A low cost collision avoidance system based on a ToF camera for SLAM approaches

Un sistema de prevención de colisiones de bajo costo basado en una cámara ToF para enfoques SLAM

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Keywords

TOF camera; SBC; SLAM; obstacle detection; indoor localization.

Abstract

Indoor positioning is a problem that has not yet been solved efficiently and accurately. In outdoors the most effective solution is the Global Position System (GPS), but it cannot be used indoors due to the weakening of the signal, so other solutions have been studied. These approaches could be applied to define a map for the guidance of blind people, tourism or navigation for autonomous robots. In this paper, the study, design, implementation and evaluation of a robust obstacle detection and mapping system is proposed. Thus, it can be used to alert of near objects presence and avoid possible collisions in an indoor navigation. The system is based on a Time-of-Flight (ToF) camera and a Single Board Computer (SBC) like Raspberry PI or NVIDIA Jetson Nano. In order to evaluate the system several real experiments were carried out. This kind of system can be integrated on a wheelchair and help the handicapped person to move indoors or take data from an indoor environment and recreate it in a 2D or 3D images.

Palabras clave

Cámara TOF; SBC; SLAM; detección de obstáculos; localización en interiores.

Resumen

El posicionamiento en interiores es un problema que aún no se ha resuelto de manera eficiente y precisa. En exteriores la solución más eficaz es el Sistema de Posicionamiento Global (GPS), pero no se puede utilizar en interiores debido al debilitamiento de la señal, por lo que se han estudiado otras soluciones. Estos enfoques podrían aplicarse para definir un mapa para la orientación de personas ciegas, el turismo o la navegación para robots autónomos. En este trabajo se propone el estudio, diseño, implementación y evaluación de un sistema robusto de detección y mapeo de obstáculos. Por tanto, se puede utilizar para alertar de la presencia de objetos cercanos y evitar posibles colisiones en una navegación interior. El sistema se basa en una cámara de tiempo de vuelo (ToF) y una computadora de placa única (SBC) como Raspberry PI o NVIDIA Jetson Nano. Para evaluar el sistema se llevaron a cabo varios experimentos reales. Este tipo de sistema puede integrarse en una silla de ruedas y ayudar a la persona discapacitada a moverse en el interior o tomar datos de un entorno interior y recrearlos en imágenes 2D o 3D.

Introduction

In recent years, there has been a wide demand for services related to the lo- cation of people or objects. Currently, in outdoors, the Global Position System (GPS) is widely used and is capable of providing great accuracy when locating. Unfortunately, due to the attenuation of the satellite signal, the effectiveness of location in indoor environments is attenuated and then, less accurate, being even impossible to use to locate with certain accuracy. Therefore, in recent years

the development of indoor location systems has acquired great relevance using as a basis other types of sensors, such as the power level received from the signal of Wi-Fi access points, Bluetooth and information from inertial sensors. Today there are a variety of solutions, but none of them is optimal [2].

Thus, Simultaneous Localization And Mapping (SLAM) [11] is a technique that investigates the problem that raises the construction of mathematical, geo- metric or logical models of physical environments. For that, a mobile robot and a set of sensors and actuators are usually used to gather information about environment. As another way of saying this, SLAM seeks to solve the problems posed by placing a mobile robot in an unknown environment and position, and that the robot itself is capable of gradually building a consistent map of the environment while using this map to determine its own location. In general, SLAM is used to map an environment beforehand unknown by the automaton and at the same time estimate the path it is taking with the exclusive use of sensors it carries. There are several SLAM techniques such as using LIDAR [10], use of ultrasonic sensors or vSLAM (visual SLAM) [4]. Their applications can be focused to different fields, such as: robotics, tourism, rescue, navigation for blind people, etc. Smartphones and low-cost computers, such as Raspberry PI, have been recently considered as appropriate devices to easily obtain user information using various groups of embedded sensors. The vSLAM variant is based on a sensor camera to extract data from the environment. The cameras used can be either commercial cameras or Time of Flight (ToF) cameras [5, 3].

A ToF camera is capable of providing a depth-sensing of a scene which each gathered pixel stores its X, Y, and Z coordinates in the image. Z value represents the distance from the camera to the point of focus [6]. This type of camera provides high quality measurements, and it is ideal for applications that requires high performance and high accuracy. With this system, stable measurements in both accuracy and recurrence are achieved, even with objects of different colors and reflectivity within the image.

On the other hand, point cloud processing is an important aspect of many systems implemented in real world. As such, a wide variety of point-based approaches have been proposed and reporting steady benchmark improvements over time [1]. Most 3D scanners give raw scanned data in form of point cloud format. The point cloud produced by 3D scanners are visualized for the ease of measurement or even representation. A point cloud is a set of data points in a 3D coordinate system, consisting by x, y, and z coordinates values. They are used to represent the surface of an object, hence, do not contain data of any internal features like color or materials. With this kind of data is possible to develop algorithms that use point clouds for certain purposes.

The aim of this work is to developed a low-cost system composed by a ToF camera and a SBC (single Board Computer) to alert of near objects presence and avoid possible collisions in an indoor navigation. In addition, the scene can be recreated from the cloud point processing.

This work is structured as follows: section 2 describes the used methodology to alert about possible collisions. In section 3, the system architecture is proposed. After that, in section 4, the results of experiments are shown and discussed. Finally, section 5 contains the conclusion and future work.

Methodology

In this section the process and concepts needed to achieve point cloud processing is explained. In addition, the detection of possible collides and representation of point clouds in 3D images is described. The methodology followed in this work is shown in figure 1, which is developed in three phases: point cloud extraction, filtering data, and collision detection and 3D representation.

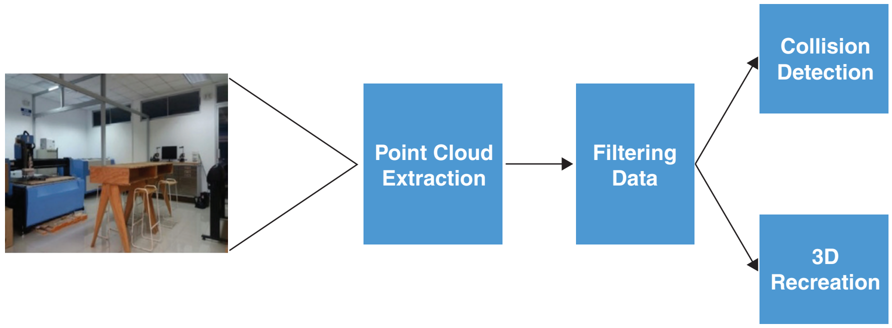

Figure 1. The proposed methodology.

The cloud point extraction phase is carried out using the API manufacturer's API. With this library, the camera is activated and the data collection is carried out. In addition, a Python library named NumPy is used for working with arrays because it provides optimized numerical computations, and therefore, it is faster than traditional operations. On the other hand, sometimes the ToF camera can return outliers which are pixel information that not match with the scene. A pixel is considered as outlier if the absolute value of the Z-value mean of their nearest neighbours is five times bigger than the Z-value of pixel. Therefore, these pixels are removed from point cloud in the filtering data phase. Next, and in order to carry out the collision detection, a threshold can be set which represents the minimum distance to avoid a collision. Using the NumPy library, the difference among each point and the threshold is computed. If it is equal or less than zero a possible collision can occur, and therefore, an alert message is indicated. If the threshold is not set, the system return the distance to closer object. Due to the camera specifications, the minimum threshold that can be set is 0.1 m. Lastly, a algorithm based on the PointCloud Library [7] is used to visualize a 3D scene representation.

System Architecture

In this section the system architecture is proposed, figure 2. Basically, the system is formed by a ToF camera and a SBC. In addition, a server has been used to store the gathered point clouds and visualize the 3D representation. Next, both ToF camera and SBC are described.

Figure 2. System architecture.

ToF Camera

As ToF camera, a CamBoard pico flexx [6] was used. It is a peripheral depth sensor with USB connection that can be integrated into a mobile device. The characteristics of this camera are a configurable capture rate that goes from 5fps up to 45fps, a measurement range up to 4 meters using 5fps, and a resolution of 224 x 171px. It has support in Android, MacOS, Windows and Linux operating systems.

Single Board Computer

Two SBC were used to test the proposed methodology: a NVIDIA Jetson Nano

[8] and a Raspberry Pi [9].

The NVIDIA Jetson Nano is a SBC designed for the development of artificial intelligence applications, ideal for robotics, image processing, object detection, segmentation and many more applications. It uses a Quad Core ARM Cortex- A57 which is 1.43 GHz powerful 64 bit quad core processor, and 128 CUDA core GPU. As for operating systems, it can run Ubuntu and other Linux operating systems. The operating system provided by NVIDIA for the Jetson Nano is adapted from Ubuntu.

On the other hand, Raspberry Pi 4 model B 4G is a SBC developed in the United Kingdom by the Raspberry Pi Foundation, with the aim of promoting computer education in schools. It uses a quad-core Arm Cortex-A53 which uses 1.5 GHz 64 bit quad core processor. The software is open source, with its Raspbian operating system, a version adapted from Debian for this type of SBC.

Results and Discussion

In this section, the methodology and the system architecture were evaluated through several experiments.

Collision Detection

In order to evaluate the collision detection several experiments were carried out varying the distance among the system and a person located in the scene. When the test begins the person starts moving from right to the center of scene and return to the original place. Figure 3 shows the distance to the person while is moving. Both Nvidia Jetson Nano and Raspberry Pi 4 have been used as SBC. Both platforms achieves similar results, nevertheless fewer point clouds are processed using the Raspberry PI because it has less computational power. Therefore, Nvidia Jetson Nano is better for real-time applications. On the other hand, in order to evaluate the accuracy of the system, a object was located to 1, 1.2, 1,5, 1,7 and 2.0 meters from ToF camera. For each position 100 point clouds were processed. Table 1 shows the average results obtained by the system. As can be seen, the system has a millimeters accuracy.

Table 1. Real distance vs estimated distance to object.

Real distance (m)	Averaged estimated distance (m)
1.00	1.002 ± 0.005
1.20	1.203 ± 0.005
1.50	1.505 ± 0.005
1.70	1.703 ± 0.005
2	2.004 ± 0.005

3D Scene Representation

This section will show a scene consisting of a bed with an electric guitar on the left and a Spanish guitar on the right. It is important to note that the electric guitar is somewhat more advanced than the Spanish one. The aim of this algorithm is to recreate this scene in detail by means of a point cloud using PointCloud Library. It should be noted that with the data collected through a single frame is possible to change and rotate the perspective of the point cloud. Figure 4 and 5 show the real scene taken from ToF camera, and its representation from the point cloud. As can be seen, the perspective of the generated point cloud has been rotated to appreciate the scene from another perspective, and thus differentiate the distance between both guitars. It is worth noting that the cavity of the Spanish guitar's soundboard can also be observed.

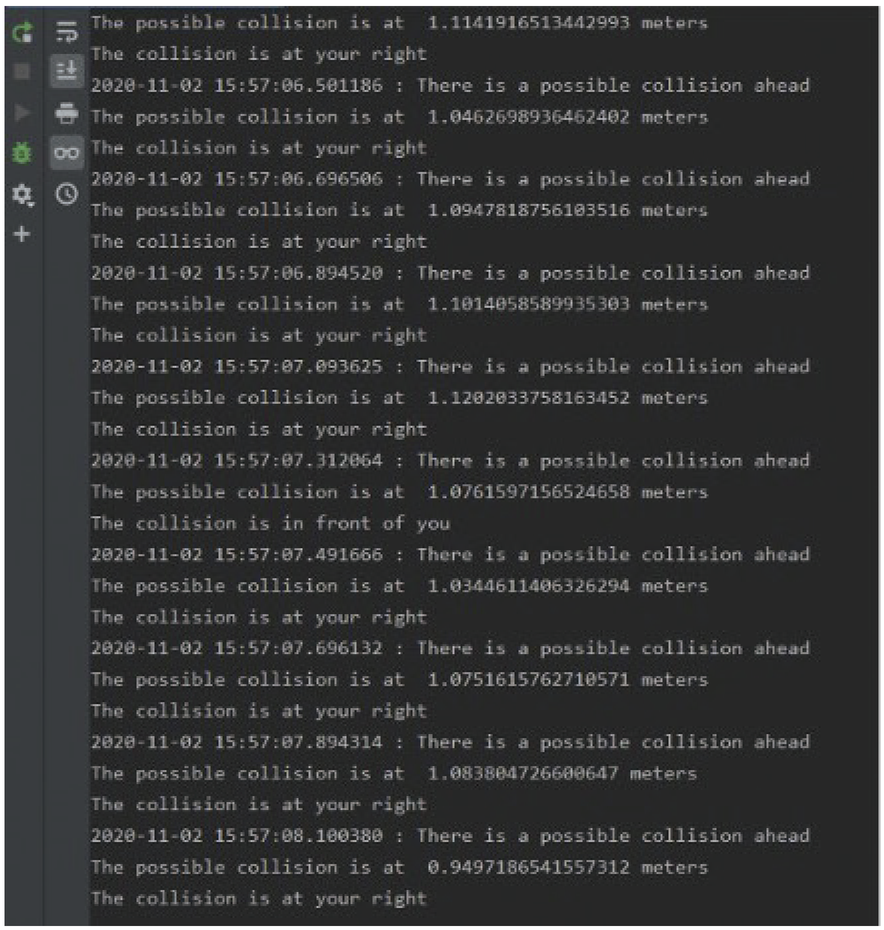

Figure 3. Obstacle detection in real-time.

Conclusion and Future Work

In this paper a methodology based on a ToF camera and a SBC is proposed to announce or alert about possible collisions in indoor environments. The approach provides a high accuracy, and besides a 3D representation of the scene can be generated from a point cloud. Therefore, it could be added to a wheelchair to provide assistance to people with functional diversity in indoor environments. Moreover, two low cost SBC were evaluated delivering better results the Nvidia Jetson Nano due to its high processing speed and better components.

In our ongoing work, we are planning to generate a map of the environment from several point clouds using the IndoorGML standard. In addition, OpenCV library can be used for the identification of both people and objects, and therefore a better feedback about obstacle is notified to the user.

Figure 4. Real scene.

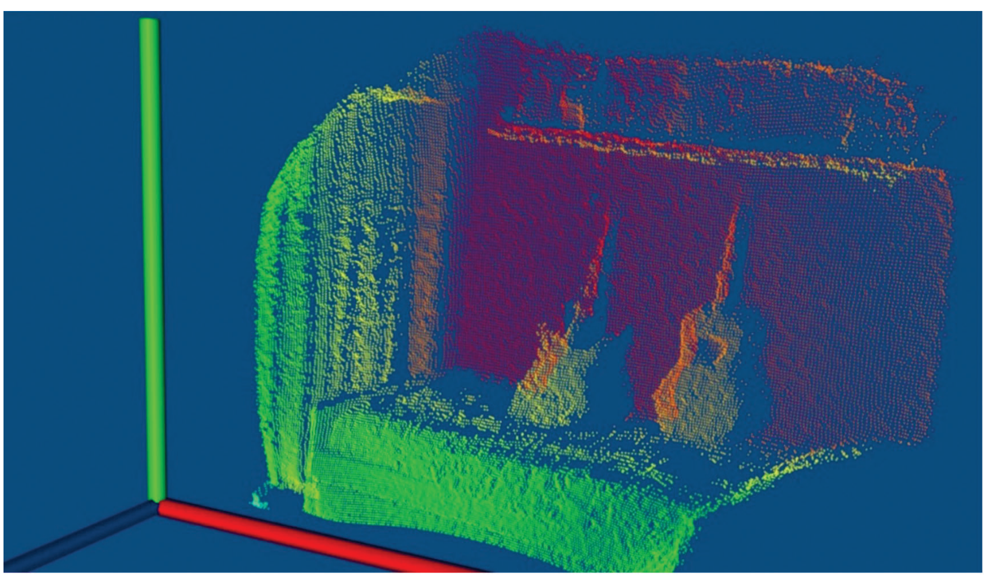

Figure 5. Scene recreation from a point cloud.

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