Additive Manufactured Capacitive Sensor for Slip Detection with Seamless Integration of Object Recognition and Differentiation in Robot Grippers

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Abstract

In this contribution, we present a novel additive manufactured capacitive sensor for slip detection with seamless integration of object recognition and differentiation in robot grippers. The sensor consists of a measuring electrode in combination with guarding and shielding electrodes to reduce edge effects and disruptive influences. The results show precise slip detection through linear sensor behavior. In addition, object detection and differentiation are possible.

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Additive Manufactured Capacitive Sensor for Slip Detection with Seamless Integration of Object Recognition and Differentiation in Robot Grippers

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Summary: In this contribution, we present a novel additive manufactured capacitive sensor for slip detection with seamless integration of object recognition and differentiation in robot grippers. The sensor consists of a measuring electrode in combination with guarding and shielding electrodes to reduce edge effects and disruptive influences. The results show precise slip detection through linear sensor behavior. In addition, object detection and differentiation are possible.

Keywords: Robotic, capacitive sensor, slip detection, object recognition and differentiation, additive manufacturing

Introduction

Safety in robotics is one of the central issues in shop floor scenarios with automated processes. The interaction between robots and humans must be safe [1]. This means safe gripping of the appropriate object and safe limitation of the gripping force [2]. In addition, the handling of sensitive and fragile components is essential. The components must be gripped without damage and prevented from slipping [3]. The combination of force and slip is usually determined tactilely by the coefficient of friction or by the deformation of the gripping surface [4]. Neither of these methods offers the possibility to detect and distinguish between objects. Therefore, this contribution presents a novel capacitive sensor for slip detection with additional object recognition and differentiation. The force measurement is performed separately as, for example, described in Hangst et al. [5].

Working Principle

In a configuration with two parallel gripper jaws in robotic grippers, as shown in Hangst et al. [5], the principle of a parallel plate capacitor is suitable as a sensor. The challenge of capacitive sensors in gripper technology is the individual freedom of movement and the associated unpredictable, disruptive influences. In addition, precise slip detection requires a homogeneous measuring field without edge effects. Fig. 1a shows the real world. The influences and edge effects can be reduced by applying guarding and shielding electrodes [6]. This results in an approximately idealized scenario according to Fig. 1b. The model can be described by

$$C = \varepsilon_0 \, \varepsilon_r \, \frac{A}{d}. \tag{1}$$

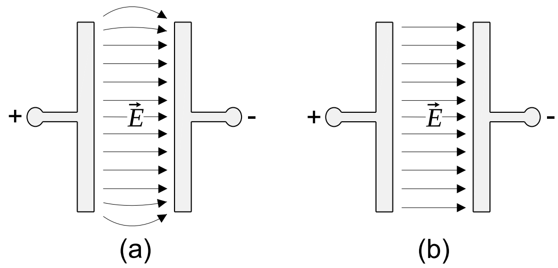

Fig. 1: Schematic representation of the electric field of a capacitive sensor. a) inhomogeneous electric field, b) homogeneous electric field.

ε_0 is the dielectric constant of vacuum, ε_r is the relative dielectric constant of the dielectric, d is the distance between the electrodes, and A is the sensor plate's area.

Sensor Design

The capacitive sensor designed by Hangst et al. [6] was utilized as the basis. The modification consists of a 1 mm thick insulating layer in the measurement area of both plates (see Fig. 2). This allows the additional possibility of gripping conductive parts. The sensor is utterly 3D printed except for the leads.

Experimental Setup

The experimental setup encompasses a capacitive sensor, an evaluation board, a PC, and an actuator. Slip detection validation was performed by pulling a 5 mm thick rectangular plastic component with uniform dimensions as the sensor out of the capacitor plates in 1 mm increments via an actuator. Capacitance measurement was performed with an EVAL-AD7747 Ca-

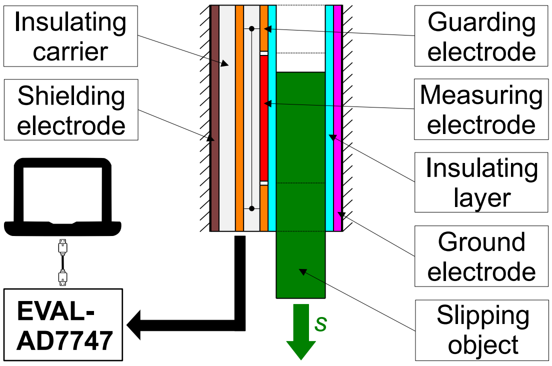

Fig. 2: Schematic experimental setup.

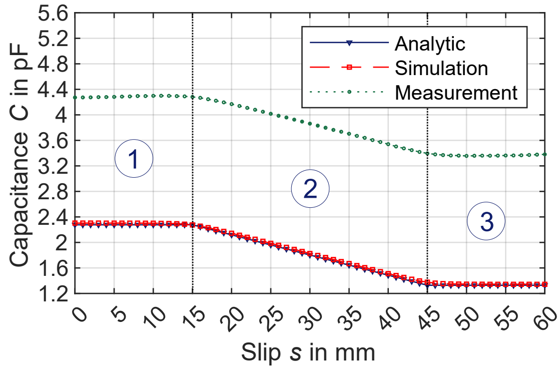

Fig. 3: Results of the analytical approach, simulation and measurement for the slip.

pacitance Digital Converter (CDC) with an accuracy of $\pm$ 10 fF and a linearity of $\pm$ 0.01 %. The CDC has a connection for an active shielding. The shield is connected to the guarding electrodes. For a statistically significant result, 100 measurements were taken, and the mean was calculated. The Data were analyzed in MATLAB. The schematic experimental setup for slip detection is shown in Fig. 2.

Results and Discussion

Fig. 3 shows the theoretical and experimental results of the sensor behavior. The analytical approach for the measuring electrode was calculated according to

$$C(s) = \frac{1}{\frac{1}{C_i} + \frac{1}{C_a + C_o}}. \quad (2)$$

C_i is the capacitance of the insulating layer, C_a is the capacitance of the air volume, and C_o is the capacitance of the object. The simulation was carried out via COMSOL 6.2. The previously unknown relative dielectric constant of the component was obtained from the measurements. The value determined was 2.0, which is close to the values found in the literature for plastics. The sensor shows a linear behavior in the measurement area (Fig. 3, region 2). Certain deviations can be seen at the edges. The capacitance is almost constant in the area of the guarding electrodes (Fig. 3, region 1 and 2). There is an offset between analytic / simulation and measurement that can be ascribed to the parasitic capacitance of the connecting wires.

The advantage of the sensor is the possibility of additional object recognition and differentiation. This can be applied to handling other sections after determining a reference value for the capacitance in the gripped state of a component. A comparison with the reference value indicates whether or not the correct object has been gripped. The limitations of the sensor are due to the fact that the slip is detected after the displacement, not when the displacement occurs. A change in the component's material properties or geometry must also appear in the measurement field. The ideal solution is a stepped edge. In the case of homogeneous components, no slip can be detected in the measurement field.

Conclusion

In this contribution, we presented an additive manufactured capacitive sensor for slip detection with additional object recognition and differentiation. Despite the low dielectric constant of plastics in the range of 2, slip detection was possible. The capacitance measurement is linear and independent of external influences using additional guarding and shielding electrodes. The position of the subsequent gripper in space is irrelevant. An advantage of this sensor is the supplementary possibility of object detection and differentiation based on capacitance.

References

[1] A. Narendiran, B. George, Capacitive tactile sensor with slip detection capabilities for robotic applications, *IEEE Int. Instrum. & Meas. Tech. Conf. (I2MTC)*, Pisa, Italy, 464-469, (2015); doi: 10.1109/I2MTC.2015.7151312

[2] S. Blankemeyer, T. Recker, A, Raatz, Hardwareseitige MRK-Gestaltung, *Handbuch Mensch-Roboter-Kollaboration*, Hanser, Munich, 37-70, (2019); doi: 10.3139/9783446453760.002

[3] J. Yu, S. Yao, X. Li, A. Ghaffar, Z. Yao, Design of a 3-D Tactile Sensing Array for Incipient Slip Detection in Robotic Dexterous Manipulation, *IEEE Trans. Instrum. Meas.*, vol. 73, 1-14, (2024); doi: 10.1109/TIM.2024.3436064

[4] R. A. Romeo, L. Zollo, Methods and Sensors for Slip Detection in Robotics: A Survey, *IEEE Access*, vol. 8, 73027-73050, (2020); doi: 10.1109/ACCESS.2020.2987849

[5] N. Hangst, S. Junk, T. Wendt, Method for Producing a Robotic Element, in Particular a Gripper, by Means of 3D Printing, *US 11,491,717 B2*, (2020)

[6] N. Hangst et al., Design of a Grounded Low-Cost Capacitive Liquid Level Sensor for Robotics Applications, especially in the Field of Gastronomy, *ITG-Fachbericht*, vol. 303, Berlin, Offenbach, 85-89, (2022); ISBN: 978-3-8007-5835-7