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Short Range Capacitive Proximity Sensing

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***Abstract*— In this paper we investigate a short range capacitive proximity sensor as complementary sensor system in situations, where conventional optical based sensor systems have short comings, e.g., due to space requirements. In the presented collision avoidance scenario it can be used even without any vision or Lidar based sensor system. Our sensor is capable of detecting humans and objects made of conductive and non-conductive materials in short range surrounding of the robot. The sensing range can be tailored according to the needs of the application and robot. The sensor front end of the capacitive proximity sensor provides full flexibility to be attached on rounded surfaces. Due to the sensing principle it can even be mounted underneath the surface. In addition, the presented capacitive proximity sensor is fully supported by the Robot Operating System (ROS) to be utilized on a broad variety of robot platforms.**

I. INTRODUCTION

Capacitive sensing is well studied as an alternative to conventional optical based distance measurement systems opening new possibilities for sensing in the field of robotics and enhancing the safety in human robot interaction. The field of application comprises pretouch sensing for grasping and object manipulation [1], [2] or proximity sensing for a collision avoidance system for measurement ranges up to $100\,\mathrm{mm}$ with a high response rate up to $1\,\mathrm{kHz}$ [3]. Furthermore, safety applications including a sensor fusion of ultrasonic and capacitive sensors have shown promising performance in automotive applications, where the capacitive sensor closes the gap of the blind spot of ultrasonic sensors [4]. This is especially of interest for autonomous and self driving cars. Moreover, it can also be used as imaging technique, where an image of the surrounding of the sensor front end is obtained and information, e.g., position, about objects can be extracted [5].

The sensing principle is based on the interaction of the object and the electric field, where an object causes a deviation which can be measured and the distance between the approaching object and sensor can be estimated. The obtained measurement rate of the proximity sensor in the presented setup is higher in comparison to state-of-the-art Lidar based sensors, e.g., Sick LMS100 [6] or LMS500 [7].

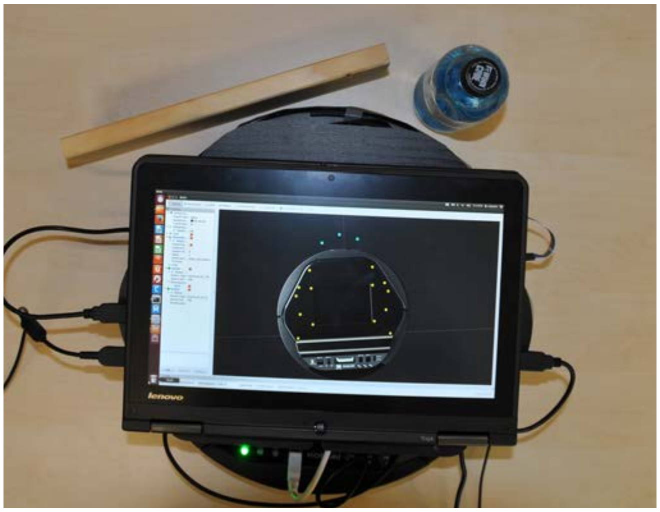

Fig. 1. In this demonstration the capacitive proximity sensor is attached on the surface of the front side of the robot to measure the distance to approaching objects. It extends the capability of the robot to detect objects without the need of any vision or Lidar based sensor system.

II. SYSTEM DESCRIPTION

A. SENSING THEORY

The sensing principle is based on the measurement of the capacitance between two electrodes also known as the differential measurement method. In this case an AC excitation signal, e.g., sinusoidal $250\,\mathrm{kHz}$ signal, is applied onto an electrode generating an electric field. An approaching object interacts with the electric field, changing the capacitance between the transmitter and receiver electrode which is measured on the receiver side. The measurement principle is shown in Figure 2.

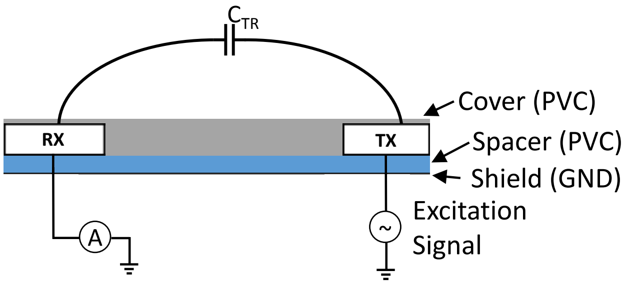

Fig. 2. Differential measurement method comprising the transmitter (TX), receiver (RX) electrode, a spacer and a shield layer on the back side.

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III. SOFTWARE ARCHITECTURE

Our implemented ROS software interface for capacitive sensors collects the raw measurement readings of all connected sensors [8]. Specific sensor information is provided in a parameter file. The raw measurement data is pre processed using reconstruction and object detection algorithms to determine the position of objects in front of the sensor. The position data is published as ROS message ”MSG Reconstruction/Detection” for high level applications and ”MSG Visualization” for visualization of the position in RVIZ.

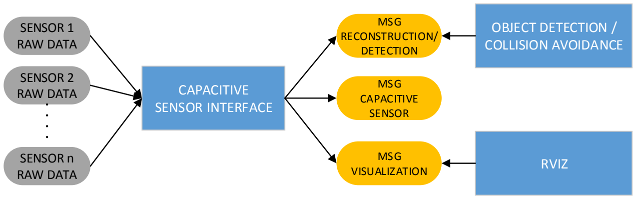


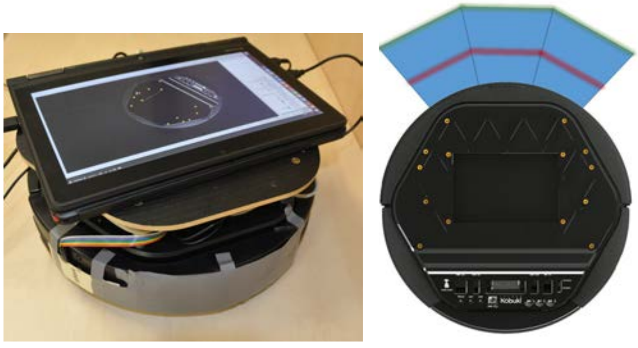
Fig. 3. The architecture of the capacitive sensor interface supports multiple capacitive sensor node readings, processing the measurement data and publishing the detection data (distance between object and sensor front end) for the collision avoidance application. In addition, it also provides the visualization data for ROS 3D visualization tool RVIZ.

IV. SENSOR AND ROBOT PLATFORM

The capacitive sensor platform is based on a flex print with a commercially available Capacitance to Digital Converter (CDC), where electrodes manufactured using a precision ink-jet printer are connected as shown in Figure 4. Utilizing ink-jet printing enables to further minimize the thickness of the electrodes down to $600\,\mathrm{nm}$ (one layer) further increasing the flexibility. Due to the flexibility the sensor can be easily bended on rounded surfaces while being wear resistant and mechanically robust. A polyimide foil is used as substrate, where each layer of the electrodes is printed onto it using a silver ink with a metal loading of $35\,\%$. The electrodes are assembled utilizing four sandwiched layers: a conductive layer at the bottom used as shield, an isolation layer, an electrode layer and an isolation layer at the top. The design of the electrodes can be optimized using Finite Element Model (FEM) simulation according to the needs of a certain application. The sensor can be operated wired or fully wireless using the energy harvesting module and the RF link to transmit the measurement data of the sensor according to the needs of the application.

Fig. 4. Capacitive proximity sensor $270\,\mathrm{mm}\ x\ 60\,\mathrm{mm}$ in size, where the gray area is the isolation layer of the electrodes.

For the experimental setup the ROS and Gazebo simulation supported mobile robot platform Kobuki is utilized. Kobuki is a mobile research platform providing several actuators, e.g., differential drive, and sensors, e.g., odometry and gyroscope, where self developed sensors and applications can be easily integrated on top of the platform. Our capacitive proximity sensor (see Figure 4) is mounted on the front side of Kobuki as shown in Figure 5(a).



(a) (b)

Fig. 5. (a) Capacitive proximity sensor mounted on the front side of Kobuki. (b) Sensing range of the capacitive sensor is split up into three areas, where objects can be detected (blue). The green line depicts the maximum sensing range and the red line depicts the predefined threshold distance.

V. EXPERIMENTAL SETUP AND RESULTS

As experimental setup we implemented a collision avoidance for humans, conductive and non-conductive objects utilizing one capacitive proximity sensor. The robot moves forward as long as the measured distance to the object is above a predefined threshold distance. The minimum distance to avoid a collision is $40\,\mathrm{mm}$. Therefore, the threshold distance is set to $d_{th} = 40\,\mathrm{mm}$, which is lower than the sensing range up to $d_r = 100\,\mathrm{mm}$. Within this area the range resolution is $1\,\mathrm{mm}$. In the configuration we use three areas where objects made of conductive and non-conductive materials and humans can be detected. The behavior is comparable to, e.g., ultrasonic sensors of cars where the areas in front and rear of the car are split up into subareas where objects are detected. The obtained sensing areas are shown in Fig 5(b). Once the distance is below the threshold distance the robot makes a 90 degree left turn and will move forward again as long as the threshold distance is not violated to demonstrate the performance of the sensor. The current distances to the objects are shown as markers in RVIZ. The blue dots in Figure 1 depict the distances between the objects (piece of wood and water bottle) and the robot. The obtained measurement rate of the proximity sensor is $f_m = 108\,\mathrm{Hz}$. The detection results in Fig. 4 in combination with the obtained measurement rate show that short range capacitive proximity sensing can be used for collision avoidance in situations where other sensing technologies can not be used, e.g., due to space requirements or no direct line of sight.

VI. CONCLUSIONS

In this work we present a novel short range capacitive proximity sensor to detect objects made of conductive, non-conductive materials and humans. The sensor is fully supported by ROS and comes with a higher measurement rate than state-of-the-art Lidar based sensor systems. The size and flexibility of the sensor is sufficiently high to bend the sensor on rounded surfaces. The experimental results of the collision avoidance show the feasibility of the approach utilizing capacitive proximity sensing for short ranges up to $100\,\mathrm{mm}$.

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