LiDAR Localization in Rugged Environment

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Abstract. Accurate localization in industrial robotics is one of the crucial attributes. One of the most popular localization approaches in robotics is localization with LiDAR. However, when a robot enters a rough environment with smoke, dust or fog, the LiDAR sensor may provide inaccurate measurements. This paper is aimed to confirm the influence of smoke of different densities on LiDAR-based localization and provide a possible solution to overcome the erroneous measurements of light detection sensors.
A simulation environment was designed to analyze the level of smoke impact. It includes the simulation of warehouse premises, an industrial robotic platform equipped with LiDAR together with smoke of different densities. Preliminary results from the simulation verify that smoke obfuscates the localization algorithm. It has also been observed that the simulator response time increases considerably when the number of particles increases.

Keywords: LiDAR, Localization, ROS, Sensor fusion

1 Introduction

More and more warehouses are now equipped with mobile robots that are used for the manipulation of various goods. Not only the goods can be in danger in case of fire appearance but also the valuable robots, as happened in Ocado's warehouses in Great Britain in 2019 and 2021 [1]. Different fire prevention and suppression systems are widely provided by various companies [2,3,4]. However, most of them can be used in free-of-people spaces only. As there is a small number of fully-automated warehouses nowadays, all staff should be firstly evacuated, which leads to prolonging the extinction process. Thus, one of the ideas is to move robots outside of the smoked building to save them. In such a situation a robot should still perceive its position accurately.

Many localization, navigation, and mapping approaches use Light Detection And Ranging (LiDAR) sensors. However, particles in the air can interfere with the laser trajectory, generating light scattering or absorbing a part of light energy. Such a situation may happen during a fire when not burned-out material particles appear in the air, producing smoke. According to the paper [5], LiDAR sensors in a harsh environment can exhibit one out of four behaviors.

The first one is when the particles of smoke, dust, or fog do not influence the LiDAR measurement, and LiDAR can measure accurately. However, three other situations are

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not desired at all. Here, the measurement of the object can be partially or fully absorbed and reflected by particles from smoke. Thus, in harsh environments containing smoke, fog, or dust, LiDAR is unreliable, and sensor fusion approaches should be considered.

The purpose of the paper is to study how smoke interferes with LiDAR. One of the practical ways how to proceed is to check the influence of smoke on LiDAR-based localization algorithms' time. Several experiments were conducted using simulated environments.

2 Materials and Methods

To conduct experiments a simulation of a warehouse, a robot, sensors and smoke should be created. The following sections give sufficient information about each of the simulated components.

2.1 Mobile Platform

The industrial robot – Neobotix MP-500 [6] – was chosen (see Fig.1). It has a SICK S300 2D LiDAR onboard and it works on Robot Operation System (ROS) middleware.

Fig. 1. Neobotix platform with SICK 300 LiDAR [6]

In the work, ROS libraries and libraries for Neobotix robots were used to simulate real MP-500 robot behavior, obtain the map of the space and test the localization in a harsh environment.

2.2 Simulation Environment

A simulation environment in the Gazebo Ignition tool was created to verify the obstructiveness of the smoke and check its influence on LiDAR. It consists of a warehouse filled with various boxes, shelf stands and MP-500 Neobotix robot with 2D LiDAR. In Fig.2. it is also possible to observe the rays of LiDAR, which are presented as a dark region.

Fig. 2. Gazebo simulation of warehouse with Neobotix robot

RViz (short for “ROS visualization”) tool in ROS has been used to visualize the MP-500 perception of surroundings. This tool is depicted in Fig.3. To simulate the same SICK S300 sensor, data from the sensor datasheet and MP-500 documentation were taken [7, 8]. Since it is an idea to simulate more realistic conditions, the setting parameters of SICK S300 were taken from the specification of the MP-500 robot, not from the LiDAR datasheet. For example, the scanning angle of LiDAR can be up to 270°, though Neobotix producer set it to 170°. The settings of LiDAR are shown in Fig.4.

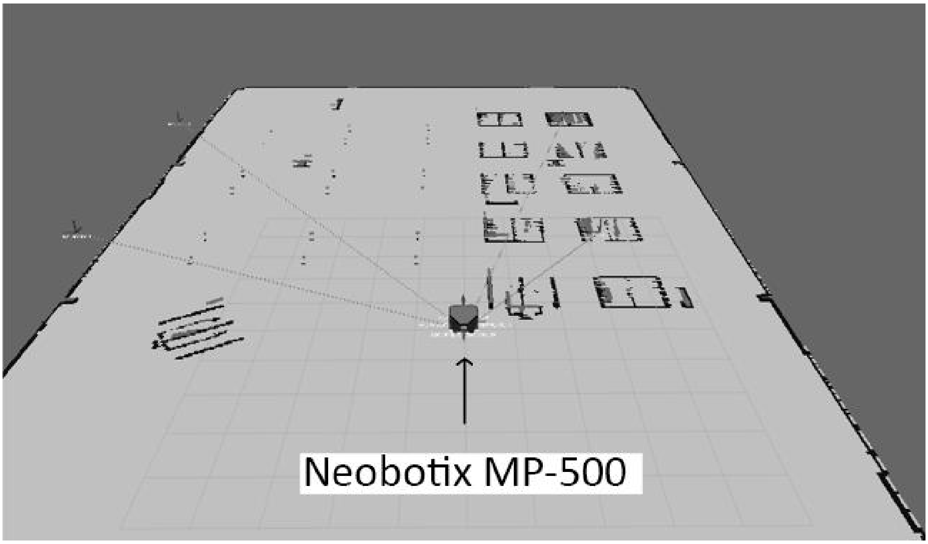

Fig. 3. RViz visualization environment of warehouse with Neobotix robot

```
<sensor name="mp_500/base_link/lidar_1_link" type="ray">
  <pose>0 0 0 0 0 0</pose>
  <visualize>true</visualize>
  <update_rate>40</update_rate>
  <ray>
    <scan>
      <horizontal>
        <samples>720</samples>
        <resolution>1</resolution>
        <min_angle>-1.48353</min_angle>
        <max_angle>1.48353</max_angle>
      </horizontal>
    </scan>
    <range>
      <min>0.10</min>
      <max>30.0</max>
      <resolution>0.05</resolution>
    </range>
    <noise>
      <type>gaussian</type>
      <mean>0.0</mean>
      <stddev>0.01</stddev>
    </noise>
  </ray>
  <plugin filename="libgazebo_ros_laser.so" name="lidar_1_link">
    <topicName>lidar</topicName>
    <frameName>mp_500/base_link/lidar_1_link</frameName>
  </plugin>
</sensor>
```

Fig. 4. Parameters of LiDAR used in the simulation

With the same settings, a map of the premise was obtained and used in the experiments.

To simulate smoke a particle system was introduced. A particle system is a technique used to model objects that are difficult to model with classical surface-based modeling. That system creates a volume of particles with individual properties rather than a surface with a texture. It contains small smoke particles that move independently from each other [10]. In the Gazebo Ignition tool, it is possible to simulate smoke with such a particle system.

The particle size, material properties, lifetime, and the number of them can be configured. Various configurations of the aforementioned parameters could help to analyze the influence of fumigation intensity on LiDAR measurements and predict the marginal environmental conditions when the LiDAR-only localization can be used.

2.3 Description of Experiments

All the experiments were conducted in Linux Ubuntu 20.04 in ROS1 with Gazebo Ignition of the 5th version and classical RViz. The Ignition bridge was used to connect Gazebo with ROS1.

The goal is to simulate a "kidnaped robot" scenario by providing the wrong initial position and orientation coordinates. The study will measure the time the robot needs to localize itself correctly.

Before the localization algorithm is tested a map of the surroundings should be provided. It can be gained with any of the Simultaneous Localization and Mapping Algorithms (SLAM). In the work SLAM gmapping algorithm was harnessed for the aforementioned purpose.

The localization algorithm that is used once the map is obtained is specially created for Neobotix robots. It provides a simple but effective replacement for the standard Adaptive Monte Carlo Localization (AMCL). Authors of the algorithm state that the algorithm is similar to a particle filter, except the particles are created from scratch on every update and each particle is optimized using multiple Gauss-Newton iterations [9]. The authors also claim that depending on the quality of the map a localization accuracy of up to 1 mm can be achieved. Speaking about our experiments, the Neo-localization algorithm automatically switches into a constrained 1D mode or even into 0D mode (continue with just odometry) in case of insufficient surroundings to localize with, which can help to understand if the algorithm gets stuck.

To observe if there is a difference in the localization algorithm operation experiments with and without smoke should be considered. Once we tested the algorithm in the chamber with normal warehouse conditions, we can try to introduce the smoke of different parameters to see how each particular parameter affects the LiDAR measurements.

In the paper, the following parameters of smoke to be checked in experiments has been considered:

- Particles life-time
- Amount of particles
- Size of particles
- Smoked area
- Velocity range

3 Results and Discussion

In Fig.5 reader may observe the simulation environment where smoke was introduced. Already from the Gazebo simulation environment, it is possible to notice the change in LiDAR rays if to compare it with the simulation from Fig.2. Now, when we look at the right part of Fig.5, it would be possible to notice some “burned” particles that LiDAR sees in smoke. In that figure, we suppose that the robot was moved during its sleep – or, in other words, kidnapped – from the position we observe here, to the position on the left figure. The robot has a known map in the memory with which it compares LiDAR measurements and tries to find its real position with the help of the localization algorithm.

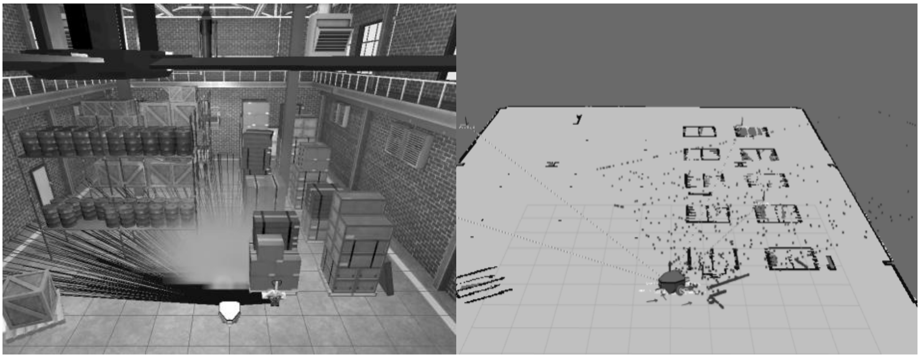

Fig. 5. Simulation of smoke (left) and its visualization (right)

To produce smoke the code from Fig.6 is used. Size attribute in the code states for the size of the smoked area. Particle size parameter is used to adjust particle dimension. With the lifetime one can set the number of seconds each particle exists before being destroyed. Min_velocity and max_velocity parameters are used to set a velocity range, within which each particle is emitted. The difference between rate and scale rate is that the first one is used to set the number of particles being emitted per second, whereas the use of the second one is to adjust the amount by which to scale the particles in both X and Y directions per second. It is also possible to set the material together with particles scattering ratio. The scattering ratio determines the ratio of particles that will be detected by sensors. By increasing the ratio, a higher chance of particles reflecting and interfering with depth sensing arises, making the emitter appear denser. The same can be tuned with material parameters. More information of them can be found in [11].

```
<particle_emitter name="emitter" type="box">
<emitting>true</emitting>
<size>1 1 1</size>
<particle_size>0.000001 0.000001 0.000001</particle_size>
<lifetime>1</lifetime>
<min_velocity>0.1</min_velocity>
<max_velocity>0.2</max_velocity>
<scale_rate>1</scale_rate>
<rate>50</rate>
<particle_scatter_ratio>0.8</particle_scatter_ratio>
<material>
    <diffuse>1 1 1</diffuse>
    <specular>1.0 1.0 1.0</specular>
    <pbr>
        <metal>
            <albedo_map>fog.png</albedo_map>
        </metal>
    </pbr>
</material>
```

Fig. 6. Code of Smoke Generator

Firstly, the influence of particles' lifetime on the localization algorithm was checked. There are 4 timings that were chosen. For each of the timing from 7 to 11 experiments were conducted. The results of the experiments with lifetime are presented in Table 1.

Table 1. Influence of particles' lifetime on the operation time of localization algorithm

Condition	Smokeless	Smoke			
Particles lifetime (s)		1	2	3	5
AVG of time (s)	67.5	208.3	4673	inf	inf

Table 2. Influence of particles' number on the operation time of localization algorithm

Condition	Smokeless	Smoke		
Particles number		5	10	50
AVG of time (s)	67.5	208.3	338.6	inf

Table 3. Influence of particles' size on the operation time of localization algorithm

Condition	Smokeless	Smoke		
Particles size (m)		1e-3	1e-6	1e-9
AVG of time (s)	67.5	166.3	167.5	149.4

Inf value in tables means that the time of the localization algorithm is too long to rely on it. Even the average time of algorithm operation with the particles' lifetime parameter of 2s is too long, but still, it was decided to present that result here for comprehension of timings in smokeless and smoked environments of different smoke parameters.

When the smoked area is changed, the density of the smoke changes as well. It is quite obvious that the same number of particles in different box sizes (that is the smoke simulation area) create various densities. The same was shown in the experiments.

Table 4. Influence of particles' velocity on the operation time of localization algorithm

Condition	Smokeless	Smoke		
Particles velocity range (m/s)		0.01-0.02	0.1-0.2	1.0-2.0
AVG of time (s)	67.5	197.2	167.5	148.8

In Table 4 the average time of the algorithm operation decreases with the rise of the particles' velocity range. So, the longer was a particle in the LiDAR view, the more impact it had on the localization algorithm. Almost the same was shown when the lifetime of particles was increased (Table 1). Since more and more particles were being evaporated each second and the previous ones were still in the observation of LiDAR.

Overall results of experiments demonstrated that the highest effect on the localization algorithm had particles number and particles lifetime. Particle size, on the other hand, has no direct influence on the localization algorithm (Table 3). That was the situation of a closed space where all particles stayed in the same chamber as it was in warehouses.

4 Conclusions

It has been observed that the time of localization algorithm is affected by some smoke parameters (see Tables 1, 2) that LiDAR observes as a cloud of randomly distributed particles. Moreover, the results of the work can help to calculate the limited conditions in which LiDAR-only localization can still be used. In case of an emergency evacuation, it is not favorable to have a localization time of an hour, as was shown in experiments with particles lifetime and particles number in section 3.

In case the LiDAR-only localization is not sufficient a sensor fusion may be considered. For example, in [12] authors try to overcome localization complexity in a smoked room by introducing a fusion between LiDAR and radar sensors. In [13] another decision of LiDAR and inertial navigation systems sensor fusion is presented. There are other ideas like [14], where localization in the tough environment is carried by Ultra-wideband (UWB) sensors only. But since UWB sensors are not as correct as LiDAR, their fusion in an internal chamber can be examined. That is the idea that is being currently tested in the same rugged environment (UWB sensors may be observed in Fig.3). Since the influence of particles material and the different number of objects in a room have not been considered here, it is assumed that several additional experiments will be provided in the UWB-LiDAR fusion paper. Moreover, real-world experiments are planned, so that there is a possibility to compare the simulation and real-world data.

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