

# VRX Competition Technical Guide

*Virtual RobotX 2022 Competition**www.RobotX.org*

## 1. Introduction

The purpose of this document is to provide Virtual RobotX (VRX) teams with the information necessary to successfully prepare for and participate in the VRX competition. It covers the following topics: the robotic platform, competition tasks, propulsion and sensor configuration, runs and environmental envelopes, the application programming interface (API), and instructions for submitting your code for the competition.

Related documents include the following:

- Virtual RobotX 2022 Competition and Task Descriptions

## 2. Robotic Platform

The VRX competition will be executed using the Gazebo simulation environment. All teams must use the simulated version of the Wave Adaptive Modular Vessel (WAM-V) surface craft distributed with the [VRX software](#). The WAM-V as supplied by the VRX software is standard for all teams. No modification of the standard platform model (URDF description, etc.) is allowed during competition.

The simulated WAM-V includes models of the rigid body dynamics, hydrodynamics, external forcing (waves and wind) and propulsion. The rigid body dynamics are captured via the Gazebo physics engine. The hydrodynamic, external forcing and propulsion forces are generated by VRX plugins with fixed parameters. No modification of the standard VRX model parameters is allowed during competition.

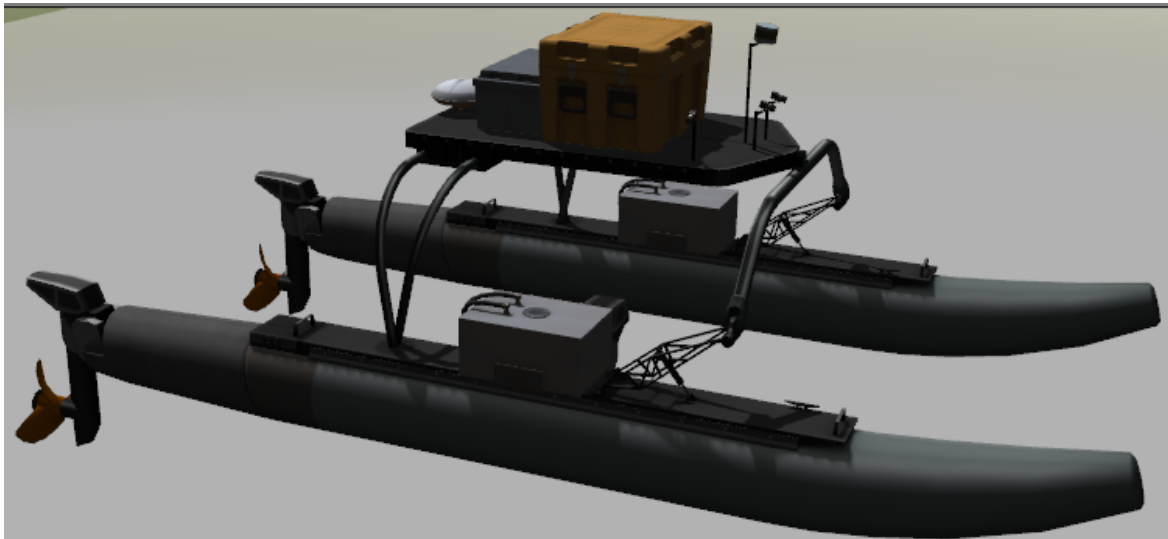


Figure 1: Simulated WAM-V model

### 3. Propulsion configuration

As part of the competition, teams may customize the propulsion system with which their WAM-V is equipped. Vehicle propulsion is provided by a set of identical thrusters. The details of the thruster model are available through the [documentation](#) page of the VRX Wiki. The maximum number of allowed thrusters is four. The pose (position and attitude relative to the vessel) of each thruster is configurable via a YAML file.

In order to preserve realism, not all possible thruster positions will be accepted. The valid set of allowed positions are represented in Figure 2 as five red bounding boxes. In order for a thruster configuration to be considered valid, the origin of each thruster must be contained within one of these bounding boxes and each bounding box must contain no more than one thruster. Additionally, all thrusters have the ability to dynamically rotate and thus change the thrust direction.

Teams can visit the [tutorials](#) section of the VRX website for information about how to customize the WAM-V for running simulations locally. The same tutorials describe the format of the YAML file used for propulsion configuration.

During an actual event, teams will need to provide a valid YAML file named `propulsion.yaml` with their propulsion configuration. Working examples of YAML configuration files with typical propulsion configurations are described in the VRX [tutorials](#).

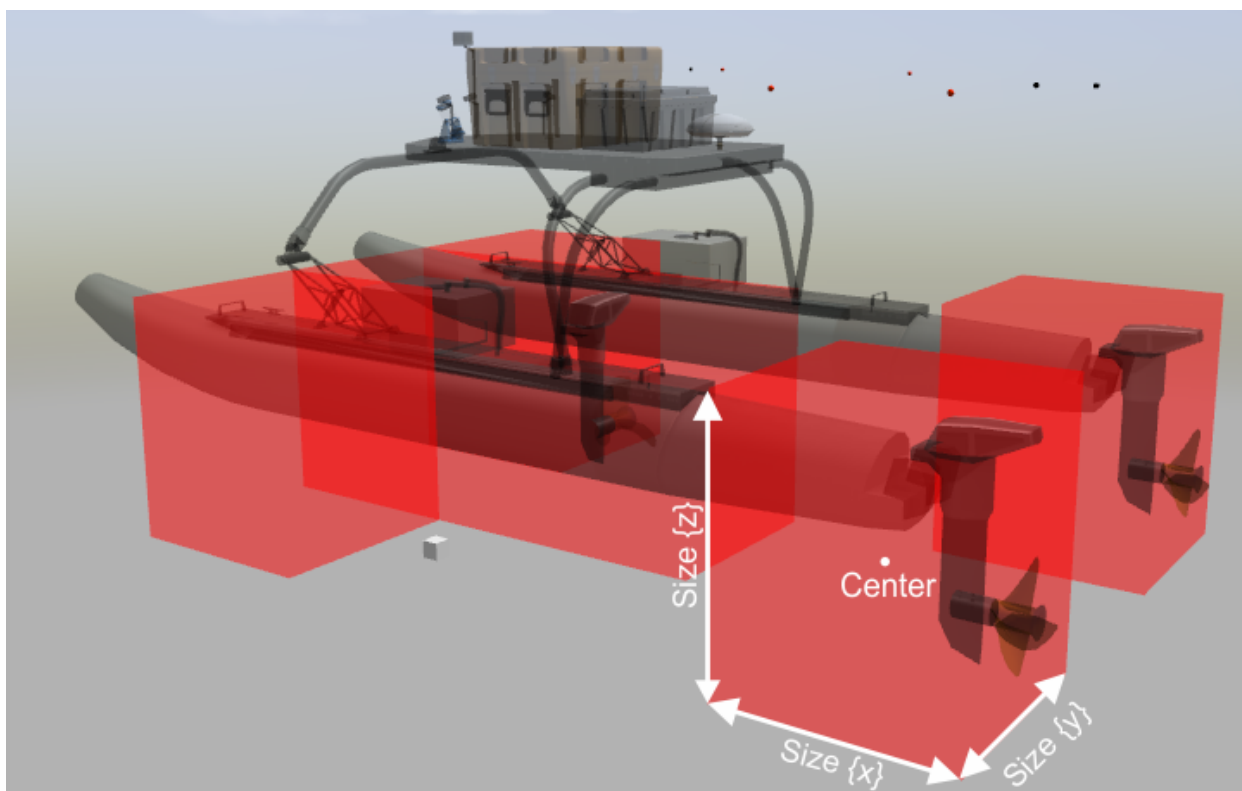


Figure 2: Allowed thruster regions in WAM-V

**Table 1: Dimensions of Bounding Boxes**

Name	Position and Orientation of Center of Bounding Box (x y z R P Y) (Relative to the Origin of the WAM-V)	Size (x y z)
Front Left	1.25 1 0 0 0 0	1 1 1.2
Front Right	1.25 -1 0 0 0 0	1 1 1.2
Center	0.25 0 0 0 0 0	2.5 1 1.2
Back Left	-2.25 1 0 0 0 0	1 1 1.2
Back Right	-2.25 -1 0 0 0 0	1 1 1.2

## 4. Sensor configuration

As with the propulsion system, teams should customize the sensor system with which their WAM-Vs are equipped by choosing the type of sensors and placement of those sensors. Standard sensors include navigation sensors (GPS and IMU) and perception sensors (cameras and lidars). In addition to configuring sensor types, teams may also customize the sensor placement.

**Table 2: Maximum number of sensors allowed per sensor type**

Sensor type	Maximum number of instances
Camera	3
Lidar	2
GPS/IMU	1

The available sensor types and their performance characteristics have been chosen to reflect commonly used sensors from the RobotX physical competition. These characteristics do not represent any specific sensor choice but are meant to be representative of typical hardware options.

Note: While the sensor performance specifications below (update rates, noise values, etc.) are detailed, the exact values of these specifications may change before the final release of this document.

### 4.1. Navigation Sensor

A single standard navigation sensor, representing a GPS-aided IMU, will be used for VRX. This single sensor is simulated through the use of two Gazebo plugins (see the [hector\\_gazebo\\_plugins](#)) which generate GPS information (position and velocity) and IMU information (attitude, attitude rate and accelerations). While these two measurements are presented separately, the characteristics of the measurements are consistent with a sensor that estimates a complete navigation solution, e.g., a GPS-aided IMU.

**Table 3: Characteristics of VRX Navigation Sensor**

GPS-Aided IMU		
GPS	Update Rate	20 Hz
	Horizontal Position Noise <sup>1</sup>	0.85 m
	Vertical Position Noise	2.0 m
	Velocity Noise	0.1 m/s
IMU	Update Rate	100 Hz
	Acceleration Offset/Bias	+/- 0.002 g
	Acceleration Noise	0.275 g
	Attitude Rate Noise	0.08 degrees/s
	Heading Noise	0.8 degrees

## 4.2. Camera Sensor

A standard camera is simulated via the Gazebo camera plugin. Teams may provision their system with up to three cameras.

**Table 4: Characteristics of VRX Camera Sensor**

Camera	
Update Rate	30 Hz
Resolution	1280x720 px
Color format	R8G8B8

## 4.3. Lidar Sensors

Two types of lidar sensors are provided for VRX: 16 beam and 32 beam. Teams may provision their system with up to two lidars.

**Table 5: Characteristics of VRX Lidar Sensors**

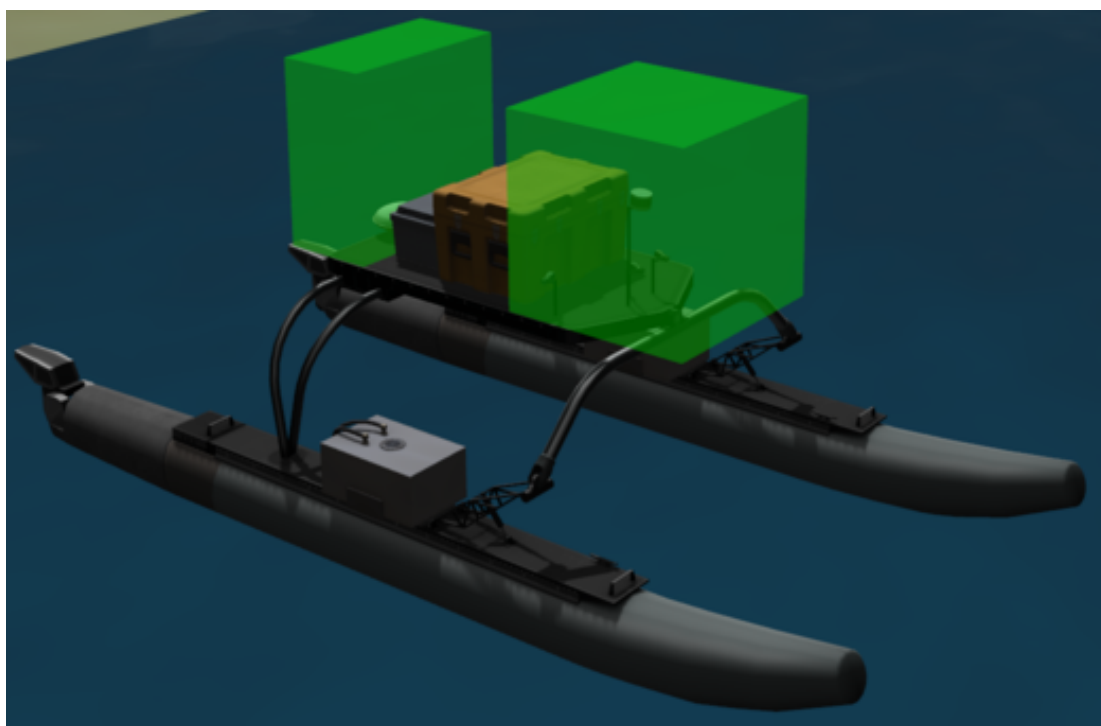
	16 Beam	32 Beam
Update Rate [Hz]	10	10
Lasers (Number of beams)	16	32
Samples (Number of horizontal rotating samples)	1875	2187
Min Range [m]	0.9	0.9
Max Range [m]	130	130
Noise [m]	0.01	0.01

<sup>1</sup> Unless otherwise noted, noise values are specified as one standard deviation and represent a Gaussian distribution.

Min. Horizontal Angle [rad]	$-\pi$	$-\pi$
Max. Horizontal Angle [rad]	$\pi$	$\pi$
Min. Vertical Angle [rad]	$-\frac{\pi}{12}$	$-0.186$
Max. Vertical Angle [rad]	$\frac{\pi}{12}$	$0.54$

#### 4.4. Sensor Placement

The pose of each sensor is configurable via a YAML file. In order to preserve realism, not all possible sensor positions will be accepted. The valid set of allowed positions are represented in the next figure as green bounding boxes. The origin of each sensor needs to be contained within one of these bounding boxes to be considered valid. Note that the specification of the sensor is not customizable; all teams share the same sensor types.



**Figure 3: Allowed sensor regions in WAM-V**

Teams can visit the [tutorials](#) section of the VRX Wiki for information about how to customize their WAM-Vs for running simulations locally. The tutorial also describes the format of the YAML file used for sensor configuration.

During an actual event, teams will need to provide a valid YAML file, named `sensors.yaml`, with their sensor configuration.

Table 6: Allowed sensor regions in WAM-V

Placement region	Bounding box center (x y z)	Bounding box size (x y z)
Front	0.8 0 1.8	1 1 1
Back	-0.9 0 1.8	0.5 1 1

## 5. Task Information

Teams face multiple independent tasks during VRX. These tasks require different actions from the participant's controller code. During every task, the status of the task is published as a custom ROS [Task message](#) over a ROS topic. Table 6 lists the information this message provides about the status of the simulated task. Please refer to the VRX API section of this document for further details.

Table 7: ROS Task message definition

Field Name	Description
name	Unique task name (e.g.: "station_keeping", "wayfinding").
state	The current task state = {initial, ready, running, finished}. See the <i>Task States</i> section for more information.
ready_time	Simulation time at which the task transitions to the <i>ready</i> state.
running_time	Simulation time at which the task transitions to the <i>running</i> state.
elapsed_time	Elapsed time since the start of the task (since <i>running_time</i> ).
remaining_time	Remaining task time.
timed_out	Whether the task has timed out or not.
score	Current task score.

Teams are expected to subscribe to this task ROS topic and select their appropriate robot behavior given the current task under execution. In addition, teams need to react to the task states accordingly. The *initial* state is only used to stabilize the vehicle, allow for initial transients to decay and make sure that all the software blocks are ready. While the system is in the initial state, teams receive sensor information, but the robot control will be very limited. In the *ready* state, teams have full control of their robot and we expect them to get ready for the start of the task. Teams need to monitor the simulation time published over the clock ROS topic and compare it with the *ready\_time* and *running\_time* to be prepared to take control of the vehicle and start the task respectively. Once the task is in the *finished* state, teams still can control the vehicle, but the score will not change.

## 6. Task States

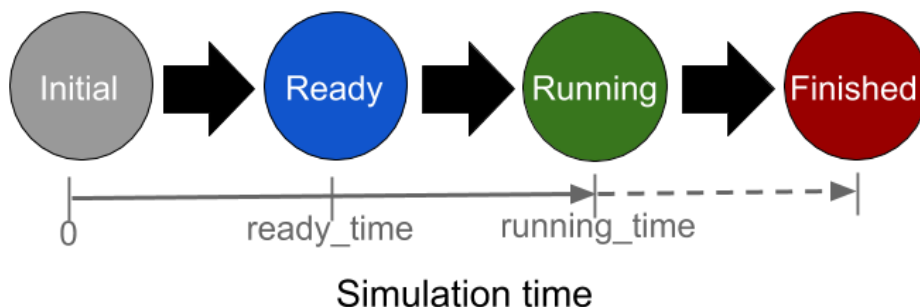


Figure 4: Task states as a function of time

A task can be in one of four different states. The task state is set by Gazebo according to the task configuration. The current state is included in the task message periodically published on the task information ROS topic.

### 6.1. Initial

After Gazebo starts, the task is in the *initial* state. The robot's motion is fixed in the X (surge), Y (sway) and yaw degrees of freedom, but allowed to move in Z (heave), pitch and roll degrees of freedom. Thus, the robot is pushed up and down by the waves and wind and will change its orientation (except in yaw) but stays in the same 2D position. The purpose of this initial state is to allow for simulation startup transients to decay and for all the user's software to have sufficient time to initialize.

### 6.2. Ready

The task transitions to *ready* when simulation time reaches the value *ready\_time*. In the *ready* state, the robot motion is free in all degrees of freedom and is under the participant's full control. While in the ready state no scoring is performed.

### 6.3. Running

The task transitions to *running* when simulation time reaches the value *running\_time*. In the *running* state, the task officially starts. The scoring and the task timer are enabled.

### 6.4. Finished

The task transitions to *finished* when the *remaining\_time* field of the task message reaches 0 or when the task is considered complete. If all task time has been consumed, but the task has not been fully solved, the field *timed\_out* of the task message will be set to true. The score will not be updated in this state.

## 7. Runs and Environmental Envelopes

In the competition, each team shall conduct multiple runs per task, where each run will use a different set of environmental conditions. Though conditions will be distinct from run to run, these distinct configurations will be identical for each team; i.e., each team will see the same set of conditions as the other teams in the competition. The subsections below describe elements of the simulation that may change between runs.



### 7.1. Object Location and Orientation

Relevant objects will be moved between runs to discourage training the team's controllers to handle known geometry across runs. This will include the placement of obstacles (for example, buoys or docks), as well as the starting pose of the robot itself.

### 7.2. Fog

Gazebo will optionally simulate fog with different densities and colors. The two images below illustrate the addition of fog to the visual scene.

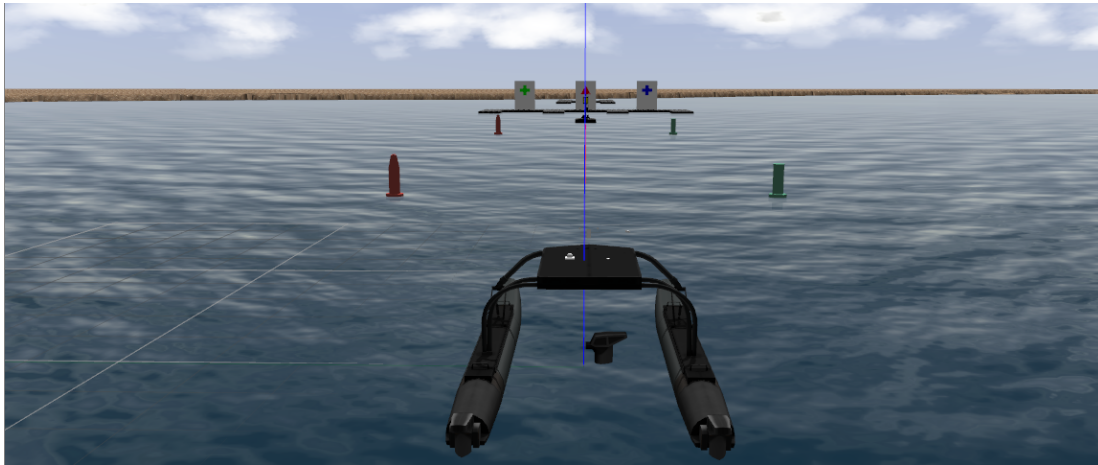


Figure 5: Visual scene with no fog



Figure 6: Visual scene with fog

### 7.3. Wind

Wind exerts a force on objects in the VRX environment. The total wind velocity is a combination of a constant mean velocity component and a variable wind speed (i.e., gusting). The variable component of the wind speed is modeled as a first-order linear spectrum defined by two components: the variability gain and the variability time constant. The variability gain specifies the magnitude (root-mean-square) of the variable

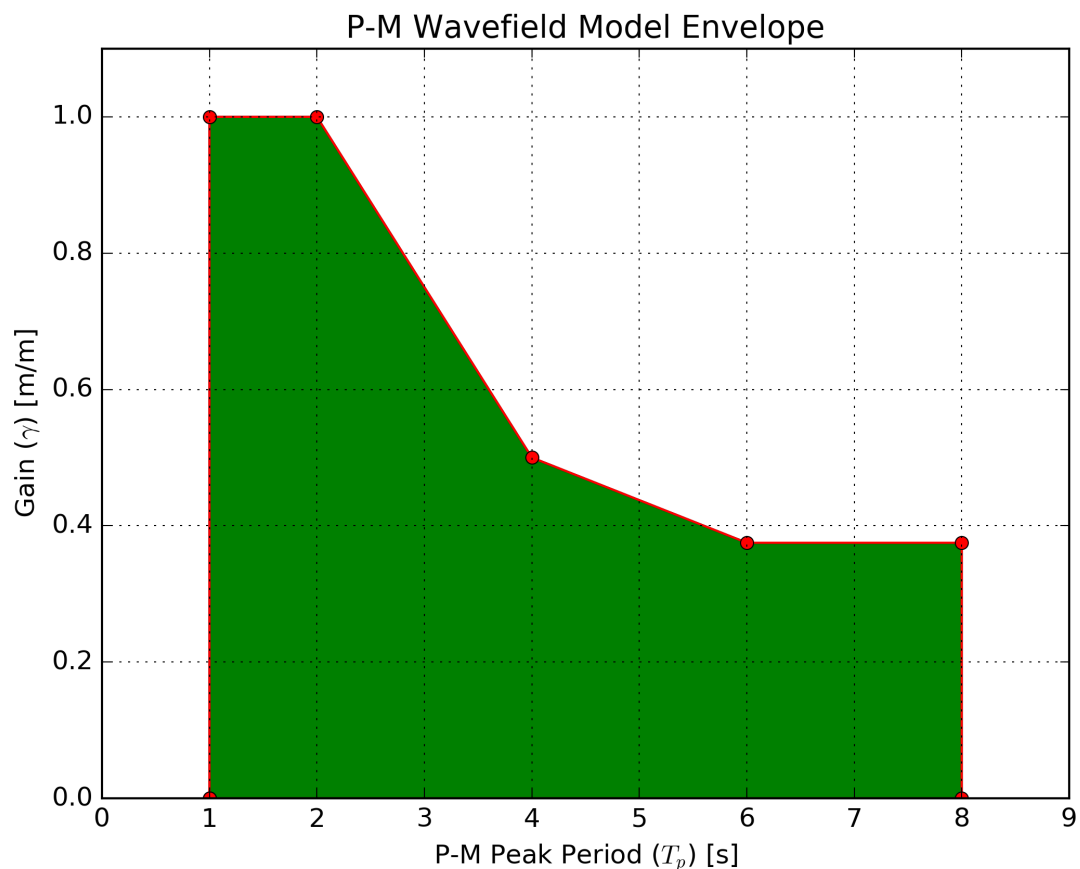


component of the wind speed, and the variability time constant specifies how rapidly the wind speed changes with time. For details on the wind model and implementation see the [Theory of Operations](#) on the VRX Wiki. For examples of how to change the wind parameters see the [tutorial on Changing Simulation Parameters](#) on the VRX Wiki.

## 7.4. Waves

Surface waves affect the motion of objects in the simulated environment. The simulated sea state is generated using a summation of individual regular waves to create the three-dimensional water surface geometry as a function of time. The amplitudes of the individual waves are determined from sampling a Pierson-Moskowitz (P-M) ocean wave spectrum. The pertinent parameters associated with specifying a particular sea state are as follows:

- Peak Period ( $T_p$ ) – wave period with the highest energy.
- Gain ( $\gamma$ ) – constant multiplier applied to the individual wave amplitudes
- Wave Direction – direction of travel of the wave component corresponding to the peak period
- Wave Angle – angular difference in direction between component waves



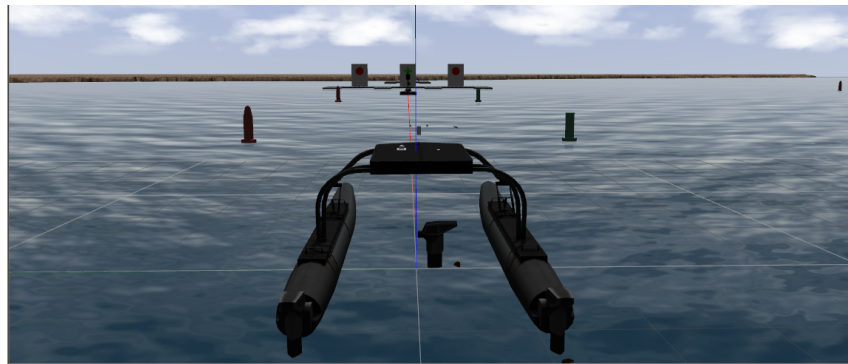
The combination of  $T_p$  and  $\gamma$  parameters determine the energy in the specific sea state. For the VRX competition combinations of  $T_p$  and  $\gamma$  as illustrated in Figure 7 will be used for evaluation.

**Figure 7: Envelope for sea state parameters used in VRX evaluation.**

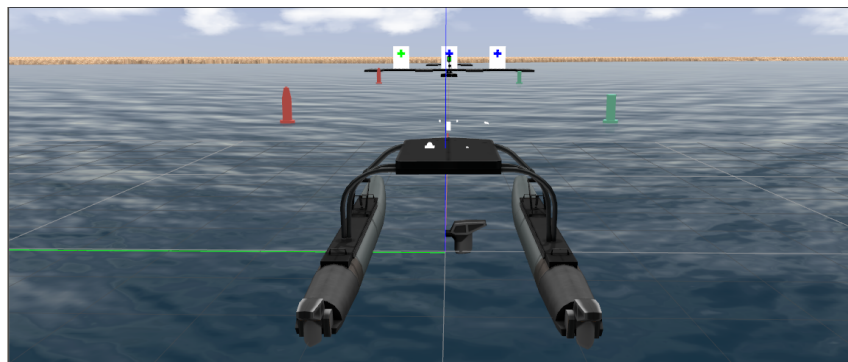
For details on the sea state model see the [Theory of Operations](#) on the VRX Wiki.

## 7.5. Ambient Light

The color of the ambient light. The two images below illustrate changes to the ambient lighting conditions.



**Figure 8: Visual scene with reduced ambient light**



**Figure 9: Visual scene with regular ambient light**

## 7.6. Summary of Environmental Parameters

Table 7 summarizes the ranges of all the parameters that can change during runs:

**Table 7: Environmental variable parameters**

Gazebo Parameter	Minimum value	Maximum value
scene::fog::color	[0.7, 0.7, 0.7, 1]	[0.9, 0.9, 0.9, 1]
scene::fog::density	0	0.1
scene::ambient	[0.3, 0.3, 0.3, 1]	[1, 1, 1, 1]
wamv_gazebo::wind_mean_velocity	0	8
wamv_gazebo::wind_variance_gain	0	8
wamv_gazebo::wind_variance_time	2	20
wamv_gazebo::wind_direction	0	360
wamv_gazebo::wave_period	See Figure 7.	
wamv_gazebo::wave_gain		
wamv_gazebo::wave_direction	0	360
wamv_gazebo::wave_angle	0	360

The characteristics of the simulated environment will be varied during competition runs. Final specifications for the exact characteristics will be released as part of the final technical specification; however, teams can expect values to be within the ranges described in the table above.

## 8. VRX API

VRX provides a ROS interface to the teams for controlling all available actuators, reading sensor information and sending/receiving notifications. The use of ROS as the interface between the team's software and the simulation environment does not require that the team's software internally use ROS. The intention of the competition is to be technology agnostic with regard to solution architecture and implementation. However, a single standard interface is required for the feasibility of the virtual competition. Every effort will be made to offer all teams support implementing the ROS interface to their software. For teams not familiar with ROS we highly recommend going through <http://wiki.ros.org/ROS/Tutorials> to get familiar with ROS and, in particular, with ROS topics and services.

Tables 8-11 summarize the ROS API used for the competition. Note that all topic names used for propulsion and sensors are configurable via their respective YAML files.

**Table 8: Thruster actuation API (default topics)**

Thruster Actuation	
Topic Name	Description
/wamv/thrusters/<thrustername>_angle	Next angle command for the <thrustername> thruster
/wamv/thrusters/<thrustername>_cmd	Next power command for the <thrustername> thruster

Table 9: Sensor information API (default topics)

Sensor Information	
Topic Name	Description
/wamv/sensors/cameras/<sensorname>/camera_info	Meta information for <sensorname> camera. See <a href="#">CameraInfo message</a> for details.
/wamv/sensors/cameras/<sensorname>/image_raw	Raw image data for <sensorname> camera. See <a href="#">Image message</a> for details.
/wamv/sensors/gps/gps/fix	GPS position data.
/wamv/sensors/gps/gps/fix_velocity	GPS velocity data.
/wamv/sensors/imu/imu	IMU data describing attitude, attitude rate and accelerations.
/wamv/sensors/lidars/<sensorname>/points	<sensorname> 3D lidar output
/wamv/sensors/pingers/pinger/range_bearing	A distance (range) and two angles (bearing and elevation) indicating the relative position of the acoustic pinger from the USV, with noise.

Table 10: Task information API

Tasks <sup>2</sup>	
Topic Name	Description
/clock	Simulation time
/vrx/task/info	Task information

<sup>2</sup> Each task can use an additional set of ROS topics/services. Please consult the Virtual RobotX 2022 Competition and Task Descriptions document for additional information.

Table 11: Debug information API (not available during competition)

Debug <sup>3</sup>	
Topic Name	Description
/vrx/debug/wind/direction	Wind vector (units in degrees and ENU coordinate)
/vrx/debug/wind/speed	Magnitude of the wind
/vrx/debug/contact	WAM-V collisions

The interface described above is generic to the entire competition, including all tasks. The task-specific elements of the interface are described in the Virtual RobotX Competition and Task Descriptions, which details the additional ROS topics and services used to support individual task execution. Finally, note that the VRX interface also includes elements that are not used in either the generic or task-specific APIs; these are not needed for the competition and can be disregarded.

## 9. Submission and Code Execution

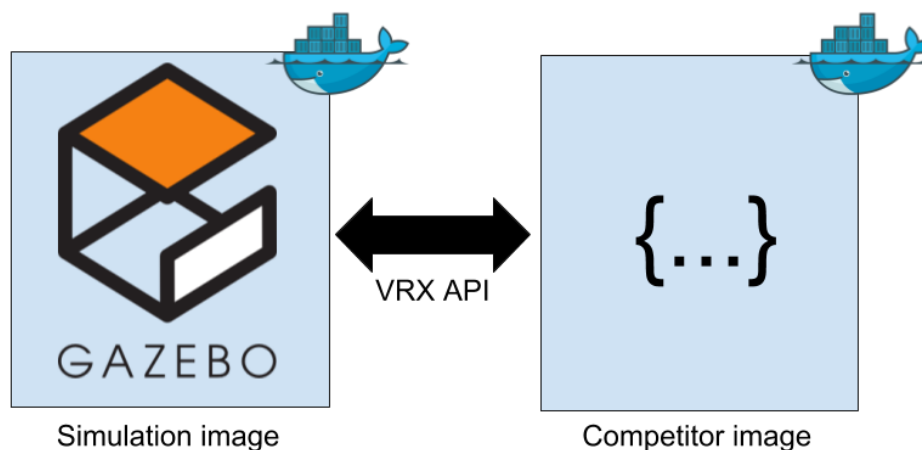


Figure 9: Architecture used to execute competitor code

We expect to receive multiple files from each competitor prior to the event associated with each phase of the competition. These files will specify different aspects of the WAM-V configuration, as well as the team's controller. Please, see the VRX Wiki for an [overview of how to participate](#) in each phase, as well as detailed instructions about how to submit a solution for a given event.

Performance for each task will be evaluated as follows:

1. Each team's customized WAM-V will be generated.
2. A Docker container running the VRX simulation image will be executed. This container will execute Gazebo with the VRX environment configured to run a particular task. Additionally, Gazebo will be configured to record a log of the execution.
3. A ROS bag (log file) will capture all task messages containing the score.

<sup>3</sup> All Gazebo topics to query ground truth information and other simulation aspects are available for debugging.

4. A team's Docker container (running the team's image) will be executed. It's expected that the entry point of this Docker instance spawns all the necessary elements of the team's code.
5. The competitor's code should interact with the simulation via the VRX API, determine the current task via the VRX API, and try to solve it.
6. When the task has been completed or has timed out, the Gazebo log file and the ROS bag will be saved and tagged appropriately.

This process will be repeated for each run of each task and for all the teams participating in the event. This architecture allows the execution of the entire competition in batch mode. Teams may run a competition themselves locally using the same set of tools that the organization will use during the official events. These automatic evaluation tools are available in the [vrx-docker repository](#). We encourage all teams to use it for testing their solutions.