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## 1 SIMLAN, Simulation for Multi-Camera Robotics (5.1.0)

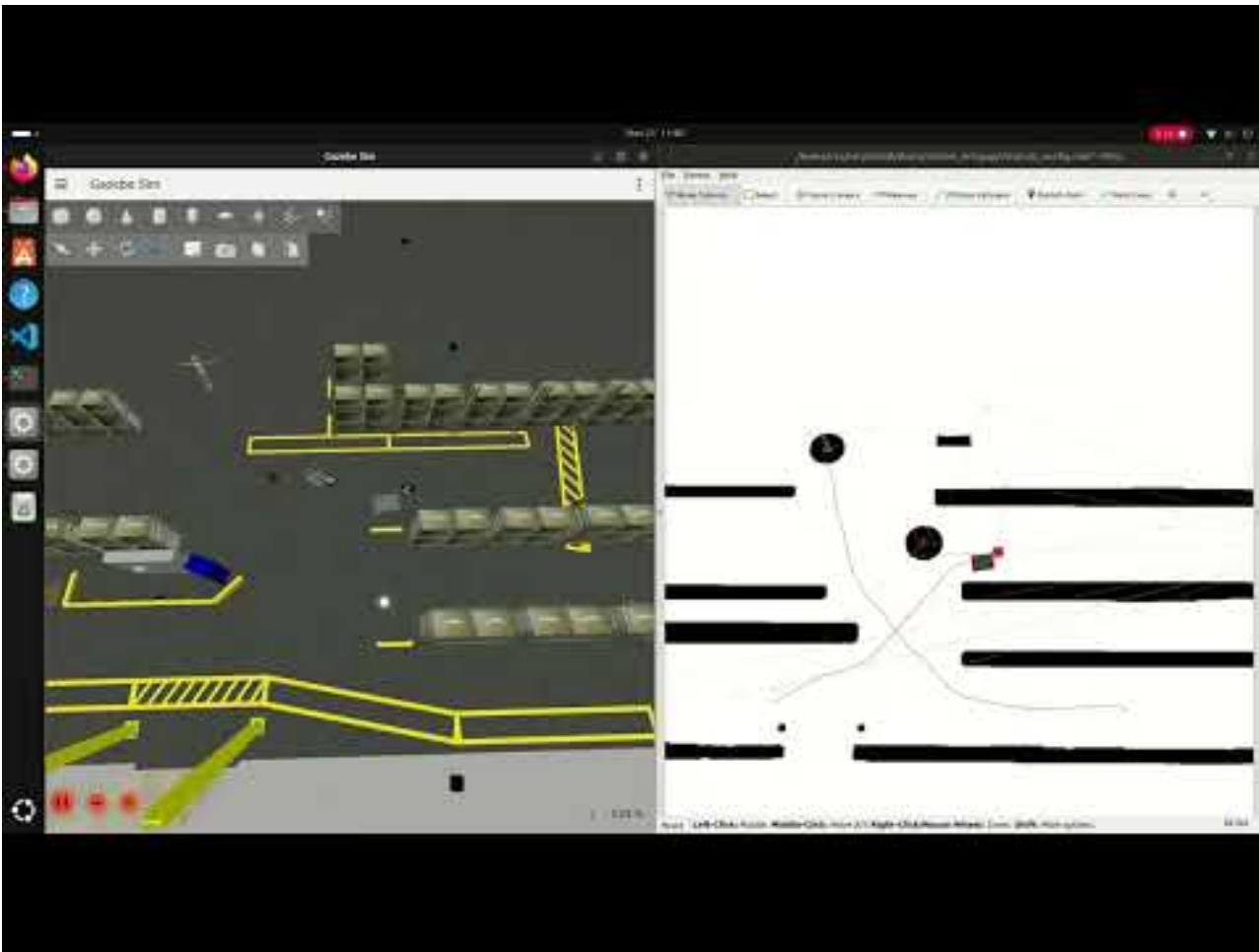
This simulation environment, based on the Ignition Gazebo simulator and ROS 2, resembles a Volvo Trucks warehouse and serves as a playground for rapid prototyping and testing of systems that rely on a multi-camera setup for perception, monitoring, localization or even navigation. This project is inspired by [GPSS \(Generic photo-based sensor system\)](#) that utilizes ceiling-mounted cameras, deep learning and computer vision algorithms, and very simple transport robots. [ [GPSS demo](#)]

- [Online Documentation](#)
- [PDF Documentation](#)

### 1.1 SIMLAN Features

- Ignition Gazebo
- Library of assets
- Real-World environment inspired design (camera position and warehouse layout)
- ROS 2 interfaces (Humble and Jazzy)
- Simple GPSS (Generic Photo-based Sensor System) navigation
- Multi-Robot localization and navigation using Nav2
- ArUco marker localization
- Bird's-Eye view projection
- Multi-Sensor Support (LiDAR, RGB camera, semantic segmentation, depth, etc.)
- Geofencing for safe zones and safe stop on collision
- Humanoid worker model
- Panda arm robotic arm
- Deep-learning-based human pose capture and replay,

Click the YouTube link below to view the SIMLAN demo video:



## 1.2 Installation [ [Demo](#)]

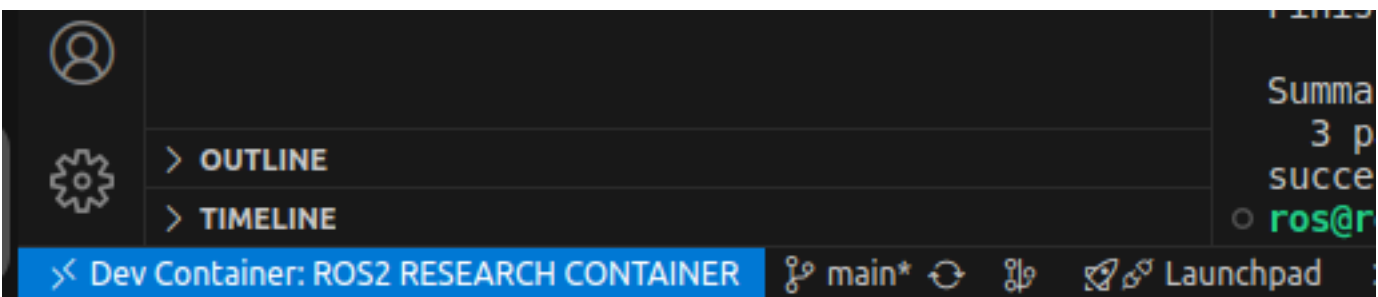
### 1.2.1 Dependencies

**Ubuntu 24.04:** use the instructions in [dependencies.md#linux-dependencies](#) to install Docker and ensure that your Linux user account has `docker` access. *Attention:* Make sure to restart the computer (for the changes in group membership to take effect) before proceeding to the next step.

**Windows 11:** use the instructions in [dependencies.md#windows-dependencies](#) to install dependencies.

**Production environment:** follow installation procedure used in [.devcontainer/Dockerfile](#) to install dependencies.

**Development environment:** To improve collaboration we use VS Code and Docker as explained in [this instruction](#) and [docker files](#). Install Visual Studio Code (VS Code) and open the project folder. VS Code will prompt you to install the required extension dependencies. Make sure the `Dev containers` extension is installed. Reopen the project in VS Code, and you will be prompted to rebuild the container. Accept the prompt; this process may take a few minutes. Once VS Code is connected to Docker (as shown in the image below), open the terminal and run the following commands:



(if you don't see this try to build manually in VS Code by pressing `Ctrl + Shift + P` and select `Dev Containers: Rebuild and Reopen in Container`.)

## 1.2.2 Quick Start

The best place to learn about the various features, start different components, and understand the project structure is [./control.sh](#).

*Attention:* The following commands (using `./control.sh`) are executed in a separate terminal tab inside VS Code.

To kill all the relevant processes (related to Gazebo and ROS 2), delete build files, delete recorded images and rosbag files using the following command:

```
./control.sh clean
```

To clean up and build the project:

```
./control.sh build
```

(optionally, in VS Code you can click on Terminal-> Run Task/Run Build Task or use `Ctrl + Shift + B`)

## 1.3 GPSS controls (pallet trucks, aruco) [ [Demo](#)]

It is possible for the cameras to detect ArUco markers on the floor and publish their location to TF, both relative to the camera, and the ArUcos transform from origin. The package `./camera_utility/aruco_localization` contains the code for handling ArUco detection.

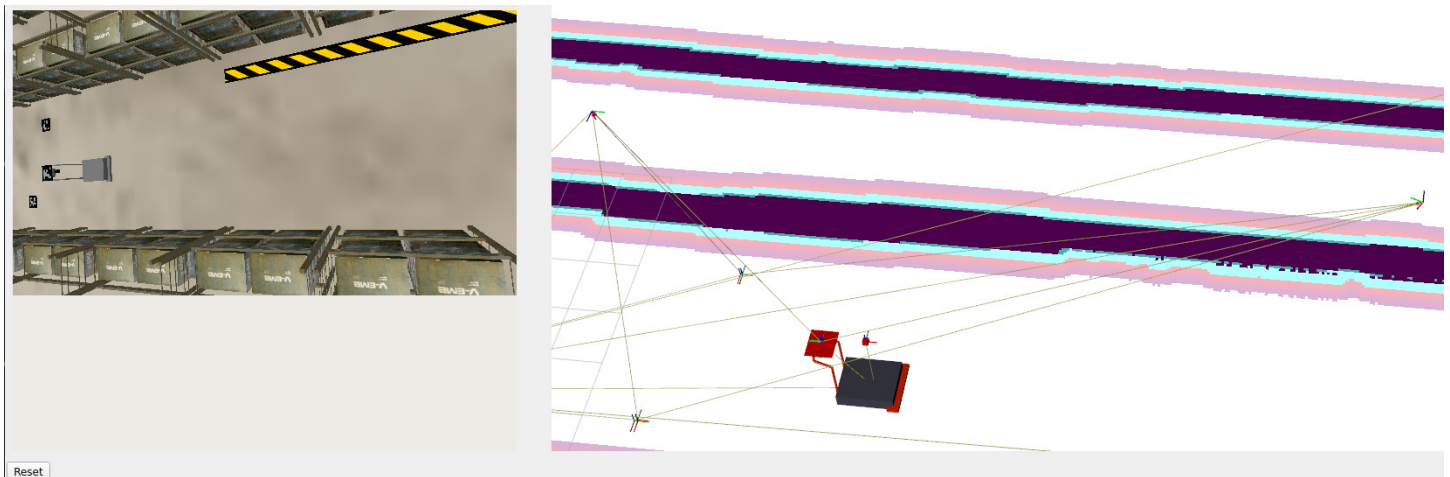
You can also use Nav2 to make a robot\_agent (that can be either robot/pallet\_truck) navigate by itself to a goal position. You can find the code in [simulation/pallet\\_truck/pallet\\_truck\\_navigation](#)

**Run these three in separate terminals**

```
./control.sh gpss # spawn the simulation, robot_agents and GPSS ArUco detection
```

```
./control.sh nav # spawn map server, and separate nav2 stack in a separate namespace for each robot_agent
```

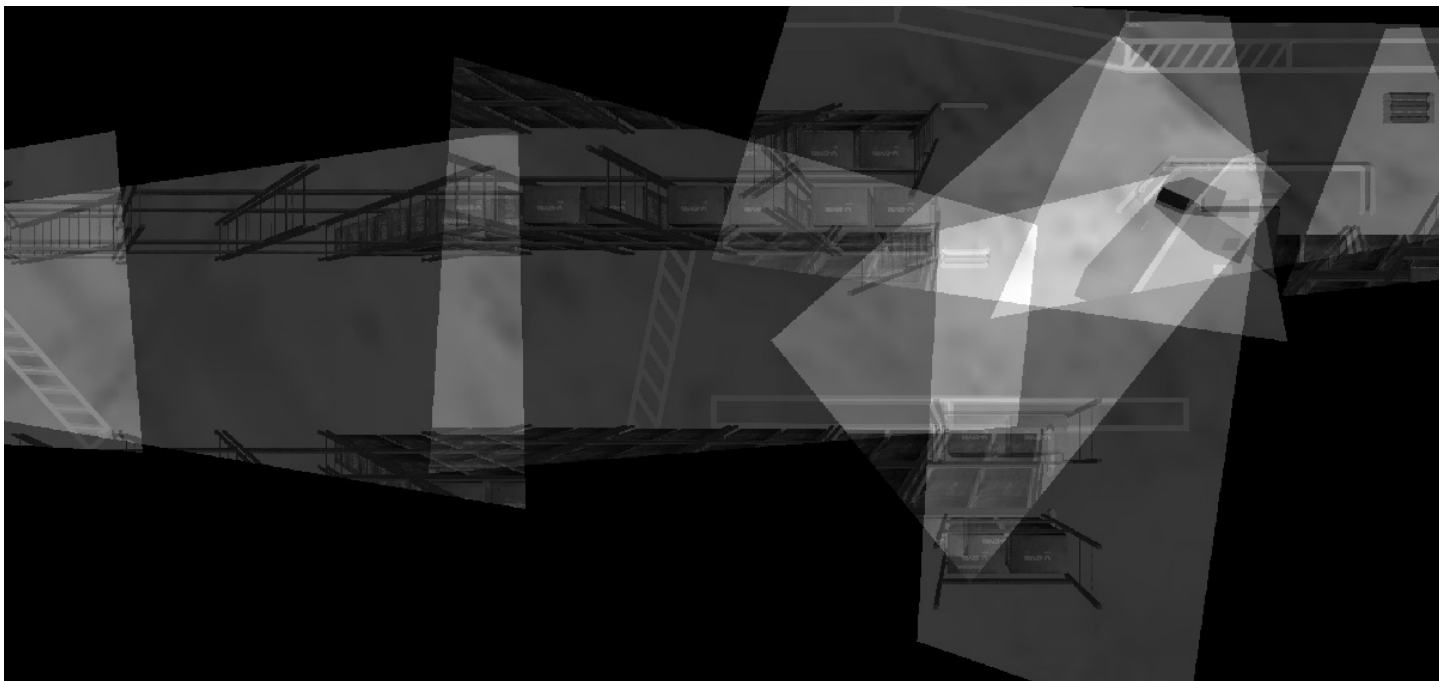
```
./control.sh send_goal # send navigation goals to nav2 stack for each robot_agent
```



`camera_enabled_ids` in `config.sh` specifies which cameras are enabled in the GPSS system for ArUco code detection and bird's-eye view.

```
./control.sh birdeye
```





## 1.4 RITA controls (humanoid, robotic arm) [ [Demo](#)]

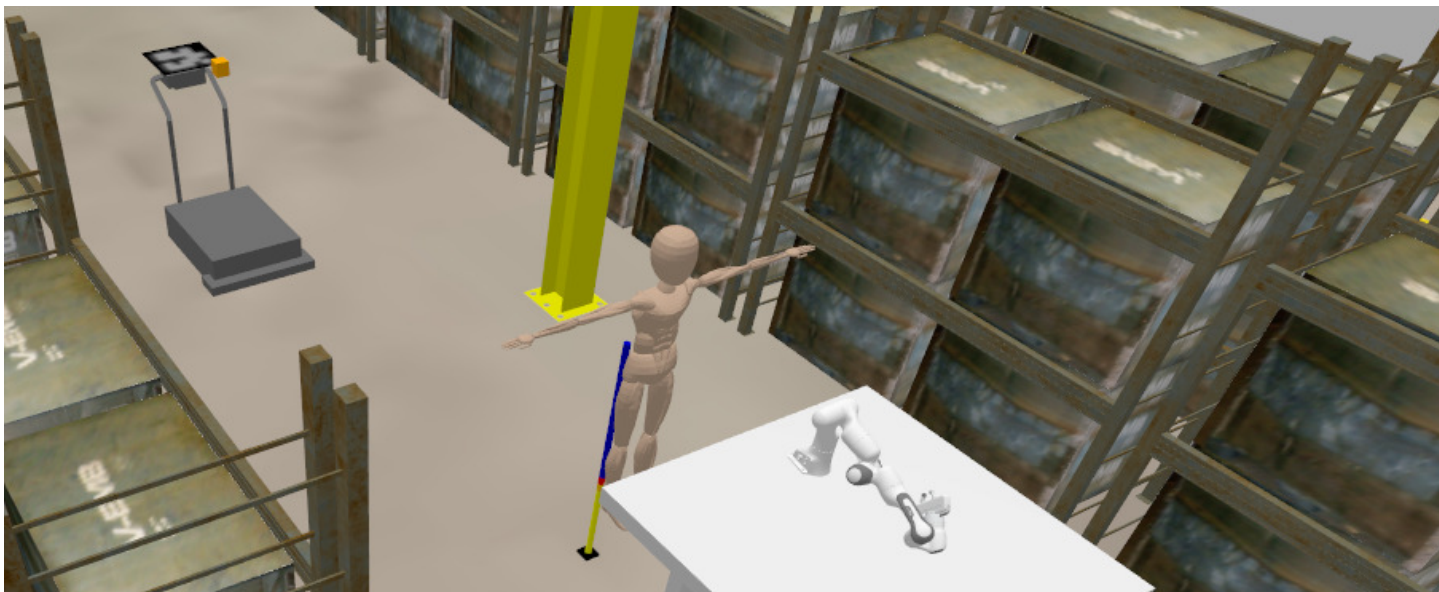
To spawn a human worker run the following command

```
./control.sh sim
./control.sh humanoid
```

We employ a deep neural network to learn the mapping between human pose and humanoid robot motion. The model takes 33 MediaPipe pose landmarks as input and predicts corresponding robot joint positions. Read more about it [Humanoid Utilities](#)

**1.4.0.1 Arm controls** Spawn the Panda arm inside SIMLAN and instruct it to pick and place a box around with the following commands:

```
./control panda
./control plan_motion
./control pick
```



## 1.5 Testing

Integration tests can be found inside of the `integration_tests/test/` package. Running the tests helps maintain the project's quality. For more information about how the tests are set up, check out the package [README](#). To run all tests, run the following command:

```
./control.sh build
./control.sh test
```

## 1.6 Customized startup

In `config.sh` it is possible to customize your scenarios. From there you can edit what world you want to run, how many cameras you want enabled, and also edit Humanoid-related properties. Modifying these variables is preferred, rather than modifying the `control.sh` file.

### 1.6.1 Headless gazebo

In `config.sh` there is a variable `headless_gazebo` that you can set to “true” or “false”. Setting it to true means will run without a window though the simulation will still run as normal. This can be useful when visualization is redundant. Setting it to false means the gazebo window will be visible.

### 1.6.2 World fidelity

in the `config.sh` script, you can adjust the world fidelity

- **default:** Contains the default world with maximum objects
- **medium:** Based on default but boxes are removed
- **light:** Based on medium but shelves are removed
- **empty:** Everything except the ground is removed

### 1.6.3 Older versions

- `gz_classic_humble` branch contains code for **Gazebo Classic (Gazebo11)** that has reached end-of-life (EOL).
- `ign_humble` branch contains code for **ROS 2 Humble & Ignition Gazebo**, an earlier version of this repository.

## 1.7 Documentation

You can build the online documentation page or a PDF file by running scripts in `resources/build-documentation`.

- `control.sh` script is a shortcut to run different launch scripts, please also see [these diagram](#).
- `config.sh` contains information about which world is loaded, which cameras are active, and what and where the robots are spawned.
- [Marp Markdown Presentation](#)
- [Configuration Generation](#)
- [Bringup and launch files](#)
- [Pallet Truck Navigation Documentation](#)
- [Camera Utilities and notebooks:](#) (Extrinsic/Intrinsic calibrations and Projection )
- [Humanoid Utilities](#) (pose2motion)
- [CHANGELOG.md](#)
- [credits.md](#)
- [LICENSE](#) (apache 2)
- [contributing.md](#)
- [ISSUES.md](#) : known issues and advanced features
- [simulation/](#): ROS2 packages
  - [Simulation and Warehouse Specification](#) (fidelity)
  - [Camera and Birdeye Configuration](#)
  - [Building Gazebo models](#) (Blender/Phobos)
  - [Objects Specifications](#)
  - [Warehouse Specification](#)
  - [Pallet truck bringup](#)
  - [Aruco Localization Documentation](#)
  - [Geofencing and Collision safe stop](#)
  - [Visualize Real Data](#) **requires data from Volvo**



- [Humanoid bringup](#)
- [humanoid\\_robot simulation](#)
- [Humanoid Control](#)

## 1.8 Research Funding

This work was carried out within these research projects:

- The [SMILE IV](#) project financed by Vinnova, FFI, Fordonsstrategisk forskning och innovation under the grant number 2023-00789.
- The EUREKA ITEA4 [ArtWork](#) - The smart and connected worker financed by Vinnova under the grant number 2023-00970.



[SIMLAN](#) project was started and is currently maintained by [Hamid Ebadi](#). To see a complete list of contributors see the [changelog](#).

## 2 Dependencies

### 2.1 Docker

```
sudo apt install curl git
curl -fsSL https://get.docker.com -o get-docker.sh
sudo sh get-docker.sh
sudo groupadd docker
sudo usermod -aG docker $USER
newgrp docker
```

### 2.2 Nvidia GPU

see [resources/ISSUES.md](#) if you faced any problem after running the commands below:

#### 2.2.1 NVIDIA Driver

Use 'nvidia-smi' to ensure that the right NVIDIA driver is installed. If you have not installed **Additional Drivers** when installing Ubuntu, you need to manually install NVIDIA drivers.

#### 2.2.2 nvidia-container-toolkit

To install Docker and nvidia-container-toolkit, use the following commands:

```
curl -fsSL https://nvidia.github.io/libnvidia-container/gpgkey | sudo gpg --dearmor -o /usr/share/keyrings/nvidia-container-toolkit-keyring.gpg
&& curl -s -L https://nvidia.github.io/libnvidia-container/stable/deb/nvidia-container-toolkit.list | \
    sed 's#deb https://#deb [signed-by=/usr/share/keyrings/nvidia-container-toolkit-keyring.gpg] https://#g' | \
    sudo tee /etc/apt/sources.list.d/nvidia-container-toolkit.list

sudo sed -i -e '/experimental/ s/^#//g' /etc/apt/sources.list.d/nvidia-container-toolkit.list
```

```
sudo apt-get update
```

```
sudo apt-get install -y nvidia-container-toolkit
```

```
sudo nvidia-ctk runtime configure --runtime=docker
```

```
INFO[0000] Config file does not exist; using empty config
INFO[0000] Wrote updated config to /etc/docker/daemon.json
INFO[0000] It is recommended that docker daemon be restarted.
```

```
sudo systemctl restart docker
```

```
sudo nvidia-ctk runtime configure --runtime=containerd
```

```
INFO[0000] Using config version 1
INFO[0000] Using CRI runtime plugin name "cri"
WARN[0000] could not infer options from runtimes [runc crun]; using defaults
INFO[0000] Wrote updated config to /etc/containerd/config.toml
INFO[0000] It is recommended that containerd daemon be restarted.
```

Restart the computer to apply the group and user changes.

To check for correct installation of Docker's NVIDIA runtime:

```
docker info|grep -i runtime
  Runtimes: nvidia runc
  Default Runtime: runc
```

Otherwise you get the following error message in VS Code: Error response from daemon: unknown or invalid runtime name: nvidia

On a **host** machine's terminal (**not** inside Visual Studio Code terminal): `xhost +local:docker`.

### 2.2.3 No Nvidia GPU

To start the project **without NVIDIA GPU**, please comment out these lines in `docker-compose.yaml` as shown below:

```
# runtime: nvidia
#
# factory_simulation_nvidia:
#   <<: *research-base
#   container_name: factory_simulation_nvidia
#   runtime: nvidia
#   deploy:
#     resources:
#       reservations:
#         devices:
#           - driver: nvidia
#             count: "all"
#             capabilities: [compute,utility,graphics,display]
```

## 2.3 Windows Dependencies

These instructions are tested on Windows 11, Docker Desktop for Windows ARM64 and VS Code.

To get the Docker container up and running, download and install Docker Desktop for your system: <https://www.docker.com/products/desktop/>

When this is done, clone the repo and open the folder in VS Code. Then you should automatically be prompted to download and install VS Code extensions that are needed and recommended for the project.

Once that is completed, make sure Docker Desktop is running and then you should be able to start the container environment in VS Code by pressing Ctrl+Shift+P and searching for Dev Containers: Rebuild and Reopen in Container.

To make Gazebo's and RViz's GUIs visible from the Docker container on your screen, download and install the following program: <https://sourceforge.net/projects/vcxsrv/>

When this is done, start the XLaunch program and configure it with these settings:

#### 2.3.0.1 Select display settings

Multiple windows  
Fullscreen  
One large window  
One window without titlebar

Display number: -1

---

#### 2.3.0.2 Select how to start clients

Start no client  
Start a program  
Open session via XDMCP

---

#### 2.3.0.3 Extra settings

Clipboard (optional)  
Primary Selection (optional)  
Native OpenGL  
Disable access control

---

Before continuing, make sure Docker Desktop is running.

## 3 Contributing

Legal Notice: When contributing to this project, you must agree that you have authored 100% of the content, that you have the necessary rights to the content, and that the content you contribute may be provided under the project license.

We try to use:

- [Docker](#), [vscode](#) + [dev-container extension](#) to develop inside a container
- [Markdown](#) for documentation
- [Conventional Commits](#) for commit messages
- [pre-commit](#) for git pre-commit hooks and basic QA
- [Semantic Versioning](#) for versioning
- [Draw.io](#) for drawing diagrams for documentation

### 3.1 Technical

- Avoid optimization unless you have a clear, measurable performance problem, as premature optimization can lead to overly complex and unreadable code.
- [PEP 20 – The Zen of Python](#)
  - Simple is better than complex.
  - Readability counts.
  - If the implementation is hard to explain, it's a bad idea.
- Please be generous in giving credit when using an image or a piece of code created by others. Add a link to the original author in [credits.md](#).
- Avoid pushing binary files such as images, models, etc. (use [.gitignore](#)), especially if they are constantly changing.

### 3.1.1 git

- Try to avoid breaking the `main` branch, but don't be obsessed with having a perfect merge request. We can always revert back to the working version or fix the issues. That is why we are using `git`.
- Follow this simple git process:

```
git checkout main
git pull
git checkout -b "branch_name"
# update files
git commit -m "conventional_commit_type: conventional_commit_message"
git push
# Create a pull request.
```

Common commit types:

- `feat`: Introduces a new feature.
- `fix`: Patches a bug or issue.
- `chore`: Routine maintenance or changes that don't affect the app's functionality.
- `docs`: Documentation changes.

Conventional commit message:

- A conventional commit message uses the imperative mood in the subject line

Example of

- `feat(auth)`: add login functionality
- `fix(ui)`: resolve button color issue

<https://www.conventionalcommits.org>

### 3.1.2 Misc

- Don't use absolute paths. Your code should run correctly both inside the VS Code Dev Container and independently outside of it. If you need to modify a configuration file at build time, use relative paths from the project root directory (avoid using `..` as it becomes hard to see which scripts are using a specific directory). For ROS2 resources, use `get_package_share_directory(project_name)` to locate package files.
- When adding a new feature, add it to `control.sh`. Otherwise, `control.sh` should remain unchanged.
- Any configuration that requires modification should be defined in `config.sh`.

### 3.1.3 Documentation

Documentation is done in a markdown file. Try to keep our documentation close to your code. Keep the documentation short and clear.

- `#` : Only used once for the title of the project.
- `##` : usually once in each markdown file and usually shares semantics with the markdown filename.
- `###` : Different topics, try to split your documentation into at least 4 topics.
- `####` : subtopics. Try to avoid when you can use simple paragraphs.

Follow this subset of [Markdown](#) tags.

## 4 Config Generation

When building the workspaces, the generation scripts found in the `scripts/` directory are run. These automatically generate the `bt.xml`, `control.yaml`, `gz_bridge.yaml`, `nav2_params.yaml`, as well as validate the setup of the `ROBOTS` list in the `config.sh` script. This is done to automatically set up the ROS2 controllers, navigation stack parameters, and other `/topics` depending on what robots and namespaces are spawned.

Every time the workspace is built, the `generate_XXX` files print that they were generated, and at the top of each generated file, a comment specifies from where the auto-generation occurred. As of now, the parameter files are saved in the package in which they're used instead of directly in the `share/` directory to increase code readability for new users.

Explanation of the different `generate_XXX` files:

- `generate_bt_xml.py`: The `bt_navigator` needs the namespace of the robot it is checking conditions for.

- [generate\\_control\\_yaml.py](#): The `ros2_controller` maps namespaced `/cmd_vel` topics to `wheel_joint` movements.
- [generate\\_gz\\_bridge\\_yaml.py](#): Some `gz_topics` need to be mapped to ROS2 topics.
- [generate\\_humanoid\\_control\\_yaml.py](#): The `ros2_controller` maps namespaced `/cmd_vel` topics to `wheel_joint` movements for humanoids.
- [generate\\_humanoid\\_nav2\\_params\\_yaml.py](#): The individual frame IDs and some ROS2 topics are needed to define humanoids and their corresponding maps.
- [generate\\_nav2\\_params\\_yaml.py](#): The individual frame IDs and some ROS2 topics are needed to define robots and their corresponding maps.
- [validate\\_humanoids.py](#): A converter from string to list of dicts including a sanity check to throw errors if the `HUMANOID` variable is wrongly configured.
- [validate\\_robots.py](#): A converter from string to list of dicts including a sanity check to throw errors if the `ROBOTS` variable is wrongly configured.

## 5 Simulation

### 5.1 World Fidelity

It is possible to adjust the level of fidelity for a world in `config.sh`; there the `world_setup` is sent to

- `simulation/simlan_brinup/launch/sim.launch.py`.
- `simulation/simlan_gazebo_environment/launch/simlan_factory.launch.py` (for world generation)
- `simulation/simlan_gazebo_environment/launch/generate_world_file.py` (both `original_world` and the `world_setup`)

### 5.2 Adding Aruco and camera (static agents)

Aruco codes and cameras are all attached to the same link in Gazebo. To create new static agents, go to `simulation/static_agent_launcher`. There you only need to add a new line on the form `<xacro:camera number="1" x="3" y="3" z="6" r="0" p="0" w="0"/>` for a new camera, or a new line on the form `<xacro:aruco number="1" x="3" y="3" z="0.1" r="0" p="0" w="0"/>` for a new aruco. The commands are identical apart from the name.

- **Number** is added to the name to make the static agent unique. For cameras this means they will publish on, e.g., the topic `static_agents/camera_[number]/image_raw`. For aruco the number indicates which aruco png to use.
- **x, y, z** is the coordinate offset from the link the agents are all attached to.
- **r, p, w** are the rotation, pitch, and yaw of the camera, dictating in which direction and at what angle the cameras are looking.

Gazebo supports [simulation of camera](#) based on Brown's distortion model. It expects 5 distortion coefficients `k1, k2, k3, p1, p2` that you can get from the camera calibration tools. The `k` coefficients are the radial components of the distortion model, while the `p` coefficients are the tangential components.

- `<aspect_ratio>`: The ratio of the width and height of the camera.
- `<horizontal_fov>`: The horizontal field of view of the camera in radians.

[OpenCV](#) uses five parameters, known as distortion coefficients given by like this: `k1, k2, p1, p2, k3` # pay attention to the order.

### 5.3 Using actors in Gazebo

- Placed in `sdf` or world file
- Actors use the `actor` tag (as opposed to the `model` tag most other objects use).
- `actor` tags contain links like usual, but also a `<script>` tag.
- The `script` tag contains:
  - `loop`: Whether the script should loop on completion
  - `delay_start`: Time to wait before running the script, also waits between loops
  - `auto_start`: Whether the script should start automatically when the sim starts
  - A trajectory tag, which has an (unique) id and a type (used to couple it with an animation)
    - \* Inside the trajectory tags we define waypoint tags which consist of a pose and the time where we are supposed to reach the pose.
    - \* Note: The trajectory is smoothed as a whole. This means that you'll get a fluid motion, but the exact poses contained in the waypoints might not be reached.

Script structure:

```

<script>
  <loop>1</loop>
  <auto_start>1</auto_start>
  <trajectory id='0' type='square'>
    <waypoint>
      <time>0</time>
      <pose>-1 -1 1 0 -0 0</pose>
    </waypoint>
    <waypoint>
      <time>1</time>
      <pose>-1 1 1 0 -0 0</pose>
    </waypoint>
    <waypoint>
      <time>2</time>
      <pose>1 1 1 0 -0 0</pose>
    </waypoint>
    <waypoint>
      <time>3</time>
      <pose>1 -1 1 0 -0 0</pose>
    </waypoint>
    <waypoint>
      <time>4</time>
      <pose>-1 -1 1 0 -0 0</pose>
    </waypoint>
  </trajectory>
</script>

```

- Gazebo supports two different skeleton animation file formats: COLLADA (.dae) and Biovision Hierarchy (.bvh).
  - .bvh: Text-based format with section ‘HIERARCHY’ and section ‘MOTION’.
  - .dae: XML-based format, structured into multiple sections.
- .bvh works for Ignition, while .dae works for both Gazebo classic and Ignition
- Skin is similar, simply import a collada file.
- <interpolate\_x>true</interpolate\_x> makes the animation match the movement. The animation is done briefly along the x-axis and then it can be interpolated into any direction by gazebo.
- In a top down positive x,y frame of reference: 0 = right, 1.57 = up, -1.57 = down, 3.14 = left
  - Pos/negative matters! 0 to -1.57 does not behave the same as 0 to 4.71!
  - In other words increasing the angle of rotation means rotating left, and decreasing it means rotating right.
- Tension = how strictly it follows the waypoints in a span 0-1 where 0 is not very strict, 1 very strict

## 5.4 Simulation Specification

Environment (world)

- An in-door factory warehouse
- An out door street/sidewalk (side walk or street) (FUTURE WORK)

Objects

- human actor
- shelves
- [standard euro pallets](#)
- [pallet racks](#)
- traffic cone
- Boxes
- [differential-drive AMR \(Autonomous Mobile Robot\)](#) (FUTURE WORK)
- forklift (FUTURE WORK)

Textures

- Aruco tag on actor and floor
- objects texture
- Floor texture

Placement of sensors



- camera (depth) on ceiling
- 2D Lidar/camera on AMR (FUTURE WORK)

#### Physics

- mass
- moment of inertia
- collision
- friction (FUTURE WORK)
- damping

#### Lighting

#### Agents movements:

- deterministically following waypoints trajectories (in curve or in form of A-B-C...Z)
- AMR differential-drive using nav2 with obstacle avoidance (FUTURE WORK)
- replaying scenario using rosbag (FUTURE WORK)

Additionally, these are expected from the simulator:

- following realistic and standard measurements and sizes for warehouse, pallettes, shelves, cart, human body, etc
- agent/robot status (position) and control via ROS
- exposing and recording camera images and agent status (e.g. positions) in Python
- tele-operation with keyboard and programmatically from python

## 5.5 AMR

differential-drive (caster wheel)/Ackermann (car) type of robot

/cmd\_vel topic accepts **Twist** formatted messages; only non-zero value for linear.x (forward/backward) and non-zero value for angular.z (differential drive, rotating around the z axis).

## 5.6 Warehouse

The warehouse was created in FreeCAD's BIM Workbench. This workbench isn't available by default, but can easily be acquired by going to **Tools -> Addon Manager -> BIM -> Install/update Selected**.

Using the measurements found in the blueprint in the documentation folder, I drew four lines and turned them into walls (line tool and wall tool respectively). By default the wall will be created around the line, so that the line is in the middle of the wall. This can be changed in the wall properties so that it ends up entirely on one side of the line. As the blueprint lacked walls I used the dimensions specified there as the inner measurements, meaning that the origin point is located at the inner bottom left corner of the wall. All the inner space is in positive x and y coordinates, while the two of the walls are in negative coordinate space. I used the Aligned Dimension tool from the Annotation tools to confirm that the inner measurements matched those of the blueprint.

While the BIM Workbench has support for door objects, they tend to act as solids when imported into Gazebo, so the door is just a hole in the wall. This hole was created by adding a cube object and having it intersect the wall where the door should be located. Then you select the cube and the wall (in that order) in the tree view and press **Remove Component**. This should remove the cube object and create a hole where the cube and wall overlapped. The hole didn't appear in the right place, but it was possible to edit the position of the hole in its properties. I measured the location of the hole using Aligned Dimension to make sure it ended up in the right spot.

Going to the top view, I created a new rectangle object covering the whole warehouse. Then I turned it into a slab with the slab tool to create a floor for the warehouse.

Everything was added to a level object (note: by default this level object is named "Floor", but don't confuse it with the slab that constitutes the physical floor) so that it's grouped together. If we set the wall heights to 0, they will automatically inherit the height of the Level object, so we can change all the walls easily by changing the height of the level.

I added two materials from presets, concrete and wood. I applied the concrete material to all walls and the wood material to the floor. These should be considered to be temporary placeholders.

Finally, I exported the project as a Collada file (.dae) and added it to a simple .world file to see if it loaded properly in Gazebo, and the results seemed correct.

Since the warehouse will be static, we shouldn't need to define any additional parameters like mass or inertia; visuals and collision should be enough. Textures might need some improvement, as currently they're just basic colors, but it should be possible to add those in FreeCAD and have them included in the .dae file so we can load them visually in Gazebo later.

I also added windows for slightly better visibility.

## 5.7 Add warehouse to world-file

The floor of the warehouse goes below  $z=0$ , so the ground plane was lowered by 0.2 so that the warehouse still rests on top of it. As our simulations will mainly take place inside the warehouse, the warehouse floor replaces the ground plane at  $z=0$ . The warehouse itself was placed in the models directory and loaded into the world with an `<include>` tag. Additionally, the maze in the stage4 world was moved away from the origin so that it is fully contained inside the warehouse, though in the future it should be removed altogether.

## 5.8 Textures

Shelf, pallet, warehouse walls are using CC0 textures from <https://polyhaven.com/textures> Box and warehouse floor are using images from Volvo as a base.

- box: picture from [Volvo-group-packaging-specifications\\_2015.pdf](#)

### 5.8.1 Conventions

- Keep your links/joints paired, and use the suffix `_link` and `_joint` (e.g. `arm_link` and `arm_joint`) and maybe follow [REP 120 naming conventions](#).
- Define visual, collision, inertial and Gazebo material (and maybe friction) for all objects

### 5.8.2 cartography, localization, navigation

```
ros2 launch pallet_truck_navigation cartography.launch.py
ros2 run nav2_map_server map_saver_cli -f simulation/mapname
```

## 6 Gazebo Worlds

```
<physics type="ode">
  <ode>
    <solver>
      <type>world</type>
    </solver>
    <constraints>
      <contact_max_correcting_vel>0.1</contact_max_correcting_vel>
      <contact_surface_layer>0.0001</contact_surface_layer>
    </constraints>
  </ode>
  <max_step_size>0.001</max_step_size>
</physics>
```

Two solvers: world step gives an accurate solution if it is able to solve the problem, while quick step depends on the number of iterations to reach an accurate enough solution.

### 6.1 contact/collision parameters

dampingFactor double Exponential velocity decay of the link velocity - takes the value and multiplies the previous link velocity by  $(1 - \text{dampingFactor})$ . maxVel double maximum contact correction velocity truncation term. minDepth double minimum allowable depth before contact correction impulse is applied maxContacts int Maximum number of contacts allowed between two entities. This value overrides the `max_contacts` element defined in physics.

`contact_max_correcting_vel` : `contact_max_correcting_vel` This is the same parameter as the `max_vel` under `collision->surface->contact`. `contact_max_correcting_vel` sets `max_vel` globally. `contact_surface_layer` : `contact_surface_layer` This is the same parameter as the `min_depth` under `collision->surface->contact`.

*Note:* We had issue getting global settings (`contact_max_correcting_vel` and `contact_surface_layer`) working. We therefore define object level `minDepth` and `maxVel` for each object

“quick” solver parameters `min_step_size` The minimum time duration which advances with each time step of a variable time step solver. `iters` The number of iterations for the solver to run for each time step.

## 6.2 objects:

As of now there are many objects in the world file and if you want to move them all it's quite cumbersome. Therefore the `move_objects.py` was added to be able to increment the poses by `x` amount if needed. See `move_objects.py`

## 6.3 reference:

- [Physics Parameters](#)
- [SDF format](#)

# 7 Converting meshes to SDF models

Here are the steps to convert FreeCAD meshes to SDF models (for Gazebo):

## 7.1 Script step-by-step

- Install FreeCAD `sudo apt-get install freecad=0.19.2+dfsg1-3ubuntu1` (Tested with version 0.19)
- Install Blender v3.3 LTS
- Download `phobos.zip` (tested with [phobos 2.0 “Perilled Pangolin”](#).)
- Install phobos by following [the guide on their GitHub](#)
- In your phobos settings (easiest accessed through the Blender GUI), change the models folder to where you want the output to be. You can add a relative path here so that the output folder depends on where you run the script, e.g., setting the model folder to `./phobos_out/` would create a `./phobos_out/` directory as a sub-directory to wherever you run the script and save the exported SDFs there.
- Enter FreeCAD and load your `.FCstd`, then select the body in the tree view and select **File->Export** and choose to export it as a Collada (`.dae`) file.
- Run `./build.sh`

You should now be able to load the model/directory created by the reformat script directly through Gazebo.

```
wget https://download.blender.org/release/Blender3.3/blender-3.3.0-linux-x64.tar.xz
tar -xf blender-3.3.0-linux-x64.tar.xz
mv blender-3.3.0-linux-x64 blender
alias blender="`pwd`/blender/blender"
blender --version
git clone git@github.com:dfki-ric/phobos.git
cd phobos
git checkout 2.0.0
blender -b --python install_requirements.py
cd ..
./build.sh
```

## 7.2 In GUI

- Import `.dae` file
- Set phobostype to `visual`
- Select the object and set the `geometry type`
- [Guide](#) says to **Object->Apply->Rotation & Scale** here, but I'm not sure what it actually accomplishes
  - This will apply the scaling of objects to their mesh information (vertices) and applies the current orientation to the mesh as well. After this option, all objects have zero orientation. If this is not desired, one can also only apply the **Scale**.
- Create a “visual” collection and put the model into there; this lets us create a tree structure. (unsure of necessity when we only have one model)
- Select the object and press **Create Link(s)**, make sure `selected objects` mode is chosen.
- Select the visual and then **Create Collision**.
- Select the object and then **Create Inertials**.
  - Here we need to manually enter our mass; we should check if that can be adjusted somehow.
- Save and export.

- Then we need to move around the resulting files so they're structured in the way Gazebo wants them, i.e.:

```
model
  meshes
    filename.dae
  model.config
  model.sdf
```

In order to accomplish this, we'll have to create the model.config file; however, this is relatively simple as it doesn't contain any unique data between different models aside from the model name.

Example of a successful build:

```
simulation/raw_models$ ./build_models.sh
```

```
../simlan_gazebo_environment/models/aruco/materials/textures/0.png
../simlan_gazebo_environment/models/aruco/materials/textures/1.png
../simlan_gazebo_environment/models/aruco/materials/textures/2.png
../simlan_gazebo_environment/models/aruco/materials/textures/3.png
```

Color management: using fallback mode for management

Color management: Error could not find role data role.

Blender 3.0.1

Read prefs: [HOME]/.config/blender/3.0/config/userpref.blend

Color management: scene view "Filmic" not found, setting default "Standard".

/usr/lib/python3/dist-packages/scipy/\_\_init\_\_.py:146: UserWarning: A NumPy version >=1.17.3 and <1.25.0 is required  
warnings.warn(f"A NumPy version >={np\_minversion} and <{np\_maxversion}"

Checking requirements:

ensurepip is disabled in Debian/Ubuntu for the system python.

Python modules for the system python are usually handled by dpkg and apt-get.

```
apt install python3-<module name>
```

Install the python3-pip package to use pip itself. Using pip together with the system python might have unexpected results for any system-installed module, so use it at your own risk, or make sure to only use it in virtual environments.

WARNING: We couldn't do ensurepip; we try to continue anyway

Checking yaml

Checking numpy

Checking scipy

Checking collada

Checking pydot

Checking lxml

Checking networkx

Checking trimesh

Checking PIL

Importing phobos

IMPORT: phobos.blender.defs

Parsing definitions from: [HOME]/.config/blender/3.0/scripts/addons/phobos/data/blender/definitions

defaultControllers.yml

defaultSensors.yml

defaultMaterials.yml

defaultJoints.yml

defaultSubmechanisms.yml

defaultMotors.yml

Creating new definition type: joints

Creating new definition type: motors

```

IMPORT: phobos.blender.display
IMPORT: phobos.blender.io
RELOAD: phobos.blender.model
IMPORT: phobos.blender.operators
RELOAD: phobos.blender.phobosgui
RELOAD: phobos.blender.phoboslog
RELOAD: phobos.blender.phobossystem
RELOAD: phobos.blender.reserved_keys
RELOAD: phobos.blender.utils
Registering operators.selection...
Registering operators.io...
Registering operators.editing...
TypeError: EnumProperty(..., default='mechanism'): not found in enum members
ValueError: bpy_struct "PHOBOS_OT_define_submodel" registration error: 'submodeltype' EnumProperty could not r
Registering operators.naming...
Registering operators.misc...

Registering phobosgui...
... successful.
+-- Collada Import parameters-----
| input file      : ./objects/meshes/eur-pallet.dae
| use units       : no
| autoconnect     : yes
+-- Armature Import parameters ----
| find bone chains: yes
| min chain len   : 0
| fix orientation : yes
| keep bind info  : no
| IOR of negative value is not allowed for materials (using Blender default value instead)+-- Import Scene ---
| NODE id='node0', name='node0'
+-----+
| Collada Import : OK
+-----+
Error in sys.excepthook:

Original exception was:
File "[HOME]/.config/blender/3.0/scripts/addons/phobos/blender/operators/editing.py", line 1048, in toggleVisu
Error in sys.excepthook:

Original exception was:
File "[HOME]/.config/blender/3.0/scripts/addons/phobos/blender/operators/editing.py", line 1051, in toggleColl
[20231211_08:52:53] WARNING No text file README.md found. (phobos/blender/utils/blender.py - readTextFile (125
Collada export to: [PATH]simulation/raw_models/phobos_out/unnamed/meshes/dae/Body.dae
Info: Exported 1 Object
Info: Exported 1 Object
Collada export to: [PATH]simulation/raw_models/phobos_out/unnamed/meshes/dae/Body.dae
Info: Exported 1 Object
Info: Exported 1 Object
Info: Phobos exported to: phobos_out/unnamed
Info: Export successful.
Info: Phobos exported to: phobos_out/unnamed
Info: Export successful.

-----
Unregistering Phobos...
Unregistering phobosgui...
Unregistering display...
Unregistering icons...
Unregistering classes...
Unregistering manuals...

```

... successful.

Blender quit

Error: Not freed memory blocks: 14, total unfreed memory 0.002426 MB

## 7.3 Blueprint

This document contains explanations and motivations for the measurements as well as names for variables that should be used when designing the objects. The categories are mostly self-explanatory; the one that might need more of an explanation is the color red. This refers to loose objects such as pallets, barrels, boxes, and things that will be placed directly on the ground.

### Measurements:

Category	Part / Object	Variable Name	Value [unit]
Shelf	Load Beam	beam_length	2.7 [m]
Shelf	Load Beam	beam_depth	0.05 [m]
Shelf	Load Beam	beam_height	0.14 [m]
Shelf	Load Beam	beam_weight	15.2 [kg]
Shelf	Footplate	footplate_length	0.111 [m]
Shelf	Footplate	footplate_width	0.1 [m]
Shelf	Footplate	footplate_height	0.004 [m]
Shelf	Stand / Pole	stand_length	0.07 [m]
Shelf	Stand / Pole	stand_width	0.08 [m]
Shelf	Stand / Pole	stand_height	3 [m]
Shelf	Stand / Pole	stand_weight	8.5 [kg]
Shelf	Cross Brace	brace_length	0.96 [m]
Shelf	Cross Brace	brace_width	0.01 [m]
Shelf	Cross Brace	brace_height	0.02 [m]
Shelf	Cross Brace	brace_weight	1 [kg]
Loose Object	EUR-Pallet	EUR_pallet_length	1.2 [m]
Loose Object	EUR-Pallet	EUR_pallet_width	0.8 [m]
Loose Object	EUR-Pallet	EUR_pallet_height	0.144 [m]
Loose Object	EUR-Pallet	EUR_pallet_weight	25 [kg]
Loose Object	Steel Drum	steel_drum_radius	0.3 [m]
Loose Object	Steel Drum	steel_drum_height	0.9 [m]
Loose Object	Steel Drum	full_steel_drum_weight	188 [kg]
Loose Object	Steel Drum	empty_steel_drum_weight	15 [kg]
Loose Object	Traffic Cone	traffic_cone_radius	0.22 [m]
Loose Object	Traffic Cone	traffic_cone_angle	-10 [degrees]
Loose Object	Traffic Cone	traffic_cone_total_height	1 [m]
Loose Object	Traffic Cone	traffic_cone_base_length	0.52 [m]
Loose Object	Traffic Cone	traffic_cone_base_width	0.52 [m]
Loose Object	Traffic Cone	traffic_cone_base_height	0.03 [m]
Loose Object	Traffic Cone	traffic_cone_base_angle	-20 [degrees]
Loose Object	Traffic Cone	traffic_cone_weight	6.5 [kg]
Loose Object	Box	box_length	Varies [m]
Loose Object	Box	box_width	Varies [m]
Loose Object	Box	box_height	Varies [m]
Loose Object	Box	box_weight	Varies [m]
Warehouse	Support Pole	pole_length	0.3 [m]
Warehouse	Support Pole	pole_width	0.3 [m]
Warehouse	Support Pole	pole_hole_side_length	0.27 [m]
Warehouse	Support Pole	pole_hole_side_width	0.13 [m]
Warehouse	Support Pole	pole_height	6 [m]
Warehouse	Support Pole	pole_weight	Undefined [kg]



## 7.4 AMR

### AMR

It is defined in the XY plane, and the center of the AMR is on x,y=0,0, and the bottom of the robot is on z=0.

Define **scale**, **pos**, and collision in these files:

We write our AMR description in `simlan_gazebo_environment/urdf` and use `xacro` to create a `urdf` file with gazebo tags (so not a pure urdf file) that can be used both by `state_publisher` and `gazebo` (unlike 2 separate files: `model.sdf` that is used for Gazebo and `turtlebot.urf` that is used for state\_publisher in the original Turtlebot\_simulation git project).

There are two actual diffdrive wheels that are named `left` and `right` and four supporting wheels to balance the robot that are named `front_left`, `front_right`, `back_left`, and `back_right` (they have no friction and can be moved to different positions) with the radius of 0.98 of the main wheels.

**Note:** The reason for the shake is the difference between the radius of the real wheels and caster wheels.

Orientation:

- x: forward
- y: left
- z: up

## 7.5 Objects Modeled in FreeCAD

All the objects are located in `objects`. Below follows a list of the objects currently available, models created in FreeCAD.

- EUR-pallet
- Shelf
- Modular Shelf - a stackable shelf part that can create shelves of varying sizes
- Steel Drum
- Traffic Cone
- Support Pole
- Boxes with measurements in mm [Box-Length x Width x Height]
  - Box-160x130x70
  - Box-185x185x75
  - Box-185x185x185
  - Box-210x180x130
  - Box-230x160x85
  - Box-250x195x160
  - Box-430x250x260
  - Box-440x320x175
  - Box-570x380x380
  - Box-1185x785x1010
  - Box-600x800x400 (2 per level on EUR-Pallet)
  - Box-600x400x400 (4 per level on EUR-Pallet)
  - Box-300x400x400 (8 per level on EUR-pallet)

## 7.6 AMR camera

### Camera

Inspired by [CCTV Camera 3G-SDI](#)

In the model: camera base height (70mm) + camera lens height (50mm) = 120mm

## 7.7 Resources

- [Pallet Rack Specification & Configuration Guide](#)
- [Pallet Rack Estimator](#)

- [Pallet rack configurator](#)
- [pallet](#)
- Shelf typical measurements: [Shelf Measurements](#)
- Forklift height which influences Shelf height: [Forklift Height](#)
- EUR-pallet: [EUR-pallet](#)
- Shelf design: [Shelf design](#)
- Shelf exact measurements: [Shelf exact measurement](#)
- Examples of boxes: [Boxes Examples](#)
- Measurement for steel drum: [Steel Drum](#)
- Full Steel drum weight is based on the oil density of 825kg/m<sup>3</sup> and the drum fits 210 liters.
- Some values helping in constructing the traffic cone: [Traffic Cone](#)

## 7.8 Blueprint

This document contains explanations and motivations for the measurements, as well as names for variables that should be used when designing the objects. The categories are mostly self-explanatory; the one that might need more of an explanation is the color red. This refers to loose objects such as pallets, barrels, boxes, and things that will be placed directly on the ground.

### Measurements:

Category	Part / Object	Variable Name	Value [unit]
Warehouse	Walls	warehouse_length	23.2 [m]
Warehouse	Walls	warehouse_width	18 [m]
Warehouse	Walls	warehouse_height	6 [m]
Warehouse	Aisle	aisle_width	3.7 [m]
Warehouse	Door	door_height	4 [m]
Warehouse	Door	door_width	3 [m]
Warehouse	Warehouse	door_distance_to_wall	2 [m]
Warehouse	Shelf	shelf_distance_side_side	0 [m]
Warehouse	Shelf	single_shelf_wall_distance	0.1 [m]
Warehouse	Shelf	double_shelf_depth_distance	0.2 [m]
Warehouse	Shelf	shelf_total_length	2.88 [m]
Warehouse	Shelf	shelf_total_depth	1.1 [m]
Warehouse	Shelf	shelf_total_height	3 [m]

---

blueprint

---

*The storage blueprint*

---

## 7.9 Install instruction for BIM and Arch workbench

The warehouse was created in FreeCAD's BIM Workbench. This workbench isn't available by default but can easily be acquired by:

- Installing `pip3 install gitpython`
- Activating Tools -> Addon Manager -> BIM -> Install/update Selected

Using the measurements found in the blueprint in the documentation folder, I drew four lines and turned them into walls (line tool and wall tool respectively). By default, the wall will be created around the line, so that the line is in the middle of the wall. This can be changed in the wall properties so that it ends up entirely on one side of the line. As the blueprint lacked walls, I used the dimensions specified there as the inner measurements, meaning that the origin point is located at the inner bottom left corner of the wall. All the inner space is in positive x and y coordinates, while two of the walls are in negative coordinate space. I used the Aligned Dimension tool from the Annotation tools to confirm that the inner measurements matched those of the blueprint.

While the BIM Workbench has support for door objects, they tend to act as solids when imported into Gazebo, so the door is just a hole in the wall. This hole was created by adding a cube object (3D/BIM -> Cube) and having it intersect the wall where the door should be located. Then you select the cube and the wall (in that order) in the tree view and press **Modify -> Remove Component**. This should remove the cube object and create a hole where the cube and wall overlapped. The hole

didn't appear in the right place, but it was possible to edit the position of the hole in its properties. I measured the location of the hole using Aligned Dimension to make sure it ended up in the right spot.

Going to the top view, I created a new rectangle object covering the whole warehouse. Then I turned it into a slab with the slab tool to create a floor for the warehouse.

Everything was added to a level object (note: by default, this level object is named "Floor," but don't confuse it with the slab that constitutes the physical floor) so that it's grouped together. If we set the wall heights to 0, they will automatically inherit the height of the Level object, so we can change all the walls easily by changing the height of the level. Textures for the floor and walls can later be added in Blender.

Finally, I exported the project as a Collada file (.dae) and added it into a simple .world file to see if it loaded properly in Gazebo, and the results seemed correct.

Since the warehouse will be static, we shouldn't need to define any additional parameters like mass or inertia; visuals and collision should be enough. Textures might need some improvement, as currently they're just basic colors, but it should be possible to add those in FreeCAD and have them included in the .dae file so we can load them visually in Gazebo later.

I also added windows for slightly better visibility.

## 7.10 Add warehouse to world-file

The floor of the warehouse goes below  $z=0$ , so the ground plane was lowered by 0.2 so that the warehouse still rests on top of it. As our simulations will mainly take place inside the warehouse, the warehouse floor replaces the ground plane at  $z=0$ . The warehouse itself was placed in the models directory and loaded into the world with an `<include>` tag. Additionally, the maze in the stage4 world was moved away from the origin so that it is fully contained inside the warehouse, though in the future it should be removed altogether.

## 7.11 Resources

Warehouse Aisle width: [Aisle Width](#)

# 8 SIMLAN bringup

This package is responsible for launching all things related to the simulation. The launch files in the package call launch files in all other packages to start everything up with the following command

```
ros2 launch simlan_bringup full_sim.launch.py
```

This is also called in the `sim` operation in `control.sh`:

```
./control.sh sim
```

## 8.1 Launch arguments

There are different launch arguments that can be changed to launch the simulation in different states. These can either be called from the terminal by appending the argument to the launch command above.

```
rviz:='True'
```

Another way to edit what is launched is to change the *default value* in [full\\_sim.launch.py](#).

```
launch_rviz_launch_argument = DeclareLaunchArgument("rviz", default_value="False", description="To launch rviz")
```

The launch arguments are then either added as a condition straight to a Node:

```
condition=IfCondition(rviz)
```

or passed downward to the launch file being called from the top-level launch file:

```
launch_arguments={"jackal_manual_control":jackal_manual_control,}.items()
```

If you use a specific argument configuration often, it is best to create a new launch file, on top of [full\\_sim.launch.py](#). It can have the correct default values for all arguments and then just call on [full\\_sim.launch.py](#).

## 8.2 Diagram of launch structure

This diagram is made in DrawIO and the PNG contains the XML code. Drop it into [draw.io](https://draw.io) to make changes and add back to this readme. launch\_structure

## 9 Launching GPSS cameras

This package launches all the static agents, i.e., the cameras in the simulation.

When the workspace is built, the `camera_config.xacro` file is updated with `camera_ids` and their corresponding intrinsic and extrinsic values. This can be seen in the `build` function in `control.sh`.

The `camera_config.xacro` is then sent to the `robot_state_publisher` node and published to the `/static_agent/robot_description` topic. The `ros_gz_sim` package with the “create” executable then spawns the static\_agents by subscribing to the `/static_agent/robot_description` topic and spawning each agent.

### 9.1 gz\_bridge for cameras

Different configurations of the `gz_bridge` node were tested and evaluated against the simulated RTF (real time factor). In the earlier setups, a `gz_bridge` node was set up for each `camera_stream` (image, depth, semantic) for each `camera_id`. Three configurations were tested where different numbers of nodes were set up and their corresponding RTFs were captured and averaged over five tries.

SN=single node for all cameras, 1NPC=1 node per camera\_id, 1NPSPC = 1 node per stream per camera\_id

node setup	number of cameras	number of nodes	camera streams	avg RTF
SN	9	1	image	17,9%
1NPC	9	9	image	16,7%
SN	9	1	image depth semantic	5,14%
1NPC	9	9	image depth semantic	5,2%
1NPS	9	81	image depth semantic	4,7%

It doesn't seem like a big difference, so we will stick with one node, i.e., SN.

In the future it can be decided whether to keep the `gz_bridge` node as is or to generate a `gz_bridge_camera.yaml` file like the other generation scripts (`config_generation`).

### 9.2 adding new cameras

If you want to add new cameras use the jupyter notebook [generate\\_extrensic\\_content.ipynb](#) located in `camera_utility`.

To view references of how an extrensic yaml file is structured, look at any file inside `extrinsic` folder. If we want to add new cameras in the same way as the existing ones we need to define an `intrinsic` and `extrinsic` yaml file with its camera name as file name, i.e. 500.yaml.

To create an `intrinsic` yaml file, its just to copy an existing one and save the copy with the new camera name. For now, the intrinsic does not change.

To create an `extrinsic` file you must change the “rotation\_matrix”, “t\_vec”, and “position”. And these vary depending on where you want to place the camera and how it should be angled.

To solve this, use method `generate_extrinsic_complete(rpy, position)` to generate a complete multi-string of the extrinsic yaml content. Easy to copy and paste into the new extrinsic file you want to create. It inputs:

- **position:** The gazebo position, actual position relative to whatever origin you are dealing with.
- **rpy:** A list containing the roll pitch yaw. This you need to calculate/experiment with yourself to find what angle you want the camera to be.

Note: The angles are calculated using Radians, meaning  $PI=180$  degrees,  $PI/2=90$  degrees

## 10 Bird Eye View package

As preparation, make sure that the right cameras are selected in the `config.sh`

```
## CAMERA_ENABLED_IDS can be set as a string of camera_ids separated by space ' '. valid camera ids are 160-170
CAMERA_ENABLED_IDS='164 165 166 167 168'
CAMERA_STREAMS='image'
```

### 10.1 Bird eye view

This package features the ability to select areas of your choosing and create a bird-eye view of that area by using available cameras, viewing that area.

Ro run birdeye launch file in separate terminals run the following commands:

```
./control.sh build
./control.sh sim
./control.sh static_agents
./control.sh birdeye
```

bird eye view bird eye view gazebo

### 10.2 Different sensors (Depth, Semantic Segmentation, Color)

The package also includes a camera save node. This node saves raw, depth, and semantic segmentation images for all the enabled camera IDs in `config.sh`. To take a single image from different cameras, run the following command:

```
CAMERA_ENABLED_IDS='164 165 166 167 168'
## CAMERA_STREAMS can be set as a string of stream options separated by space ' '. valid camera ids are image
CAMERA_STREAMS='image depth semantic'
```

Keep in mind to change `real_time_factor` in `simulation/simlan_gazebo_environment/worlds/ign_simlan_factory.world.xacro` to small values to slow down the simulator (e.g. 0.05-0.1).

to record a camera streams as a sequence of images or a video run the following command in separate terminals:

```
./control.sh build
./control.sh sim
./control.sh static_agents
./control.sh save_depth_seg_images
./control.sh save_depth_seg_videos
```

The resulting videos are stored in `/simulation/camera_bird_eye_view/recordings/`

color

semantic

depth

## 11 Aruco Localization Package

This is the `aruco_localization` package, which runs a ROS2 node that takes images from camera topics `CAMERA_X/camera_info` and `CAMERA_X/image_raw`, processes the ArUco code, and publishes the result in the `/TF` of the detected ArUco marker, mimicking Volvo's logic for tracking robot positions and generating navigation routes. A launch file is provided to run multiple nodes, with each node dedicated and assigned to a single camera. The `camera_enabled_ids` variable found in `config.sh` is used to control which cameras are enabled.

**Note:** The marker link is named based on the camera. For example, if camera 164 detects an ArUco marker with ID of 12, the marker link in `/tf` is named `camera_164_marker_12`. This is not the final link that is used. The result from different cameras are accumulated and merged as a single frame with parent as `robot_agent_12/odom` and child `robot_agent_12/baselink`.

**Note:** The marker ID is tightly linked with the name for the robots, meaning an ArUco with `marker_ID=1` will detect the robot with name: `{namespace}/{marker_ID}`. For example `'robot_agent_1'`.

### 11.1 Important points to pay attention to:

- If two cameras are pointed at the same ArUco code, the system does not alternate between them, but instead shows the midpoint between the two detections.
- Inside the `aruco_node`, a callback logs the relative position of the newly created `aruco_link` from the `base_link`.
- Multiple cameras can be linked to the same ArUco code simultaneously.

### 11.2 Important launch files

- `aruco_detection_node.py`: Handles ArUco detection and publishes the TF between the camera and marker. (e.g. `camera_164_marker_12`)
- `aruco_pose_pub.py`: A new node that listens to all transforms of `camera_164_marker_12` as input, and outputs the transform to either TF or ODOM as `robot_agent_12/odom` and child `robot_agent_12/baselink`.
- `multi_detection.launch.py`: Launch file for the new node.

### 11.3 Odom

These have to be valid for both humanoid and pallet trucks

- `world`: is the origin (0,0,0)
- `odom`: is in the initial pose of the robot
- `base_link`: tracks the movement of the robot relative to the odom

Coordinate

## 12 Pallet Truck bringup

This package handles initialization and status of spawned robots.

- `gazebo.launch.py` - Spawns robot, handles `robot_state_publisher`, `robot_description`
- `keyboard_steering.launch.py` - keyboard steering.
- `multiple_robot_spawn.launch.py` - contains configurable list of robots you spawn in the sim.
- `sim.launch.py` - main launch file for single robot. Make sure Gazebo is running; `control`, `twist_mux`, and `keyboard_steering` are all launched.
- `rviz.launch.py` - runs RViz

The package focuses on `pallet_truck` and `forklift` for now, but could be made modular to spawn other types of robots.

### 12.1 Configuring and spawning robots inside the sim

Below is the structure which we use to spawn robots inside of the sim. Please read these notes before setting up a new or editing a robot.

Here is the information from the table presented as a markdown list:

### 12.2 Robot Spawning Attributes

- **namespace**
  - **Description:** Used to differentiate between multiple robots. Follows the format `robot_agent_N`, where N is the robot ID.
  - **Example:** `"robot_agent_1"`
- **initial\_pose\_x**
  - **Description:** The robot's initial x-coordinate position. **Float value** wrapped as a string.
  - **Example:** `"10.0"`
- **initial\_pose\_y**
  - **Description:** The robot's initial y-coordinate position. **Float value** wrapped as a string.
  - **Example:** `"1.0"`
- **robot\_type**
  - **Description:** Selects the robot mesh or appearance. Options are `"pallet_truck"` or `"forklift"`.
  - **Example:** `"pallet_truck"`
- **aruco\_id**
  - **Description:** Sets the ID shown on the robot's ArUco marker. Must match the ID in the `namespace`.
  - **Example:** `"1"` if namespace ID is 1



Would you like me to use these attributes to create a sample robot configuration?

Example robot setup:

```
{
  "namespace": "robot_agent_1",
  "initial_pose_x": "10.0",
  "initial_pose_y": "1.0",
  "robot_type": "pallet_truck",
  "aruco_id": "1"
}
```

## 12.3 Automatically generated parameter files

Some parameter files are automatically generated for the `pallet_truck_bringup` package. The generation scripts can be found in the `config_generation/` directory. The automatically generated files include the `nav2_params.yaml`, `gz_bridge.yaml` and more. To look at all the automatically generated files, build the workspace and the generated files will be printed in the terminal or look manually in the `config_generation/generate.py`.

## 12.4 Pallet Truck Package

Common packages for `pallet_truck`, including messages and robot description. These are packages relevant to all `pallet_truck` workspaces, whether simulation, desktop, or on the robot's own headless PC.

Links to read about each individual pkg - [pallet\\_truck\\_bringup](#) - [pallet\\_truck\\_control](#) - [pallet\\_truck\\_description](#) - [pallet\\_truck\\_navigation](#)

`prefix` is used to publish unique base link names of each robot agent to `/tf`. This way they are all visible in `rviz` and probably it is used for odometry done by `aruco` localization.

`namespace` is used to separate nodes and topics related to each robot agent. This way we can control each robot separately and run a separate `nav2` stack.

**Keep in mind that the value of `namespace` is used for `prefix` but they are different concepts and use cases.**

## 13 Pallet Truck Control

The `pallet_pallet_truck_control` package includes all nodes necessary for the control of the robots. These include the following:

- **twist\_mux**: Takes in velocity topics and orders them in order of relevance. from highest to lowest: `/key_vel`, `/safety_vel`, `/scenario_vel`, `/nav_vel`, `/cmd_vel`
- **twist\_stamper**: As of `ros2 jazzy` the `ros2_controllers` need the twist messages to be stamped, therefore the stamper was introduced
- **ros2\_control\_node**: Main node which uses the `control.yaml` file and maps "hardware" to controller actions.
- **spawner-joint\_state\_broadcaster**: Publishes the `joint_state` so the robot moves in `gazebo` and `rviz`.
- **spawner-velocity\_controller**: Accepts and publishes velocity commands

With this setup, the `robot_agents` can be controlled by running the teleop command in `control.sh`.

## 14 Navigation (Robot agent and Humanoid) and Map server

the `pallet_truck_navigation` consist of: - [map\\_server.launch.py](#) - starts the map server and creates necessary transforms for all of the robot agents. - [nav2.launch.py](#) - starts the navigation stack and the `update_map.py` for each robot. - [cartography.launch.py](#) - starts `cartography`. - [update\\_map.py](#) - adds the dynamic obstacles (other `robot_agents`) to each `robot_agent`'s map.

To run the navigation stack do the following either with the input=`ROBOTS` or `HUMANOIDS`

```
./control.sh nav ROBOTS
```

### 14.1 Map server

Instead of starting with an empty map, to get the general layout of the environment and detect the static object in the environment (walls, corridors and hallways) you can **optionally** build a map. To start mapping (otherwise known as

cartography), you can use `cartography.launch.py`. It requires a lidar to be mounted on the `robot_agent` and odometry to exist, which can be activated from the `camera_utility/aruco_localization` package.

Launch the following package, run gazebo, rviz, `aruco_localization`, and start moving around the simulation with the `robot_agent`. When you are finished you need to save it using this command: `ros2 run nav2_map_server map_saver_cli -f simulation/pallet_truck/pallet_truck_navigation/maps/YOUR_MAP_NAME`. Keep in mind that this step needs to be done only once and the map assumed to be static.

The navigation stack uses a base map which is updated dynamically with other `robot_agents` for each robot. This done to add the static environment and update the dynamic moving obstacles later.

```
Node( # Manually setting the joint between map and odom to initial_pose_x initial_pose_y 0, i.e. the location
    package="tf2_ros",
    executable="static_transform_publisher",
    namespace=robot["namespace"],
    name="static_map_to_odom",
    arguments=[f"{robot['initial_pose_x']}",
               f"{robot['initial_pose_y']}",
               "0",
               "0",
               "0",
               "0",
               f"{robot['namespace']}/map",
               f"{robot['namespace']}/odom"],
)
```

## 14.2 Robot\_agent navigation

This package covers the functionality of mapping, localizing, and navigation for the `robot_agent`. Each package is built using code from the `nav2` packages, thus you are able to modify the launch files but to change the node's behaviour you need to modify the config files. The code is tailored for the `robot_agent` and using the `aruco_detection` package that supplies /TF chain for the truck.

- The `aruco_localization` package runs the aruco localisation.
- The `map_server.py` creates a map for each agent
- The `nav2.launch.py` uses the localisation (from the previous steps) for the navigation of the `robot_agent`.

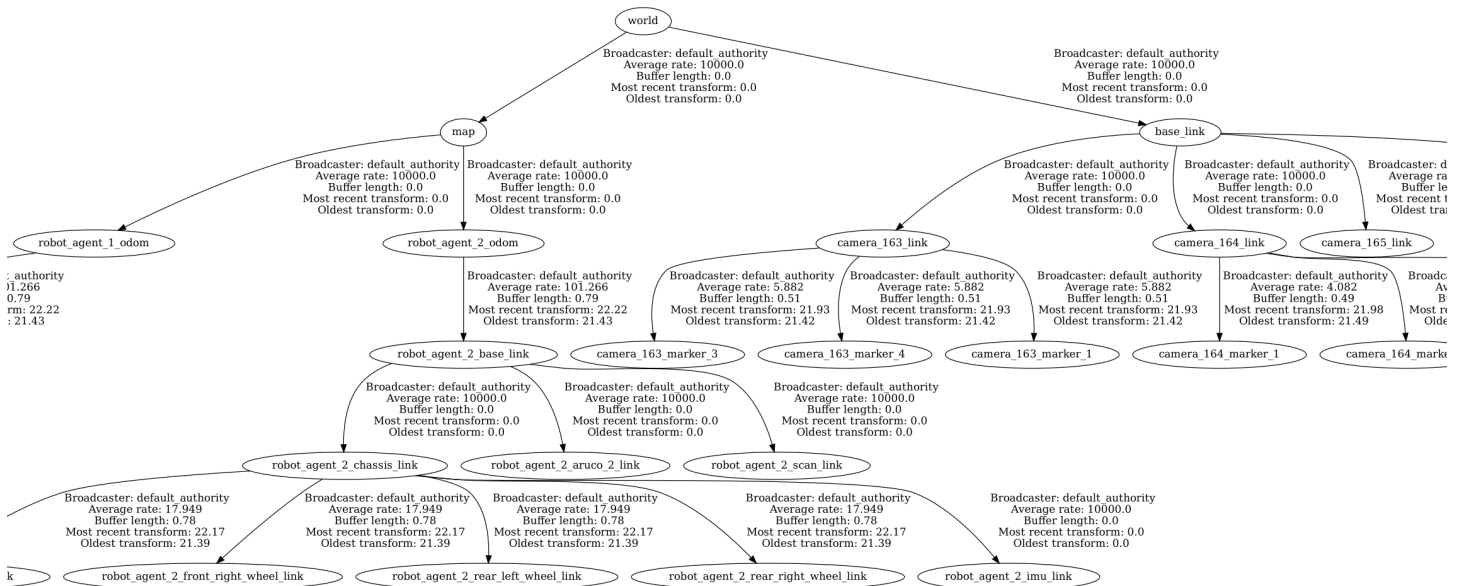
Keep in mind that the same namespace has to be used when launching the navigation stack which is done automatically: `ros2 launch pallet_truck_navigation nav2.launch.py robots:=ROBOTS`

For navigation to be able to automatically find the robot agent, we have to set a namespace that specified when launching the `robot_agent`. (see above)

To do navigation for both `humanoids` and `pallet_trucks` at the same time you need to create a merged variable of the 2 and sent that as a input to the `map_server.launch.py` and `nav2.launch.py` to make sure the obstacles are detected.

Each robot has it own navigation configuration in `nav2_params.yaml` which is dynamically generated on build based on the `ROBOTS` and `HUMANIDS` variables in `config.sh`. the `pallet_trucks` and `forklifts` also have an individual `navigate_w_replanning_and_recovery_robot_agent_x.xml` which is supposed to stop the navigation of the agents if their `aruco_markers` are not detected. To visualize which aruco markers are seen, first run the `gps` and `nav` operations and then echo the `/aruco_marker_seen` topic.

We use following /TF structure:



**Note** that `world` and `map` are static at the same position. `robot_agent_X/odom` is static at the position from where the robots are spawned and the new position of the robots are then determined by `robot_agent_X/base_link` which is a dynamic transform from `robot_agent_X/odom`.

Good video to watch for multi agent navigation: <https://www.youtube.com/watch?v=cGUueuIAFgw>

### 14.3 Humanoid\_navigation

The humanoid navigation is implemented in the same way as for the robot\_agents with the difference of calling the function `./control.sh nav HUMANOIDS`. Then the same principles apply but with a different `nav2_parameter` file being used as an argument to `nav2` nodes.

There is one major difference between the navigation of the humanoids and the robot\_agents. The robot\_agents get their `odom` frame from the `aruco_localization` pkg which find `aruco_markers` and publishes their orientation and position. The humanoids on the other hand get their `odom` frame from the `humanoid_odom_pub` node which subscribes to the ground truth of the humanoids pose from gazebo and creates a dynamic transform between the `namespace/odom` -> `namespace/base_link` frames. This means the robot\_agents get their `odom` frame from what the cameras can see and the humanoids get their `odom` frame from the actual pose in the simulation.

### 14.4 Obstacles detection (update\_map\_node)

The obstacle detection is based on a static map which is dynamically updated with all other robot agents except itself. Therefore every robot\_agent has its own map to not map itself. To not depend on the orientation of the robots, the obstacle is depicted as a circle. With this setup the map\_server is gets an action call that updates the moving obstacles

The `/map_updater/update_map_node.py` node works as following:

First it makes a copy of the `warehouse.pgm` map which is a long array of pixel values ranging from (0-255). Since the map nav2 needs has a different setup than the `.pgm` file, a conversion is needed.

The `.pgm` file has these pixels ranges

value	meaning
0	black obstacle
255	White Free space
1-254	ranges of gray, not defined at the moment

The map nav2 needs is set up with pixels ranging from (-1-100) where

value	meaning
-1	Unknown
0	Free space
100	obstacle
1-99	probabilistic occupancy

therefore this has to be parsed to match by doing the following:

```
current_array = self.original_array.copy()
occupancy_array = np.zeros(current_array.shape, dtype=np.uint8)
occupancy_array[current_array.copy()<100] = 100
```

The map is a 2D array, typically stored row-major from bottom-left, but many implementations flip it vertically (`[::-1]`) to match how image viewers treat top-left as (0,0). and therefore the following is done

```
occupancy_array = occupancy_array[::-1, :]
```

The position of all other robot\_agents are found by their transforms between robot\_agent\_x/base\_link and world and an obstacle is set at that position which is updated with 1 Hz to continuously update their positions. This can be tweaked but to limit CPU usage it was set to 1 Hz.

This concept is repeated for all namespaces sent through the `./control.sh` nav function.

## 14.5 Future improvements

**How often the new path the pallet\_trucks can take be update** Add a speed limiter instead of obstacle, in those cases the robot will slow down instead of replanning the paths. Could probably mix with the inflation radius's of the costmaps to make robot take wider turns

**Collision** Two robots that are approaching each other (from left and right) don't know where each one is planning to go. Therefore they might both plan to the same path and both try to out turn each other resulting in a race condition.

Possible solution: block future path on every other robots map!

### 14.5.1 DEBUG

Getting this warning below is a sign that the nav2 does not work as intended. If this appears repeatedly, you can check the TF tree to see if there is a connection between the `robot_agent` link and `world` link. If there is no connection, it probably means that no camera is viewing the robot. If so then either move the robot into a camera's view or add more cameras to the simulation.

```
[update_map_node-6] [WARN] [robot_agent_1.update_map] [1767949972.586691493]: Transform not available yet: Cou
```

## 15 Failsafe for the navigation

The SIMLAN systems support a failsafe and geo-fencing mechanism for the pallet trucks' navigation. The main idea is that the pallet trucks should stop the navigation as soon as a dangerous situation below is detected:

In this approach for a new Behavior Tree, the **condition node** named `StopRobotCondition` is defined and can be triggered when a safety issue occurs. We then added a `Behavior Tree plugin` that calls an action called `CancelControl` when the given condition is triggered.

Currently, this safety controller triggers `StopRobotCondition`:

### 15.1 Activation of collision sensor

When a collision is detected by the simulator, the collision's physical properties (such as the force and the object that the pallet truck collided with) are published to the pallet trucks' `/contact` topic.

### 15.2 Loss of Observability

To implement geofencing and the safety situation in which a pallet truck is not observable in any camera, the `aruco_localization` pkg under `aruco_localization/aruco_pose_pub.py` continuously publishes the list of pallet trucks that are observable in the `/aruco_marker_seen` topic. Then, if one stops being observable, the BT condition passes.

## 15.3 Behavior tree and direct implementation in `aruco_localization` pkg

At first, we define a custom `behavior_tree.xml` in `simulation/pallet_truck/pallet_truck_navigation/config/navigate_w_re`. This XML file defines which BT plugins we want to use during the navigation and which run continuously during the navigation. In this XML file, the `StopRobotCondition` and `CancelControl` plugins are defined in a fallback function. A fallback function works as it runs the first stated plugin, and when that plugin fails, it moves over to the second one and executes that plugin. So in this case, we first run the `StopRobotCondition` plugin until the robot is out of bounds. Once the plugin fails, the `CancelControl` plugin executes and stops the pallet truck.

In order to know whether a pallet truck is out of bounds or not, it is determined by looking at the aruco marker on the pallet truck and deciding if it's seen by any of the cameras. This is implemented in the `aruco_localization` pkg under `aruco_localization/aruco_pose_pub.py`. As long as the aruco marker on the pallet truck is seen by any of the cameras, the node publishes the robot namespace in a list to the topic `/aruco_marker_seen`.

The same goes for the collision sensor. It publishes to the topic `/robot_agent_X/contact` when the pallet trucks collide with something.

Step two in the failsafe is to stop the pallet truck when it gets out of bounds or collides with something. This is done by a custom-made behavior tree plugin called `StopRobotCondition`, which is found in `simulation/bt_failsafe/src/stop_robot.cpp`. This plugin listens to the `/aruco_marker_lost` and `/robot_agent_X/contact` topics. As soon as a contact is detected or a robot's namespace is lost, it fails, and the `CancelControl` behavior tree starts. This, in turn, stops the pallet truck. The `CancelControl` plugin is an existing built-in plugin in Nav2.

## 15.4 Why Nav2 behavior tree plugins were not suitable

We tried to use only built-in plugins, which most likely is the most robust and secure way to do it as the plugins are updated accordingly to ROS2 and Nav2.

We tried to use several plugins to detect if the pallet trucks are out of bounds, but none of them really suited this purpose of this project.

The first one we tried to use is the `TransformAvailable` plugin. This plugin checks if a certain TF exists. If the TF is missing, the plugin returns `FAILURE`. So in this case, we thought we could look at the TFs between the cameras and the aruco marker, and if none of them exists, it should fail and stop the pallet truck. Unfortunately, we couldn't use this plugin because it only looks at the TF from the very beginning of the navigation. And if it exists from the beginning, it will always succeed and will never return `FAILURE`. Therefore, it cannot be used in our case because we have TF from the beginning, and our TF disappears after some time during the navigation. You could probably modify the plugin to work for our case as well, but if modifications are needed, it could be implemented in a better way instead.

The second plugin we tried is the `IsStuckCondition`. This plugin checks if the robot is stuck by calculating the deceleration of the robot. If the deceleration is too big, it returns `FAILURE`. This wasn't anything we could use because the acceleration is set to zero as soon as the robot gets out of bounds. So this is probably not suitable for this case.

# 16 Humanoid Robot

There needs to be better documentation of the difference between this pkg and the `humanoid_support_moveit_config` pkg. Is this supposed to be the bring-up of that pkg? Why is the humanoid model in this pkg and the URDF that spawns the robot in `humanoid_support_moveit_config`? Are the `humanSubject01-08` used, or is only `humanSubjectWithMeshes` used? Clarification is needed. All in all, a restructure of the entire `humanoid_robot` and `humanoid_support_moveit_config` should be done.

## 16.1 Configuring and spawning humanoids inside the sim

Humanoids are configured in `config.sh` as a string in the `HUMANOIDS` variable. It is possible to add more humanoids and they are defined as:

```
{
  "namespace": "humanoid_1",
  "initial_pose_x": 5.5,
  "initial_pose_y": -10.0
},
```

## 16.2 model and URDF

Package created based on this [tutorial](#)

Note that only the human with mesh model is installed in the package; see `/model/CMakeLists.txt` for how to install the non-mesh models.

In the URDF, the fixed links and joints are (mostly) named `[muscle name]_[location]`, for example, `BicBrac_RUA` = biceps brachii\_right upper arm. In `humanSubjectWithMesh_simplified.urdf`, all fixed joints have been removed; only the skeleton joints remain.

To open Rviz with the human model:

```
ros2 launch urdf_tutorial display.launch.py model:=/home/ros/src/simulation/humanoid_robot/model/human-gazebo/
```

TODO: Explain what are the parameters (`config.sh`). Add this to `resources/build-documentation`

## 17 Humanoid

In this file, the basics of the humanoid structure will be described. In the future, all nodes will be namespaced to add the functionality of spawning and controlling multiple humanoids.

### 17.1 Moveit

For MoveIt to work, 3 components must have correct information:

- URDF link names
- SRDF joint definitions
- TF frames published by `robot_state_publisher`

There was an issue when trying to add namespaces to the humanoid project. Since the humanoid is made of 40+ links, it was decided to add the `"frame_prefix": f"{namespace}"` in the `robot_state_publisher` node. This, however, made a conflict since the URDF, SRDF, and TF frames no longer matched. This was solved by adding `base_link` in between the world and `namespace/base_link` frames and creating a static transform between them. **This means that all further humanoids will be spawned under the `base_link` frame.** (otherwise, the warning below again appears)

### 17.2 Dynamically updated URDFs

To make the `multiple_humanoid_spawn` work, we need to be able to launch different namespaces in the `robot_description`. This is done by running:

```
moveit_config = (  
    MoveItConfigsBuilder("human_support", package_name="humanoid_support_moveit_config")  
    .robot_description(  
        file_path="config/human_support.urdf.xacro", mappings={"namespace": namespace}  
    )  
    .to_moveit_configs()  
)
```

This updates the `namespace` argument inside the `.xacro` files.

### 17.3 Planning scene monitor

When working with the MoveIt package, some bugs or undesired features were found. When MoveIt is launched, the `PlanningSceneMonitor` and `PlanningFrame` subscribe to all TF frames that exist and assume they can transform any known object or sensor data into its planning frame, which is `base_link` in this case. If this cannot be done, it will throw a warning saying the following:

```
[WARN] [humanoid.moveit.moveit.ros.planning_scene_monitor] [id]: Unable to transform object from frame 'unconn
```

To limit this, a wait function was added: `ld.add_action(TimerAction(period=5.0, actions=[rsp_node]))` to make sure the transform is published before the `rsp_node` starts.

### 17.4 Figures

My Robot Diagram *Figure 1: Humanoid frames visualization*



## 17.5 Rviz2 visualization

If you want to visualize the movement in Rviz, you need to configure the `config/moveit.rviz` file and change all `/humanoid_X` instances to the namespace you want to visualize.

## 17.6 Bugs: TF visualization and Gazebo simulation not matching

When visualizing and comparing the actual TF data and simulated locations of the humanoid when doing navigation and teleop, it can be seen that these do not match. This is a major issue since that means the location of where the humanoid think they are in the map and the location of where the humanoid actually are in Gazebo will be different. This can be visualized by turning the humanoid 360 degrees in Gazebo with the `./control.sh teleop humanoid_1` command and comparing it to Rviz. There, the humanoid has turned closer to 300 degrees.

This problem probably comes from some URDF descriptions not matching the actual geometry or specifications the humanoid has in `/home/ros/src/simulation/humanoid_support_moveit_config/config/human_support_wheels.urdf.xacro`. By tuning the `mass`, `mu`, and `inertial` values in the `<xacro:macro name="wheel" params="wheel_prefix *joint_pose">` xacro tag, it was possible to tune the degree mismatch.

For proper navigation and control, this needs to be fixed!

## 18 Humanoid Motion Capture

This project develops a system for translating human pose detection to humanoid robot motion in simulation environments. Using Google MediaPipe for pose landmark detection from camera input, the system maps detected human poses to corresponding joint movements executed by a humanoid robot in the Gazebo simulator. The implementation leverages MoveIt2 for motion planning and control, with a data generation pipeline that creates training pairs of pose landmarks and robot joint configurations.

This project employs a deep neural network to learn the mapping between human pose and humanoid robot motion. The model takes 33 MediaPipe pose landmarks as input and predicts corresponding robot joint positions.

The work is based on a master's thesis "Human Motion Replay on a Simulated Humanoid Robot Using Pose Estimation" by Tove Casparsson and Siyu Yi, supervised by Hamid Ebadi, June 2025.

### 18.1 Terminology:

- **Forward Kinematics (FK):** The process of calculating the position and orientation of a robot's links given the values of its joint parameters (e.g., angles or displacements). In other words, FK answers the question: "Where is the robot's hand if I know all the joint values? (usually have one answer)"
- **Inverse Kinematics (IK):** The process of determining the joint parameters (e.g., angles or displacements) required to achieve a desired position and orientation of the robot's links. In other words, IK answers the question: "What joint values will place the robot's hand here? (usually have many answers)"
- **Pose :** 3D pose landmarks (MediaPipe) extracted by MediaPipe from a 2D image of human posture
- **Motion :** A kinematic instruction (joint parameters) sent to the robot (via MoveIt) for execution. While "kinematic instruction" would be a more accurate term, we continue to use "motion" for historical reasons (used in the word motion-capture), even though "motion" often refers to the difference/movement between two postures (e.g., posture2 - posture1).
- **Motion Capture:** Here it means using 2D images to find the motion (kinematic instruction/joint parameters) to instruct a humanoid robot to mimic the human posture.

### 18.2 Relevant Documents

- [Debug](#) : for debugging purposes and development
- [Preprocessing](#) : details about pre processing of datasets
- [motion\\_planner](#) - To execute motions in the sim from a motion.json file.

### 18.3 Dataset generation

To build the synthetic dataset, first ensure that the cameras pointing to the humanoids are active in the `./config.sh`.

```
CAMERA_ENABLED_IDS='500 501 502 503'
dataset_cameras='500 501 502 503'
```

and rebuild the project with these commands:

```
./control.sh build
```

The image below describes how the dataset generation system works.

Dataset generation overview

To create a humanoid dataset (paired pose data, motion data and reference images) in the DATASET/TRAIN/ directory:

As of now the dataset generation uses `humanoid_1` hardcoded. TODO: Fix so we can use “`replay_motion_namespace`”.

```
./control.sh dataset TRAIN/  
./control.sh dataset EVAL/
```

To find the implementation of how the dataset is created i.e. mediapipe, go to [pre\\_processing/media\\_to\\_pose\\_landmark.py](#).

## 18.4 Available datasets

We use `20251028-DATASET-TRAINONLY-MULTI.zip` (place it in DATASET for training) and `20251028-DATASET-EVAL1000-MULTI.zip` (place it in `input/` directory for prediction) that are available at [SharePoint](#) as our common datasets.

## 18.5 Raw dataset shape

DATASET:

TRAIN

```
camera_500  
    pose_data : 1.json , 2.json  
    pose_images : 1.png , 2.png  
camera_501  
    pose_data : 1.json , 1.json  
    pose_images : 1.png, 2.png  
motion_data: 1.json, 2.json
```

## 18.6 Cameras

Its important to know how the cameras are located. This is the camera setup for the cameras used for dataset creation, make sure to enable them in `config.sh`:

- 500: Back side
- 501: Right side
- 502: Front side
- 503: Left side

When selecting what cameras to use in “`dataset_cameras`” in `config.sh` it is important that the order remains the same. To avoid confusion always use the cameras in order: “500 501 502 503” meaning “Back Right Front Left”.

## 18.7 Models

### 18.7.1 PyTorch

We have more control over the PyTorch model. It has its own implementation of dataset and model definition, located inside [utils.py](#). What is specific about using PyTorch has the possibility to use Optuna is a hyperparameter optimization tool. This tool helps find the best suitable set of hyperparameters given its training data.

- Input Layer: **33** MediaPipe pose landmarks for each camera (x, y, z coordinates).
- Output Layer: Robot joint position sequences for humanoid motion control, this results in a total of 47 joints to be outputted.

Currently the model hyperparameters (`HyperparameterDict`) in `humanoid_utility/pose_to_motion/pytorch/utils.py` are tuned using Optuna. Future model can use [Optuna](#) for adjusting the values.

### 18.7.2 AutoGluon

We use [Autogluon tabular predictor](#). This model is trained as an ensemble (collection) of models where each separate model aims to predict a single joint given the complete input poses. The result from each model is then merged together and becomes a predicted list for each target joint.

## 18.8 Model Training

To train a model run the command below. The input size depends on the number of cameras you plan on using, meaning that if you only select one camera the input shape will take 1 camera into account. If you select 4 the model will have a 4 times larger input size. To set it up in the way you want, go to [config.sh](#). The variables are:

- **model\_instance**: If you want to save a model, specify its name here. Keep blank if you don't want to save.
- **dataset\_cameras**: The cameras you want to train on. This can be a list of cameras i.e. "500 501 502". For single training set this to one ""
- **model\_type**: Possible selections: "pytorch", "autogluon"

Keep in mind that we use a separate virtual environment to install machine learning related pip packages called **mlenv** with a separate [requirements.txt](#). Build the environment first using `./control.sh mlenv`. This has to be done once and `./control.sh` enables the environment automatically

Finally you specify what dataset directory (JSON) you want to use as training data which becomes the second argument, below is an example of running train using the **TRAIN/** dataset.

```
./control.sh mlenv
./control.sh train TRAIN/
```

After a training run is complete, the model is saved inside of `pose_to_motion/{model_type}/output/saved_model_states`. A summary report of the session is also generated and will be saved inside `pose_to_motion/{model_type}/output/train_report.csv`

## 18.9 Model Evaluation

```
./control.sh eval EVAL/
```

Running the command above in the terminal runs the evaluation pipeline.

The evaluation will run metrics defined in [metrics.py](#); currently MSE and MAE are calculated. The results are then saved in a summary report located in `pose_to_motion/{model_type}/outputs/eval_report.csv`. As the result MSE and MAE values are printed.

### 18.9.1 Prediction on synthetic data

The prediction pipeline uses these variables in the `config.sh`:

- **dataset\_cameras**: What cameras to take into concern for prediction. Should match the number of cameras the model was trained on.
- **model\_instance**: What trained model instance to use.
- **replay\_motion\_namespace**: What humanoid you want to replay motions on. Default "humanoid\_2".

It is possible to predict on three different types of data: images, videos, and raw JSON data.

Run the command below to predict on different types of datasets:

```
./control.sh predict JSON/ # This has the same "EVAL/", "TRAIN/" directories.
./control.sh predict VIDEOS/ # As in input/VIDEOS/
./control.sh predict IMAGES/ # As in input/IMAGES/
```

The input for prediction needs to be structured as the template below. The camera names are connected with the variable **dataset\_cameras** inside [config.sh](#).

```
input/JSON or VIDEOS or IMAGES
camera_500/
    file_1.(JSON, PNG, JPG, MP4)
    file_2.(JSON, PNG, JPG, MP4)
camera_501/
    file_1.(JSON, PNG, JPG, MP4)
    file_2.(JSON, PNG, JPG, MP4)
camera_502/
    file_1.(JSON, PNG, JPG, MP4)
    file_2.(JSON, PNG, JPG, MP4)
camera_503/
    file_1.(JSON, PNG, JPG, MP4)
    file_2.(JSON, PNG, JPG, MP4)
```

### 18.9.2 Predicting on real data/ your own data

The predict pipeline works on real data as well. It is for example possible to predict this dataset [fit3d\\*.tar.gz](https://fit3d.imar.ro/fit3d) (or alternatively <https://fit3d.imar.ro/fit3d>.)

If you want to predict on your own videos and images you can follow these steps below. This example will use the gym exercise from 5 angles dataset from [fit3d\\*.tar.gz](https://fit3d.imar.ro/fit3d) or alternatively <https://fit3d.imar.ro/fit3d>.

1. This example assume you have a trained ML model on 4 cameras. Please follow [humanoid\\_utility/README.md](#) for how to train a model.
2. download and extract the [fit3d\\*.tar.gz](#) dataset.
3. Find a suitable video feed from multiple angles. You can find good examples in the folder “fit3d\_train/train/s03/videos/”.
  1. In this folder you will find subfolders named “50591643”, “58860488”, “60457274”, “65906101”. These represent 4 different camera angles. It is the same when we name our “dataset\_cameras” in `config.sh` as “500”, “501”, “502”, “503”.
4. Going into any of the subfolders there are many different videos, this example uses “band\_pull\_apart.mp4”
5. add a new folder inside `input/` with whatever name you want. We will use the name `input/band_pull_apart/`
6. For this guide we will rename the folders “50591643”, “58860488”, “60457274”, “65906101” to “500”, “501”, “502”, “503”.
  1. **IMPORTANT:** The angles for this example is not accurate since angles: “50591643” & “58860488” both show back side and “60457274”, “65906101” show the front. Thus there become a mismatch from our camera setup where we use back, right, front, left. The ML model will become confused by the angles if not taken into account.
7. Add subfolders inside `input/band_pull_apart/` named after the cameras and add respective video inside of it. This example has 4 videos:
8. `band_pull_apart/camera_500/band_pull_apart.mp4`
9. `band_pull_apart/camera_50X/band_pull_apart.mp4`
10. **IMPORTANT:** Make sure variable “dataset\_cameras” match the names of the folders.
11. Now we can run the following command:

```
./control.sh predict band_pull_apart # based on input/band_pull_apart/
```

The videos will now be processed and the result is found in `output/band_pull_apart/`. Gazebo will also open and execute the motions from the videos.

### 18.10 Project Structure:

- `humanoid_config.py`: it contains the humanoid configuration like the number of joints and the number of pose landmarks.
- `humanoid_ml_requirements.txt`: Contains the humanoid machine learning requirements
- `/DATASET/TRAIN/`: Contains motion, pose and image files generated by `./control.sh dataset TRAIN`
  - `motion_data` : Corresponding random motion (request)
  - `camera/pose_data` : Mediapipe pose (result) for each camera
  - `camera/pose_images`: Mediapipe annotated images and original images for each camera
- `/DATASET/EVAL/`: Same as `TRAIN`
- `input/` : This folder has the pose data to be predicted
- `output/` : This folder saves the predicted motion data and intermediate results
- `pre_processing/`: contains all pre-processing files, used to convert the JSON data into tabular data.
  - `media_to_pose_landmark.py`: Handles pose detection from actual images or videos using MediaPipe
  - `dataframe_json_bridge.py`: Contains helper functions to convert json files into dataframe/numpy format and is used by the models. Running its main will generate csv files that contains both pose and motion data from the json files. Inputs the cameras you want to use, the json dir, the csv filename to generate.
- `pose_to_motion/`: Contains the ML training pipeline for pose-to-motion prediction
  - `model.py`: The main file containing implementations for training, evaluating, and predicting motions. This file acts as an orchestrator and inputs the data, what model to use, and what operation should be done.
  - `pytorch/`: directory containing model implementation for pytorch model. Handles training, evaluation, and predicting motions.
    - \* `framework.py`: Framework file, contains the implementation for train, evaluation, and prediction.
    - \* `utils.py`: Utils file, contains helper methods, and model definition. The `model.py` use this.

- \* **output/**: Contain reports of ran sessions and saved model states. Saved models will be found here
  - **saved\_model\_states/**: Saved autogluon models are stored here
  - **reports/**: Manually generated reports file containing training/evaluation run information. Good for reproducibility. The reports are generated by `generate_report.py` and the new report row is saved in `train_report.csv` or `eval_report.csv`
  - **optuna\_studies/**: Specific for pytorch. Optuna studies are stored at this folder. See optuna section for more information about Optuna.
- **autogluon/**: directory containing model implementation for autogluon model. Handles training, evaluation, and predicting motions. Has similar files as pytorch.
  - \* `framework.py`
  - \* `utils.py`
  - \* **output/**
    - **saved\_model\_states/**
    - **reports/**
- **generate\_report.py**: Contains methods to generate report files, used after a training or evaluation session has been done for any selected model. These generated reports contain information for reproducing runs and how a model performed against metrics. A new report is generated every time we run train or eval on a model and every report is saved in a single CSV file where every row is a report. The files are named: `train_report.csv` or `eval_report.csv`.
- **metrics.py**: Contains all functions for calculating metrics for models for any selected model.

## 18.11 Dataset preprocessing

- `media_to_pose_landmark.py` : To convert media file to pose landmarks using mediapipe.
- `dataframe_json_bridge.py` : to load poses and motions into a tabulated dataframe.

Models MUST use `dataframe_json_bridge.py` standard interface to load their data. This tools also has a cli interface to see the intermediate results that can be accessed by `./control.sh convert2csv ...`

Pose and motion data are first collected from JSON files and combined into a single CSV file. These processed CSV files are ready to be fed into a model of your choice, AutoGluon or PyTorch. See below to find more information about the dataset or more about the **models**.

The dataset, inputs, and outputs are in `humanoid_utility/DATASET/` directory.

The resulting files are stored as parallel `.json` files in multi-camera folders `camera_*/pose_data`, `camera_*/motion_data`, `camera_*/pose_images`. To avoid creation of `pose_images` that are only used as the ground truth and debugging purposes (especially if you are building your training data), comment out the call to `self.save_pose_image()` in `camera_viewer.py`.

Finally, to merge them all into a tabular `.csv` file, run the following command. The argument `dataset_dir` is the directory containing the JSON files and must be located as a subdirectory of `DATASET/`. Additionally, in `config.sh` you need to set the variable `dataset_cameras` to the cameras you want to take into consideration. i.e., if you use all cameras, the value is “500 501 502 503”. The resulting CSV file will then be saved as `dataset_dir/flattened_data.csv`.

By running the command below results in the following csv files being created:

```
./control.sh convert2csv TRAIN
./control.sh convert2csv EVAL
```

Results in merging:

- `DATASET/TRAIN/**` to `DATASET/TRAIN/flattened_data.csv`
- `DATASET/EVAL/**` to `DATASET/EVAL/flattened_data.csv`

Note: The `TRAIN/**` refers to the contents of folders `motion_data/` and `camera_5XX/pose_data`.

The resulting CSV file will contain these columns:

```
cam500_0_x, cam501_0_x, cam502_0_x, cam503_0_x, ..., cam503_32_z, JOINTS...
```

When the data is transformed into numpy/tabular format, each row in the CSV file represents **multiple pose** samples **from each camera** and its corresponding robot motion. The number of columns depends on the number of cameras, and it's possible to select what camera inputs you want to use; i.e., just one camera input or up to four camera inputs.

- The first columns are the 3D coordinates (x, y, z) for each of the 33 MediaPipe pose landmarks and **for each camera**, named like cam500\_0\_x, cam501\_0\_x, cam502\_0\_x, cam503\_0\_x, cam500\_0\_y, cam501\_0\_y, cam502\_0\_y, cam503\_0\_y, cam500\_0\_z, cam501\_0\_z, cam502\_0\_z, cam503\_0\_z....
- The remaining columns are the robot joint positions (motion targets) for that sample, with names like jRightShoulder\_rotx, jLeftElbow\_roty, etc.

## 18.12 Loading Dataset

For training and prediction, we have a helper library, `dataframe_json_bridge.py`, that loads the data into a pandas dataframe with the column size of `num_pose_landmarks * num_cameras * 3 + num_humanoid_joints`

### 18.12.1 Media to pose

```
python3 $humanoid_utility_dir/pre_processing/media_to_pose_landmark.py \
--mode $2 \ # image or video \
--data_dir $3 \ # input dataset directory name \
--camera_ids "$dataset_cameras" \
--input_dir $humanoid_input_dir \
--output_dir $humanoid_output_dir
```

## 18.13 Model structure

`model.py` is responsible for routing the training and prediction to the right model. When running `model.py train modelX=pytorch_model cams=[500,501]` from `./control.sh`, the pseudocode below in `model.py` loads the right model and passes the needed information for training and prediction to the model.

```
import modelX
modelX.train(pose_NP, motion_NP, cams)
motion = modelX.train(pose_NP, cams)
pred= modelX.train(pose_NP, cams)
```

`modelX` can now have all information that it needs for training or prediction. Each model has to define at least the following interfaces:

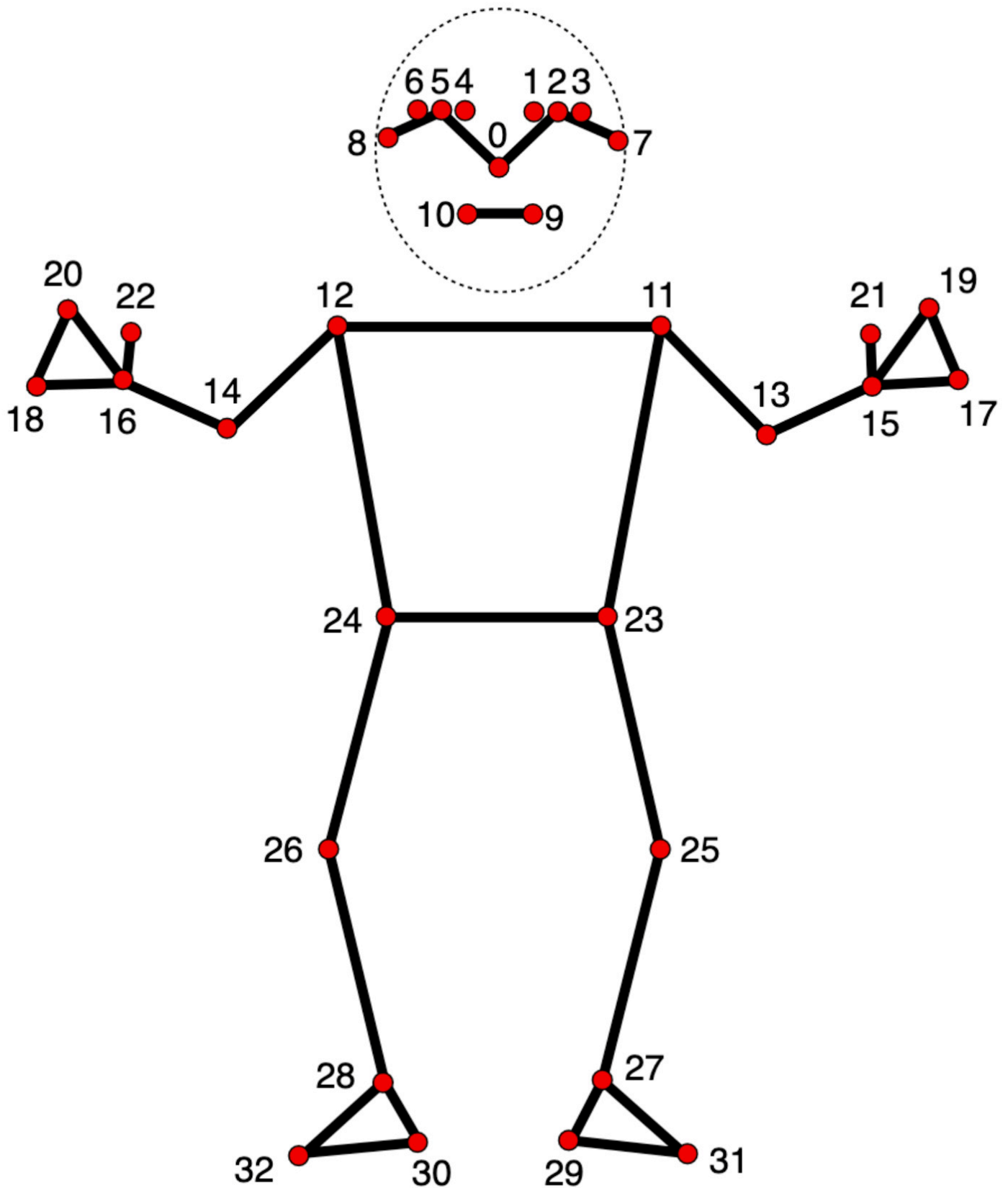
`modelX.py`:

```
def modelX.train():
    FL_POSE = FLATTEN_POSE_BY_SCENARIO(pose_NP, cams)
    // 1, [LDATA_a], [LDATA_b]
    x = join(FL_POSE, motion_NP)
    // [LDATA_a], [LDATA_b], [JDATA_a]
    train with the data above
    SAVE_MODEL_AS(str(cams))

def modelX.predict(pose_NP, cams):
    FL_POSE = FLATTEN_POSE_BY_SCENARIO(pose_NP, cams)
    LOAD_MODEL(str(cams), FL_POSE)
    WHATEVER
    return motion_np
```

### 18.13.1 Preprocessing

Pose landmark detected by [Mediapipe](#):



These landmarks can be normalised in many ways. Three potential steps of normalization (feature engineering) of MediaPipe landmarks:

- Position normalization
- Scale normalization
- Rotation normalization

normalization.png

## 18.14 Motion planner

The motion planner package has three features.

- it can execute a infinite series of random motions which is useful when you want to create synthetic data.
- you can send motions to execute directly in memory.
- you can pass a motion file to be read and executed

When the package runs it subscribes to a topic: `humanoid_X/execute_motion` which inputs a stringified message of a dict (joint\_name, value) or a filename.

**Requirement:** Running this command require you to run these nodes first:

```
replay_motion_namespace="humanoid_1"
```

```
./control.sh sim # run simulation
./control.sh humanoid # spawn humanoid
./control.sh moveit # allow humanoid to run motions
```

### 18.14.1 file mode

You can replay each motion data file separately:

```
./control.sh execute_motion simulation/motion_planner/motions/default_motion.json
```

If you don't have any motions available, there are ready ones inside the `motions/` folder.

### 18.14.2 string mode

The easiest way to use it is in python using a dictionary, stringifying it with json, and then publishing it to the topic:

```
motion_dict = {JOINT_DATA}
json_str = json.dumps(motion_dict)
cmd = [
    "ros2",
    "topic",
    "pub",
    "--once",
    f"{humanoid_namespace}/execute_motion",
    "std_msgs/msg/String",
    f"{{data: '{json_str}'}}",
]
subprocess.run(cmd, check=True)
```

### 18.14.3 random mode

To send random motion to the humanoid use the command below

```
ros2 launch motion_planner random_motion.launch.py run_random_generate:=true output_dir=$1 "log_level:=${log_
or alternatively:
```

```
./control.sh random_motion
```

## 18.15 Autogluon Model configuration

This section describes how AutoGluon is configured for a multi-label regression problem in our current setup.

To use AutoGluon for a multi-label regression problem, first we need to create a MultilabelPredictor by setting

- **labels:** the labels that we want to predict.
- **problem\_types:** the problem type for each TabularPredictor.
- **path:** path to the directory where models and intermediate outputs should be saved.
- **consider\_labels\_correlation:** Whether the predictions of multiple labels should account for label correlations or predict each label independently of the others.



For **consider\_labels\_correlation**, we set it to `FALSE` in order to disable using one label as a feature for another. The reasons for this are:

- Each joint has its own degree of freedom and control, and it is independent from the rest of the joints.
- Training stability without error propagation.
- When set to `False`, the training will be faster.
- More general and simple model.

For training the model, we should take into consideration the following hyperparameters related to:

- **Stacking**: which is an ensemble technique where multiple models are trained and then a “meta-model” learns how to combine their predictions. If we use dynamic Stacking, it will automatically determine the optimal number of stacking layers and which models to include.
- **Bagging**: multiple training versions of the same model on different subsets of data and combining their predictions.
- **preset**: which condenses the complex hyperparameter setups. For example, we can use a small model size by using `medium_quality`, which will lead to faster training but with less prediction quality. Or we can use a large model by setting `preset` to `best_quality`, which will lead to better performance but much longer training time.

The current AutoGluon uses the following hyperparameters:

- **dynamic\_stacking=False**: Disables the automatic stacking optimization.
- **num\_stack\_levels=0**: no stacking level.
- **auto\_stack=False**: Disables automatic ensemble stacking.
- **num\_bag\_folds=0** and **num\_bag\_sets=1**, which means no bagging.

So here is the current training flow for each joint:

- Train `NN_TORCH`, `GBM`, and `XGB` models.
- No bagging: Each model trains on the full dataset once, no multiple training versions of the same model on different subsets of data and combining their predictions.
- No stacking: No meta-models combining predictions.
- Best model selection: Choose the best performing model per joint.

**Eliminating dynamic stacking and multi-level stacking will lead to 50% to 70% time savings.**

Overall, this configuration prioritizes training speed and stability over ensemble complexity, making it suitable for fast iteration and independent joint predictions.

## 18.16 Hyperparameter Tuning

In the current AutoGluon model, we are training `NN_TORCH`, `GBM`, and `XGB` models by using their default built-in hyperparameter settings. The next step for performance improvement is to add the **hyperparameter\_tune\_kwargs** argument to enable AutoGluon’s internal hyperparameter optimization. This will allow AutoGluon to automatically search for the best hyperparameters for each model type, balancing training time and prediction quality.

## 19 Moveit Panda robot

This package contains code for a robot called “Panda” which includes a description/URDFs (see `panda_description/`). Inside the `panda_moveit_config/` exist all code and config files that allow you to spawn a panda robot in Gazebo and be able to plan and execute motions. Inside `config/` there are several `*.yaml` files which act as configurations, and many `*.srdf`, `*.urdf`, `*.xacro` files. These are all related to the same panda robot. The main description file is `panda.urdf.xacro`.

To run our package, make sure that the Gazebo simulator is running. Then we can run the `panda_moveit_config/launch/demo.launch` which will do the following:

- Spawn a panda robot in Gazebo and publish its `robot_description`.
- Start RViz with a preset MoveIt config.
- Start the `move_group_node`, which handles all planning and executing of motions.
- Load all controllers for panda so that it can be controlled in Gazebo.

### 19.1 Moveit motion planner using Python API

The folder `custom_motion_planning_python_api` has scripting files that plan and execute motions for a panda robot. It uses the official MoveIt2 Python API to achieve this. In this package’s `scripts/` folder exist these Python files. Look at the demo scripts for inspiration. To run any of the scripts, you run the launch file:

- `motion_planning_python_api_planning_scene.py` is an original demo from MoveIt2.
- `motion_planning_python_api_tutorial.py` is an original demo from MoveIt2.
- `demo_pick_and_place.py` is custom made.

The `moveit2_py` package is not currently available for Humble, but Jazzy supports it. The prerequisites to run a motion planner script are to run these in parallel terminals: `gazebo sim & panda_moveit_config/launch/demo.launch.py`. When these two are finished initializing, run the motion script with: `motion_planning_python_api_tutorial.launch.py`

## 20 Object Mover package

Dyno-robotics/Infotiv delivery

Setting `self.MODE = "abnormal/normal"` in the main script causes the object movement to deviate from the normal distribution specified above.

To reproduce

```
git checkout ....
# In three separate terminals:
./control.sh clean ; ./control.sh build ; ./control.sh sim
./control.sh move_object
```

### 20.1 Random, In Distribution Objects Movement (normal mode)

Data collection from cameras according to [requirements](#)

- Random self.objects are placed within the position range `self.grid_x`, `self.grid_y`: REQ.ID.1
- Random rotation along the z axis.
- You can use `camera_config ID.xacro` for placement of several cameras in the intersection. You can alternatively use `camera_config ID_noise.xacro` to slightly changes the camera settings (REQ.ID.2) as below:
  - at most  $\pm 10$  degree ( $\pm 0.1$ ) rotation around one of the axis
  - at most  $\pm 10$ cm ( $\pm 0.1$ ) change in x,y,z coordinates

### 20.2 Random, Out of Distribution Objects Movement (abnormal mode)

Data collection from cameras according to [requirements](#).

- Addition of other objects (spotlight, support pole, traffic cone): REQ.OD.1, REQ.OD.2.
- With some probability, the objects don't leave the scene and may coexist and collide with new objects: REQ.OD.3.
- Objects are at least rotated by  $\pi/4$  (45 degrees, upside-down object): REQ.OD.3, REQ.OD.4.
- The spotlight is tilted by  $\pi/6$  (30 degrees): REQ.OD.1.
- Objects are not placed on the ground and instead are dropped from a height of 2-3 meters: REQ.OD.4.

#### 20.2.1 Deterministic, Disentanglement One-parameter Object Movements (one\_object\_deterministic mode)

- Object: forklift
- Camera: 1
- (#Parameter: orientation of forklift)
- Annotation: Position and rotation of the forklift. Annotation in filename.
- 256x256 RGB non compression

```
./control.sh sim ./control.sh move_object
```

### 20.3 Licenses and Credits

The majority of code for the pallet truck comes from these [turtlebot3](#) and [turtlebot3\\_simulations](#) repositories (in `humble-devel` branch) with *Apache-2.0 license* and we continue using the same license: The Turtlebot3 robot project belongs to [robotis.com](#) and accessible in [git repository](#). The authors and maintainers of the original packages that all credits go to are:

- [Darby Lim](#)
- [Pyo](#)
- [Will Son](#)

- Ryan Shim

In October 2023, [Hamid Ebadi](#) renamed the [package owner information and name](#) for turtlebot3 projects to avoid dependency issues any naming confusion with the original packages and created independent packages for activities within the research project. We also got inspired and used the skeleton code from these open source project and courses:

- [https://github.com/ros-controls/gazebo\\_ros2\\_control](https://github.com/ros-controls/gazebo_ros2_control)
- [https://github.com/renan028/forklift\\_robot](https://github.com/renan028/forklift_robot)
- <https://github.com/ROBOTIS-GIT/>
- <http://turtlebot3.robotis.com>
- [Articulated Robotics](#)
- [“ROS2 for Beginners Level 2 - TF | URDF | RViz | Gazebo” Udemy course](#)
- [“ROS2 Nav2 \[Navigation 2 Stack\] - with SLAM and Navigation” Udemy course](#)
- [Visual Servoing in Gazebo grobot](#)
- The modification of [Human-Gazebo](#) in `/src/humanoid_robot/model/human-gazebo` is licensed under LGPL-2.1.
- [Moveit2](#) is licensed under BSD-3-Clause license.

## 20.4 Resources

- [Gazebo official video playlist](#)
- [Getting Ready to Build Robots with ROS](#)
- [Udemy course on ROS2 and Gazebo](#)
- [classcentral course](#)
- [theconstructsim course](#)
- [Articulated Robotics](#)
- [ROS URDF](#)
- [FoxGlove studio \(rviz alternative\)](#)
- [ROS2 Tutorials](#)
- [aws-robomaker](#)
- [model for factory](#)
- [Tugbot in Warehouse](#)
- [logistics in warehouse](#)
- [aws-robomaker](#)
- [gazebo\\_worlds](#)
- [warehouse](#)
- [forklift](#)
- [Docker install guide](#)
- [Hazard stripes taken from Tugbot warehouse](#)
- [Deadlock image](#)

Other solutions:

- [Kollmorgen: How does an AGV navigate?](#)
- [SwissLog CarryPick](#)
- [Toyota forklifts](#)
- [ILIAD Project](#)
- [GoPal](#)
- [navigation\\_oru navigation stack by Örebro University](#)
- <https://alignproductionsystems.com/equipment-category/navigation/#>

Specification of items:

- [SLAM Navigation Compact Pallet Mover Nature Navigation Mini Forklift with Payload 1000KG](#)
- [Driverless Lifting System: Single & Double Scissor Lift | AGILOX](#)
- [Wholesale Pallet Agv Trucks Jack Automated Autonomous Forklift](#)
- [Volvo modular containers](#)
- [Volvo Emballage Specifications Volvo Group Packaging System](#)
- [Freecad](#)
- [Blender](#)
- [example worlds](#)
- [SDF format](#)
- [SDF tutorial](#)
- [FreeCAD RobotCreator Workbench](#)

Coordinates:

- [odom](#)

Camera projection:

- <https://github.com/polygon-software/python-visual-odometry/blob/master/Chapter%203%20-%20Camera%20Projection.ipynb>
- [https://classic.gazebo.org/tutorials?ut=camera\\_distortion](https://classic.gazebo.org/tutorials?ut=camera_distortion)
- <https://learnopencv.com/rotation-matrix-to-euler-angles/>
- <https://www.geeksforgeeks.org/calibratecamera-opencv-in-python/>
- [https://docs.opencv.org/4.x/dc/dbb/tutorial\\_py\\_calibration.html](https://docs.opencv.org/4.x/dc/dbb/tutorial_py_calibration.html)
- [http://sdformat.org/tutorials?tut=specify\\_pose](http://sdformat.org/tutorials?tut=specify_pose)

Jackal Robot: The Clearpath Jackal Robot code is forked by Dyno Robotics from Clearpaths [jackal](#) Github. Branch foxy-devel is ported to `dyno_humble`, where changes for namespacing and a `bringup` package is added.

- To improve collaboration in development environment we use `vscode` and `docker` as explained in [this instruction](#) using these [docker files](#). For production environment follow installation procedure used in `.devcontainer/Dockerfile` to install dependencies.
- The Docker setup is added by Christoffer Johansson (Dyno Robotics), based on Dyno experience working with Docker.

Panda Arm: - [https://github.com/cpezzato/panda\\_simulation](https://github.com/cpezzato/panda_simulation) - [https://www.researchgate.net/figure/Panda-robot-with-labeled-joints\\_fig1\\_361659008](https://www.researchgate.net/figure/Panda-robot-with-labeled-joints_fig1_361659008) - <https://www.kuka.com/it-it/settori/banca-dati-di-soluzioni/2025/05/5-kuka-robots-optimize-pet-food-handling-in-74-sqm> - <https://arxiv.org/pdf/2506.12089>

AI/ML: - <https://www.calibrant.com/blog/beginners-guide-to-diffusion-models>

Humanoid: - <https://gazebo.org/docs/latest/actors/> - <https://research.google/blog/on-device-real-time-body-pose-tracking-with-mediapipe-blazepose/>

## 20.5 Licenses

`Imu_tools` is the one with several licenses, using BSD-3, GPLv3, GNU v3, but as we don't change the code so we believe there is no license conflict with the current project license. The dependency `wireless` (<https://github.com/clearpathrobotics/wireless.git>) from Clearpath robotics is the without a separate license file. There are license names within files, referencing BSD so we believe there is no license conflict with the current project license.

## 20.6 Docker and VS Code setup

The Docker setup added by [Christoffer Johansson \(Dyno Robotics\)](#), based on Dyno experience working with Docker.

## 20.7 Project maintainer

This project is currently maintained by [Hamid Ebadi](#).

## 20.8 Advanced Features

### 20.8.1 Filtering log output

In `config.sh` you can set the level of logs you want outputted into the terminal. By default it is set to “info” to allow all logs. Possible values are: “debug”, “info”, “warn”, and “error”. Setting it to “warn” filters out all debug and info messages. Additionally, to filter out specific lines you can add the phrase you want filtered inside `log_blacklist.txt` and setting the `log_level` flag to “warn” or “error” will start filtering out all phrases found in the blacklist.

### 20.8.2 Aruco detection

If you want to add the TF links between the cameras and the ArUco markers without running the `gpss` command, you can run the following command. This is primarily useful for debugging, as `gpss` runs this as well.

```
./control.sh aruco_detection
```

Finally, to view the bird's-eye perspective from each camera, run the following command and open `rviz`. Then, navigate to the left panel and under “Camera” change the Topic `/static_agents/camera_XXX/image_projected` to visualize the corresponding camera feed:

### 20.8.3 Running ROS2 commands:

To avoid conflict between ros nodes in the same network, after each build a new random ROS2 domain is created. This means that you need to adjust this random domain before running any ros2 commands. For convenience you can use

```
./control.sh cmd YOUR_ROS2_COMMANDS
```

Here is an example of extracting tf2 hierarchy

```
./control.sh cmd ros2 run tf2_tools view_frames
```

These features and commands are under development and not fully supported yet and therefore are subject to change.

**Cartographer:** With both Gazebo and rviz running you can start creating a map of a robot's surroundings.

To start: `./control.sh cartographer`

### 20.8.4 Teleop

If you want to control any robot (pallet truck, humanoid, etc.) manually you can run the following command. Remember to specify what robot you want to control by adding its namespace as argument, i.e. `./control.sh teleop pallet_truck_1`

```
./control.sh teleop ${YOUR_ROBOT_NAMESPACE}
```

To move the humanoid around in the simulator

```
./control.sh teleop ${YOUR_HUMANOID_NAMESPACE}
```

### 20.8.5 Scenarios

In `scenarios.sh` you can run predefined scenarios of the project. At the bottom of the file, commands are shown how to run it; otherwise each scenario is referenced by a number. Currently there are 3 scenarios and to run them, run this command in the shell

Before running scenario 1 that uses GPSS cameras, make sure that `CAMERA_ENABLED_IDS` in `config.sh` has the list of GPSS cameras.

Note: A previous successful setup where all scenarios worked used these cameras: '160 161 162 163 164 165 166 167 168 169 170'. If robots are not moving in your simulation, it might be that there is no camera looking at the robot.

```
./control.sh build
./scenarios.sh 1 # navigation using GPSS cameras (real time factor need to be updated)
./scenarios.sh 2 # Humanoid and robotic arm
./scenarios.sh 3 # Humanoid navigation without GPSS cameras (navigate_w_replanning_and_recovery_robot_agent_X...)
./scenarios.sh 4 # Record the video demo
```

If you want to see the planning route for all agents, load `scenario_3_planning.rviz` in Rviz.

Keep in mind to change `real_time_factor` in `simulation/simlan_gazebo_environment/worlds/ign_simlan_factory.world.xac` to small values to slow down the simulator (e.g. 0.05-0.1) before building the project. `./control.sh build`

### 20.8.6 Jackal

If you want to control the Jackal, you add the following lines into the `control.sh`:

```
elif [[ "$*" == *"jackal_teleop"* ]]
then
    ros2 launch dyno_jackal_bringup keyboard_steering.launch.py
```

And then run:

```
./control.sh jackal_teleop
```

These ones did not work, so we put them here in issues

```
elif [[ "$*" == *"move_object"* ]]
then
    ros2 run object_mover move_object
```

```
elif [[ "$*" == *"scenario"* ]]
then
    ros2 launch scenario_execution_ros scenario_launch.py scenario:=simulation/scenario_manager/scenarios/test
```

## 20.9 ISSUES

### 20.9.1 gazebo\_ros2\_control

[gzserver-1] [ERROR] [1727951819.671190014] [jackal.gazebo\_ros2\_control]: controller manager doesn't have an u  
No solution.

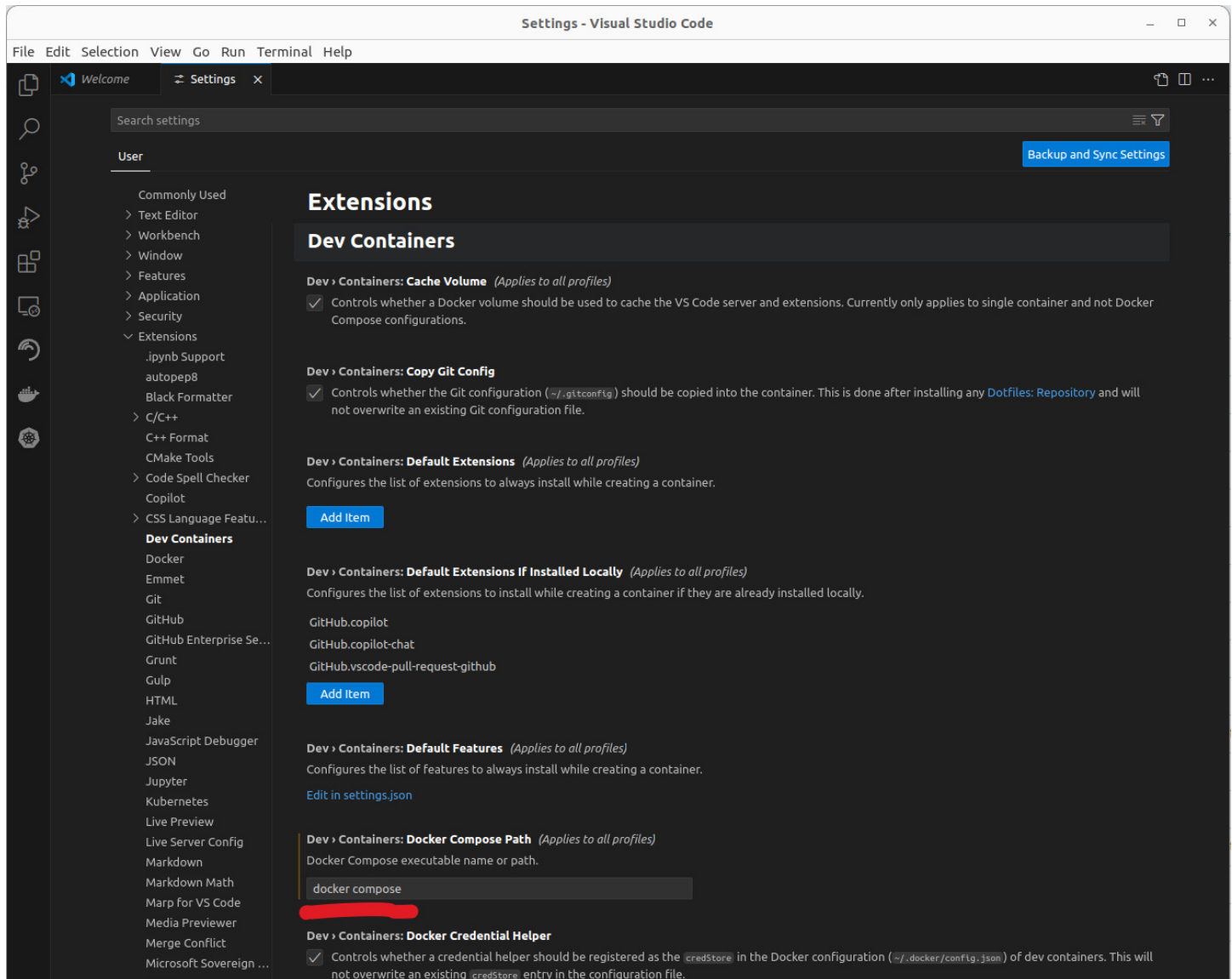
### 20.9.2 OpenAL

[gzserver-1] [Err] [0penAL.cc:84] Unable to open audio device[default]

Related to support for audio inside a Docker container. It will not be resolved.

### 20.9.3 Command failed: docker compose

If you have any issue with docker incompatibility (e.g. Error: Command failed: docker compose ...), make sure that `docker compose` or `docker-compose` is set correctly in the settings.



In `docker-compose.yaml`, uncomment the `factory_simulation_nvidia` section:

```
factory_simulation_nvidia:
```

```
<<: *research-base
container_name: factory_simulation_nvidia
runtime: nvidia
deploy:
  resources:
    reservations:
      devices:
        - driver: nvidia
          count: "all"
          capabilities: [compute,utility,graphics,display]
```

and update `.devcontainer/devcontainer.json`:

```
{
  "name": "ROS2 RESEARCH CONTAINER",
  "dockerComposeFile": "../docker-compose.yaml",
  "service": "factory_simulation_nvidia"
  ...
}
```

#### 20.9.4 Missing nvidia docker runtime

Solution: <https://stackoverflow.com/questions/59008295/add-nvidia-runtime-to-docker-runtimes>

#### 20.9.5 Docker nvidia-container-cli: requirement error

If you get this error when building the docker container:

`nvidia-container-cli: requirement error: unsatisfied condition: cuda>=12.6`, please update your driver to a new

A solution to try is first: re-install `nvidia-container-toolkit`. Or, if that does not work, update your `nvidia-drivers`.

#### 20.9.6 GLIBC\_2 issue

Sometimes the wrong `nvidia-container-toolkit` results in this issue below:

```
$/usr/lib/x86_64-linux-gnu/libc.so.6: version `GLIBC_2.38' not found (required by /usr/lib/x86_64-linux-gnu/li
$/usr/lib/x86_64-linux-gnu/libc.so.6: version `GLIBC_2.38' not found (required by /usr/lib/x86_64-linux-gnu/li
```

If so, try downgrading `nvidia-container-toolkit`. You can use these commands:

```
$sudo apt-get remove --purge nvidia-container-toolkit nvidia-container-toolkit-base libnvidia-container*
$sudo apt-get update
$sudo apt-get install nvidia-container-toolkit=1.17.4-1 nvidia-container-toolkit-base=1.17.4-1 libnvidia-conta
```

#### 20.9.7 docker issues

Make sure docker is installed correctly by following these two instructions:

- [Install docker using the convenience script](#)
- [Linux post-installation steps for Docker Engine](#)

## 21 Changelog

### 21.0.1 5.1.0: Cleanup and Documentation (Jan 2025) - Team/Tech Lead: Hamid Ebadi

- headless gazebo: Pär Aronsson
- major cleanup and documentation: Hamid Ebadi
- Improve ml prediction pipeline: Pär Aronsson

### 21.0.2 5.0.0: Refactor MoCap pipeline and sensors (Dec 2025) - Team/Tech Lead: Hamid Ebadi

- Working demo video scenario: Hamid Ebadi, Pär Aronsson
- Refactor and improve prediction pipeline: Pär Aronsson
- Review and update the mocap architecture: Pär Aronsson, Hamid Ebadi
- Pipeline for prediction on real data, images, and videos: Pär Aronsson



- Improve motion player: Pär Aronsson
- New demo scenario: Pär Aronsson
- Unify “single” and “multi” pipeline: Pär Aronsson, Hamid Ebadi
- Documentation and presentation (mkdocs, pandas): Hamid Ebadi

#### **21.0.3 4.0.0: Improvements (Nov 2025) - Team/Tech Lead: Hamid Ebadi**

- System integration tests: Pär Aronsson
- Overall system diagrams (launch files and bringups): Anton Stigemyr Hill
- PyTorch model for humanoid MoCap: Pär Aronsson
- Improved documentation and AutoGluon configuration: Marwa Naili
- Demo scenario: Anton Stigemyr Hill
- Semantic segmentation, depth, color camera sensors: Anton Stigemyr Hill, Pär Aronsson
- Humanoid navigation: Anton Stigemyr Hill
- Rework GPSS/ArUco navigation: Anton Stigemyr Hill

#### **21.0.4 3.0.0: Jazzy, humanoid (Oct 2025) - Team/Tech Lead: Hamid Ebadi**

- Collision sensor: Anton Stigemyr Hill
- Automatically generated parameter-files for robot\_agents and world fidelity: Anton Stigemyr Hill
- Shared map and obstacle generation for robot\_agents: Anton Stigemyr Hill
- Geofencing and safety stop: David Espedalen
- Humanoid motion capture: Casparsson and Siyu Yi, Hamid Ebadi
- Humanoid integration (pymoveit2 to moveit\_py): Siyu Yi, Pär Aronsson
- Mocap (humanoid) with multi-camera training pipeline: Siyu Yi, Pär Aronsson
- Panda arm integration: Pär Aronsson
- Dyno-robotics trajectory replay integration, scenario: Sebastian Olsson

#### **21.0.5 2.1.0: Namespace cleanup and multi-agent navigation (Aug 2025) - Team/Tech Lead: Hamid Ebadi**

- Implemented generic robot-agent control supporting multiple meshes (e.g., pallet truck, forklift) and distinct ArUco IDs: Pär Aronsson
- Robot-agent and navigation2 (nav2) namespace: Pär Aronsson
- Multi-agent navigation capabilities using GPSS: Pär Aronsson

#### **21.0.6 2.0.0: GPSS (May 2025) - Team/Tech Lead: Hamid Ebadi**

- Upgrade Gazebo from classic to ignition, adapting new sensors: Nazeen Alhosary
- ArUco\_localization, added localization and nav2 to new robot: Pär Aronsson
- Navigation: Pär Aronsson
- Bird’s Eye View ros package: Converting projection.ipynb to camera\_bird\_eye\_view: Hamid Ebadi, Pär Aronsson
- Deprecated: InfoBot, replaced with Pallet\_truck (based on Jackal by Clearpath Robotics)

#### **21.0.7 1.0.6: Collision (Feb 2025)**

- Add scenario execution library for ros2
- Add action servers for set\_speed, teleport\_robot and collision
- Add Node for TTC calculation
- Add package for custom messages

#### **21.0.8 1.0.5: Delivery 4 (Dec 2024)**

- D3.5 Disentanglement: One-parameter Object Movements.
- Trajectory visualization: Hamid Ebadi
- feat: added DynoWaitFor to make sure Jackal is launched last (synchronisation issue)
- simlan\_bringup pkg created: Christoffer Johannesson

#### **21.0.9 1.0.4: Delivery 3 (Oct 2024)**

- SMILE-IV and ArtWork projects contributions
- Updated camera extrinsic, fixing OpenCV camera calibration to Gazebo simulator conversion: Erik Brorsson, Volvo
- D3.4 Out distribution data collection: Hamid Ebadi



- D3.3 In distribution data collection: Hamid Ebadi
- D3.2 Images for stitching: Hamid Ebadi
- D3.1 Dataset draft for HH: Hamid Ebadi
- CI/CD and Kubernetes integration by Filip Melberg, Vasiliki Kostara
- Jackal integration: Christoffer Johannesson, Hjalmar Ruscek
- Docker/vscode
- Disable GPU support by default
- POC for camera projection to pixel coordinates (Jupyter notebook): Hamid Ebadi
- Camera image dump and image stitching: Hamid Ebadi

#### **21.0.10 1.0.3: Jackal Robot (Mar 2024) - Christoffer Johannesson**

- Added dyno fork of jackal repo from Clearpath Robotics.
- Updated to Humble, added bringup and support for namespacing. Jackal can be spawned in Gazebo and controlled through the keyboard.
- Added .devcontainer folder with Dockerfile and devcontainer.json to set up project container in VS Code.
- Added docker-compose to link all needed files and set environment variables.
- Added .vscode folder with settings and tasks for easy building of the project.
- Updated README with info on how to use Docker setup in VS Code, and some features to make it easy to share the same setup with others.
- Features include: python3 dependency install with pip, cloning of other git repositories and how to make changes to those repositories.

#### **21.0.11 1.0.2: Delivery 2 (Feb 2024)**

- Volvo warehouse 0.0.1: Hamid Ebadi
- Volvo camera calibration in Gazebo 0.0.1: Hamid Ebadi
- Integrate Infobot\_agent 0.0.2: InfoBot differential-drive AMR (Autonomous Mobile Robot) URDF and ROS launcher (GOPAL and forklift): Hamid Ebadi
- Integrate Infobot\_cartographer 2.1.5: cartographer for creating PGM maps
- Integrate nav2\_commander 0.0.2: ROS package to command Infobot where the destination is: Hamid Ebadi
- Integrate Infobot\_navigation2 2.1.5: Standard Nav2 stack launcher: Hamid Ebadi
- Integrate Infobot\_teleop 0.0.2: Teleoperation for InfoBot

#### **21.0.12 1.0.1: Delivery 1 (Dec 2023) - Team/Tech Lead: Hamid Ebadi**

- Basic warehouse model 1.0.0: Anders Bäckelie
- CAD modelling (eur-pallet, boxes, shelf, support\_pole, traffic-cone, steel\_drum) 1.0.0: Jacob Rohdin
- Physics (collision, inertia), visuals and Gazebo compatible mesh creation 1.0.0: Anders Bäckelie
- Walking actor using scripted trajectories 1.0.0: Anders Bäckelie
- Infobot\_Gazebo\_environment 1.0.0: ROS2 launcher to start Gazebo world: Hamid Ebadi
- static\_agent\_launcher 1.0.0: Camera and ArUco tags: Hamid Ebadi
- camera-viewer 1.0.0: Python code to get Gazebo camera feed: Hamid Ebadi

#### **21.0.13 high-level\_diagram\_SIMLAN.drawio**

high-level\_diagram\_SIMLAN.drawio.png

#### **21.0.14 Humanoid\_mocap\_flow.drawio**

Humanoid\_mocap\_flow.drawio.png

#### **21.0.15 humanoid\_mocap\_pipeline.drawio**

humanoid\_mocap\_pipeline.drawio.png

#### **21.0.16 launch\_bringup.drawio**

launch\_bringup.drawio.png

#### **21.0.17 SIMLAN\_DIAGRAM.drawio**

SIMLAN\_DIAGRAM.drawio.png