Simulation Model of a Time of Flight Distance Sensor Using SimTwo

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Abstract. This paper presents a simulation model of a Time of Flight distance sensor applying SimTwo robotics simulator in order to contribute to a mobile robotics application, in an educational context. The objective is to observe the sensor behavior, inside the simulation environment, face a set of experiments, such as an abrupt difference of distance, several angle inclinations and measurements to the maximum sensor range. The tests were performed using SimTwo being a high performance, open source, versatile, real time simulation environment, in which is possible to configure an specific sensor adding its features, which allows to achieve a realistic simulation. The results represented the expected sensor behavior for the proposed scenarios.

Keywords: Simulation environment · Time of Flight technology · Mobile robots

1 Introduction

Inside the context of mobile robotics, using simulators has become widespread, since it is possible to test the algorithms and controllers without the physical robot, achieving a fast and effective way to perform preliminary tests. There are a lot of benefits of applying a simulation while developing a mobile robot application such as accelerate and facilitate the development, reduce costs of design process, allow to test the software without or before the hardware, consequently avoiding accidents with the prototype [1–6].

The simulators aim to be close to the reality, applying dynamics, external environment conditions, adapting sensor and actuators models and interactions

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between the robot and its environment. Sometimes the scenarios where it is desired to test the robot are not available, being possible through a simulation environment. A simulation environment can also be useful for monitoring variables which have a difficult access in a real situation [6–8].

Besides that, the simulations play an important role in education, assisting in practical experiments, mainly when hardware or equipment resources is not accessible for the students. In addition, simulations are very useful in situations which a remote study is required, for example in the COVID-19 pandemic, allowing students to test robots performance and observe the results of interactions remotely[4,7,9].

In mobile robots several methods such as obstacle avoidance, detection of people and objects, reconstruction of objects and environments require distance measurements, being a topic mandatory in most part of mobile robots applications. In this context, the Time of Flight (ToF) technology has been widely applied due to its low cost and accuracy. In this principle there is a modulated infrared signal which is sent to the target object and reflected, allowing to calculate the distance based on the phase shift between the signal sent and received back [10–14].

Therefore, in this work it is proposed a simulation model of a Time of Flight distance sensor using the SimTwo simulator, including the features of the sensor extracted from the datasheet [15] and adapting it to have a simulation model close to reality. It is important to emphasize that this is a first approach, which will be improved adding noise and error in order to approximate this simulation model to the modelling of the ToF sensor presented in the papers [10,11].

This paper is structured as follows. Section 1.1 describes the SimTwo simulator which was used in this paper and Sect. 1.2 presents a description about the Time of Flight distance sensor which was simulated. A detailed description of the methodology and experiments created to simulate the sensor is described in Sect. 2. The results obtained are discussed in Sect. 3. Lastly, the conclusion and future work are presented.

1.1 SimTwo Simulator

SimTwo is an open source robotics simulator, which allows a fast development of robot control applications. It was developed in Object Pascal and used the Open Dynamics Engine [16], an open source library for the simulation of rigid body dynamics providing a good performance for real time simulation [9,17]. One of the main applications of SimTwo have been in robotics education, allowing students to test and developed robot control applications without a physical platform, mainly when there is not equipment available for them and also to test algorithms and scenarios for competitions [4,9,17–20].

Figure 1 shows the SimTwo software interface with all its windows. The scenario is created in the 'XML scene editor' window, where it is defined the robot, sensors and obstacles. The 'code editor' is where the control is programmed in Pascal programming language. The 'config' window represents general settings.

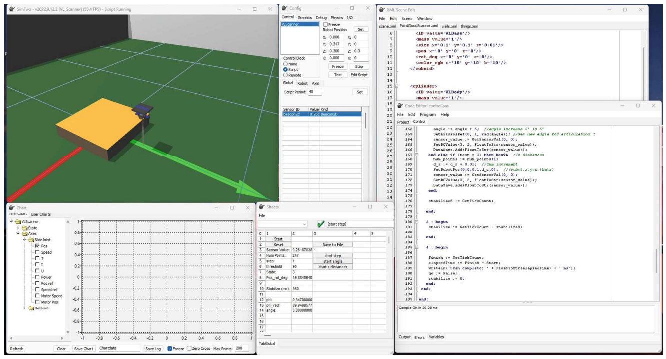

Fig. 1. SimTwo simulator interface.

In 'sheets' is possible to include buttons for specific actions and read/write variables. Lastly, in 'chart' window it is possible to plot graphs in real time [9,17].

This simulator provides a 3D environment, in which there are a set of robots supported in the simulation such as omnidirectional wheeled, industrial, humanoid, lighter-than-air vehicles and there also are a lot of components such as sensor and actuators in which its models can be added as input [17]. The possibility to add real models of sensors and actuators as well as the rigid-body parts and configuration of joints of the robots provides a dynamic realism to the SimTwo achieving simulations very close to the reality [4,9].

One interesting feature of SimTwo is the ability to send and receive data remotely, because includes several communications such as UDP, ZMQ, Modbus and Serial, being possible to apply Hardware-in-the-loop approaches and to test software directly in microcontroller without the physical robot, further contributing to the fast development of robot applications [4,9,17,19,20].

1.2 Time of Flight Sensor

The time of flight sensor measures distances based on the ToF principle, illustrated in Fig. 2, which consists of send a modulated infrared signal to the target object by an emitter, then based on the time that the signal is reflected and captured by a receiver, the distance can be calculated [11,15,21].

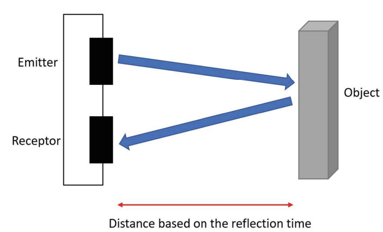

Fig. 2. Time of Flight principle illustration [11].

Usually these kind of sensors includes a infrared signal emitter operating in near-infrared range approximately 850 nm. The photonic energy is converted to electrical current by an receiver which understand the same spectrum [11,13,14,21].

The ToF sensors have been widely applied in many applications, presenting high accuracy, precision, low cost and compact construction, besides to provide satisfactory results face to background light [11–14].

In this work, the simulation was focused in the VL53L0X ToF sensor from STMicroelectronics, which includes a narrow field of view of 25º and reaches distances for up to 2 m. It operates in three different ranging modes, such as default mode, high speed, high accuracy and long range. The default mode is adequate to obtain a tradeoff between reactiveness and accuracy, because in high speed, there is a lot of noise and low accuracy, while in high accuracy the reactiveness is lost and the measurement process became slow [11,15].

2 Scenes and Experiments with the Time of Flight Sensor

For the simulation model, it was included a configuration in the simulation environment having in mind all the sensor features, obtained from the datasheet [15], such as the beam angle of 25º and the maximum beam length of 1 m, although in the datasheet the range is up to 2 m, it was taken into consideration that this sensor will be applied in a mobile robotics application that requires less than 1 m.

Figure 3 represents the distribution of the rays in the ToF sensor beam, for this simulation model the sensor was included in SimTwo with a set of 90 rays to represent the infrared signals scattered across the field of view. For now, the rays are uniformly distributed, but it is planned to change the density and position to improve the simulation accuracy.

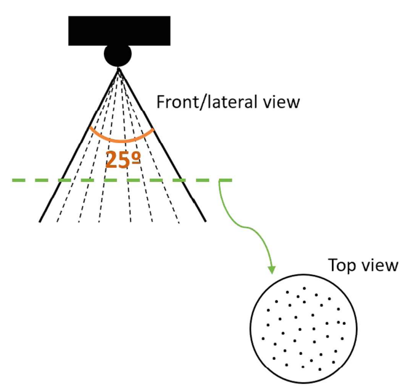

Fig. 3. Infrared rays distribution in the beam of the ToF sensor

It was created an object to attach the distance sensor, like a robot composed by two solid parts, in which the first one includes an articulation joint that allows the robot to move horizontally over an obstacle and the second one have an articulation to move the sensor in different angles.

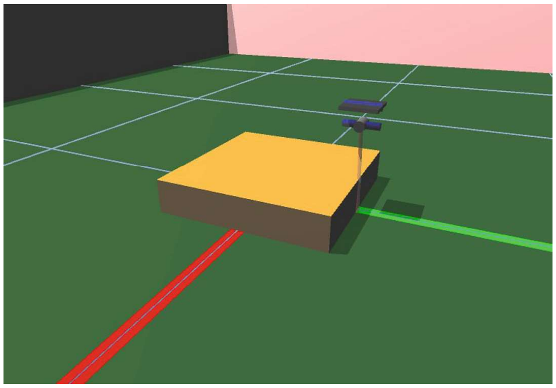

Fig. 4. Scenario for the sensor moving horizontally over a step.

For the first experiment, illustrated in Fig. 4, it was created an obstacle, like a box, with dimensions of 0.5 m × 0.5 m × 0.1 m, in order to test the sensor performance face an abrupt difference of distance. The sensor was programmed to move horizontally over the step along 0.3 m, in which the step was positioned in 0.15 m, that is, in the middle of the route. This experiment was repeated for 6 different heights from 0.05 m to 0.3 m.

For the second experiment, consisted of observe the sensor behavior face different angle inclinations, as showed in Fig. 5. The sensor was positioned far from the obstacle and performed measures from −25º to +25º of inclination also for 6 different heights from 0.05 m to 0.3 m.

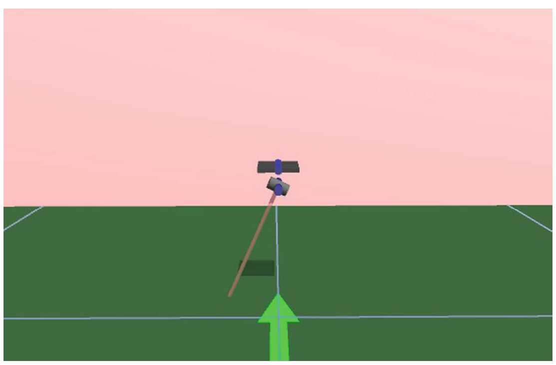

Fig. 5. Scenario for the sensor moving in different angles.

The last experiment consists of testing the sensor measurements from the shortest possible distance to the greatest one configured in the simulator of 1 m. The scenario for this test is similar to the previous one, but the sensor measures distances without inclination, just in z axis and for more heights than the previous tests (Fig. 6).

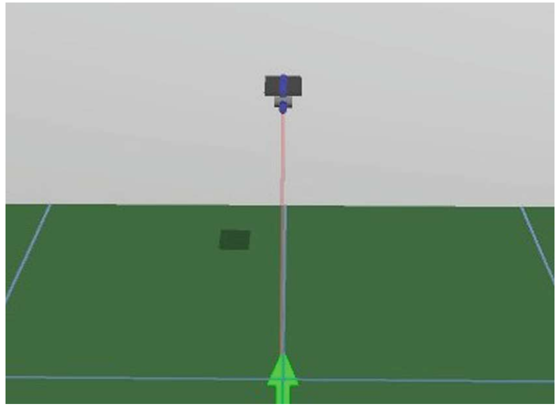

Fig. 6. Scenario for the sensor moving in different distances in z axis.

3 Results

In this section, the results obtained from the simulations are presented and the performance of the ToF sensor is discussed. For the first simulation, the ToF sensor was moved over a step with 1 m of height, in order to observe the sensor behavior face a difference of distance.

The results are showed in Fig. 7, which represents the horizontal distance traveled in function of the ToF sensor distances. Each curve represents the distances measured by the sensor moving over the step in different heights from the obstacle, as described in the legend. The right side of the graph represents the distances from the step and the left side represents the distances measured outside of the step.

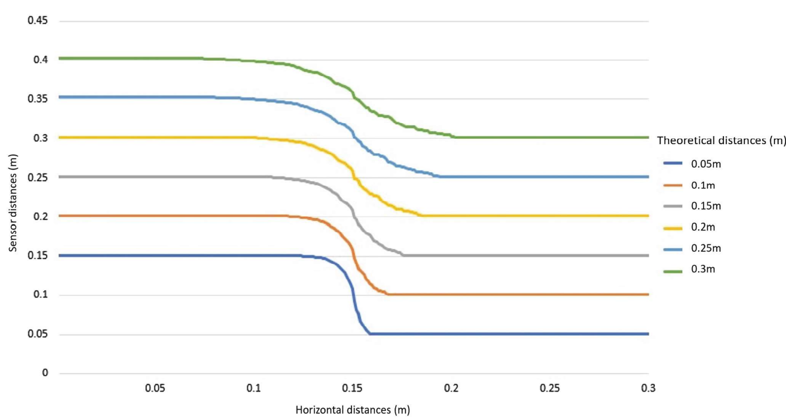

Fig. 7. Results for the sensor moving horizontally over a step.

The simulation results represented a consistency with the distances and sensor behavior expected for an abrupt difference of distance. It can be noticed how the curves values increase outside of the step (left side of the graph) due to the box height of 0.1 m, when compared with the real acquired data [10,11].

It is possible to observe sharp curves close to the obstacle and soft curves according to the distance increase, which is the expected behavior, because for long distances the field of view reaches more points outside of the step having in mind the distribution of the beams across 25º, and for short distances the measures are more precise and visible in the graph, since the field of view reaches more specific points.

It is notable that the curve kept close to the theoretical distances before and after the step, besides that, the distance between each curve also remained the same, demonstrating a good sensor response inside the simulation.

For the second simulation, it was collected distances measured by the sensor inclined in different angles. The results are presented in Fig. 8, which represents the sensor angle inclination in function of the distances measured and the colored curves represents different heights from the floor. It was not applied long distances in these simulations because the intention is to observe the ToF sensor behavior face inclinations and abrupt difference of distance as in the previous test.

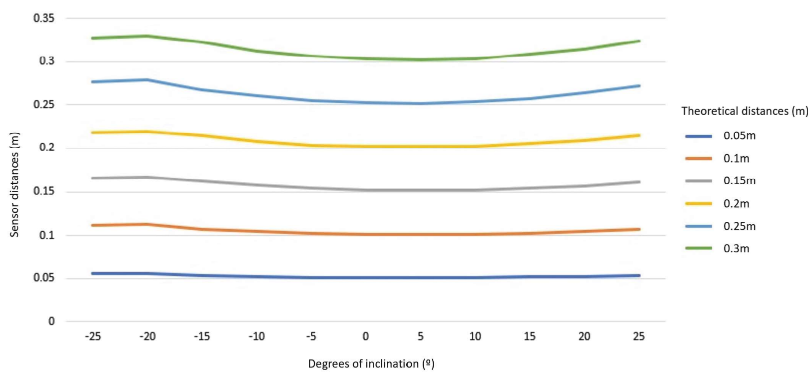

Fig. 8. Results for the sensor moving in different angles of inclination.

It can be visualized in Fig. 8, how the curves remained very close to the theoretical distance when the inclination of the sensor is 0º, that is the sensor is totally perpendicular with the floor or the obstacle, representing a good response. According to the inclinations, it is possible to note a distortion in the measurements, which is expected because represents measurement errors provided by the inclination not considered by the manufacturer, that is, the emitter and receiver are not completely aligned, what affects the emission and reception of the infrared signal.

For the third simulation, the sensor was moved until a distance of 1 m with steps of 1 mm to observe the sensor performance to the maximum range and the results are showed in Fig. 9, which is the theoretical distances in function of distances measured by the sensor.

As expected, the results for this third simulation showed a linear behavior of the sensor face a different distances in z axis, which can be observed in the graph of Fig. 9. It can be concluded that the obtained results represented accurately the sensor behavior and all the results were consistent with the modelling results presented in the papers [10,11].

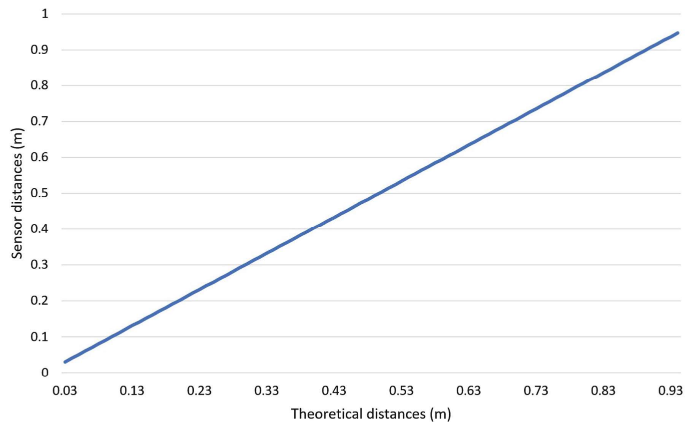

Fig. 9. Results for the sensor moving in different distances in z axis.

4 Conclusion and Future Work

It was presented a simulation model of a Time of Flight distance sensor using SimTwo simulator, which provides a realistic simulation, once it was possible to add the real sensor features.

The measurements were consistent with the expected ToF sensor performance for different situations like the sensor moving over an obstacle with an abrupt difference of height, the sensor moving in different angles of inclination and moving in different distances in z axis. The results obtained in this work were also consistent with the results of a modelling of the same ToF sensor presented in the papers [10,11].

This realistic simulation can be useful as a tool of teaching in educational context, mainly in situations where the physical components are not available for the students, becoming possible for them to observe the behavior of a Time of Flight sensor for a variety of applications.

As future work, it is planned to obtain an improved simulation, based on the real measurement data from the physical ToF sensor, in which it is added noise and error inside the simulation environment to obtain a realistic simulation. It is intended to apply the same experiments and tests, in order to match the real and simulated data.

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