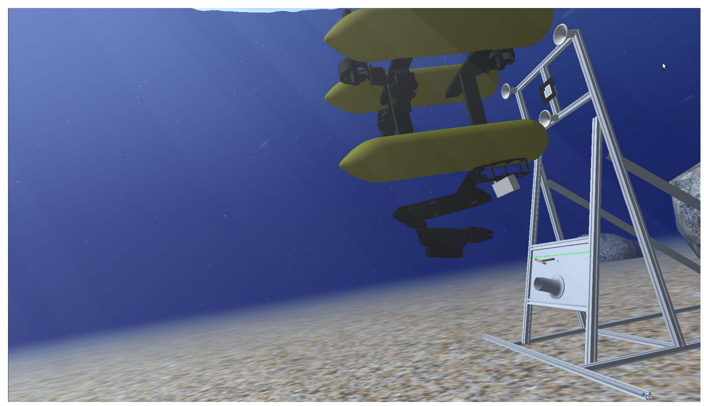

Fig. 10. Scanning the panel with the laser for 3D reconstruction

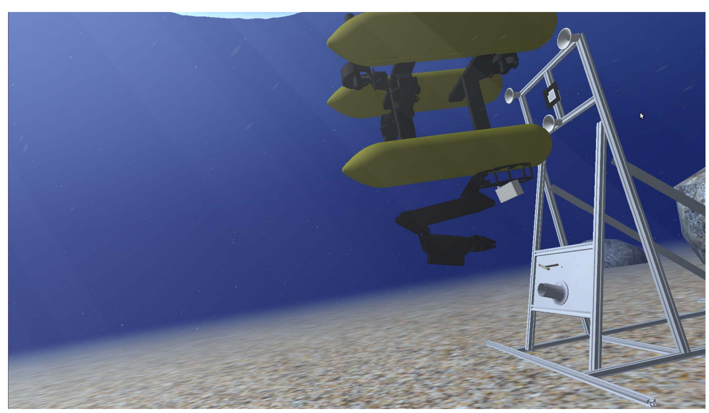

Fig. 11. The laser reaches the panel handle

As we can see in Fig. 10, 11 and 12, the panel is scanned completely from the top down. For this, the robot arm is moved providing the appropriate laser projection. At the same time, the camera is recognizing the laser images in order to get the laser peaks, as explained before.

The recognition algorithm detects the image pixels of the projected laser (see Fig. 12 bottom). Considering the position of the robot arm effector at each frame as well as its incidence vector, a whole point cloud is calculated (see Fig. 3 bottom) by using the triangulation technique described in [5].

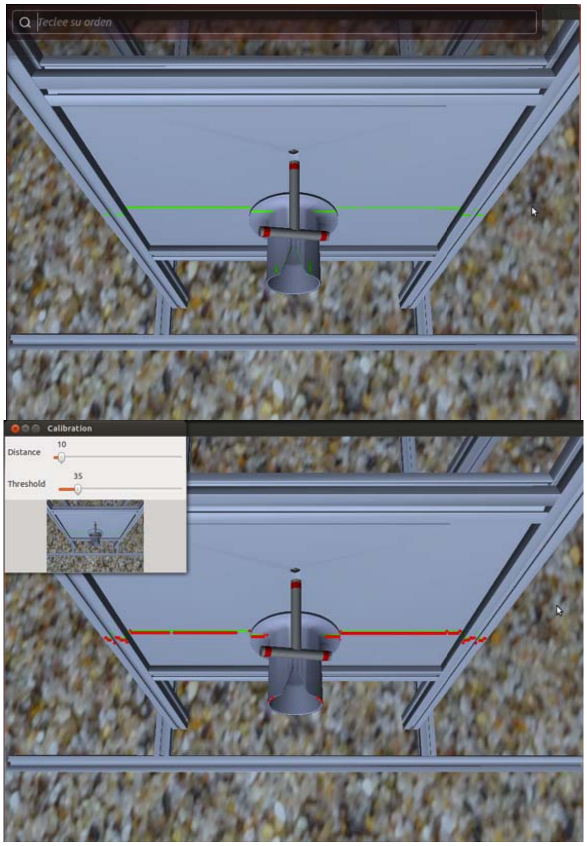

Fig. 12. Closer view of the panel. (Top) Scanning the panel with the laser for 3D reconstruction. (Bottom) The recognition algorithm detects (in red) the image pixels of the projected laser.

Once the 3D point cloud has been calculated, the RANSAC method [14] is applied to filter the scene and obtain the significant points which are part of the panel plane.

The next step, as shown in Fig. 9, is to detect the valve marker by using the camera input. This will provide the position of the valve base in camera coordinates. Having the panel plane mathematical description extracted from the 3D point cloud, and knowing the pixels that represents the valve marker, its 3D representation is calculated, where the handle is attached to the panel.

Once the position of the marker from the camera is known, the frame of the valve is calculated and using the inverse kinematics of the robotic arm the autonomous manipulation procedure begins (see Fig. 13).

For this particular experiment, the manipulation is performed by knowing the dimensions and geometrical representation of the valve. Further experiments can be done to manipulate more generic tools, by applying sophisticated grasping determination procedures.

VI. CONCLUSIONS AND FURTHER WORK

In this paper the benchmarking and HIL UWSim underwater simulator is described. Particularly, the force feedback and 3D laser reconstruction is presented, by showing the autonomous manipulation of a valve in a permanent observatory panel, as part of the GRASPER project. The system enables an easy integration of simulated and real hardware, by means of standarized ROS interfaces. The next step is to integrate the three subprojects into a unified system, which will take place at the pool of the University of Girona UdG-CIRS laboratory, in September 2013, in order to have a preliminary result of the manipulation task with the panel in more realistic and complex conditions.

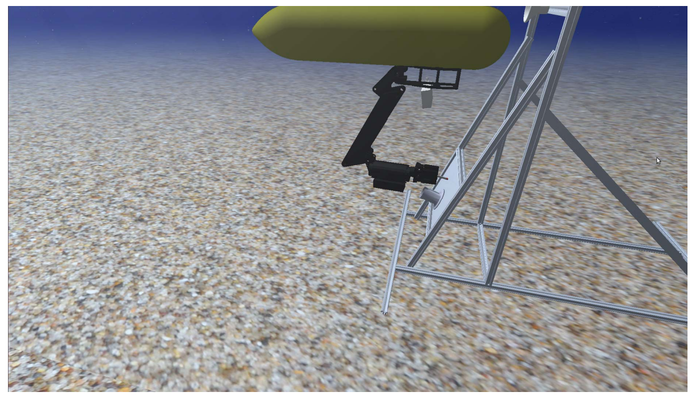

Fig. 13. Executing the valve manipulation

Further work within the simulator will be focused on enhancing its benchmarking and HIL capabilities, particularly for underwater autonomous manipulation research.

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