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Arm movement following robots using rotary sensorsleeve

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Abstract— Different types of robots help to fulfill simple work on their own like simple pick-and-place, handling and mounting tasks over long-lasting periods with no loss of accuracy and speed. However, regarding to products produced in small numbers the programming of those robots can be very time-consuming and workers have to be trained in programming the movements and tasks. Also, in the medical field where robots can be used for assistance during surgery or cancer treatment in future the surgeon or doctor has to respond to each patient individually. To train those medical specialists in programming robots would be very extensive. Therefore, the development of an intuitive robot control can help to facilitate tasks done by non-specialized workers or surgeons. Furthermore, suggestions of different future applications based on dielectric elastomer sensors for example as artificial skin of prostheses are discussed. In this contribution a concept of an intuitive control of robots via gesture control is shown. For the perception of gestures the different degrees of freedom of the worker's arm are detected by the use of a wearable sensor system based on dielectric elastomer sensors, which are generally lightweight and flexible. This paper describes the whole system consisting of an arm sleeve with attached stretch sensors, an analysis circuit board, the used software for communication and data processing as well as the controlling of the robot and the robot itself. Experiments show promising results, which are also specified in this paper.

I. INTRODUCTION

Human-robot interaction is an emerging topic in the industrial as well as in the medical sector. Until now simple handling, pick-and-place or assembly tasks can be executed by robots over a long period of time without exhaustion or loss of accuracy and dexterity. Therefore, autonomous solutions are suitable for frequently repeated tasks, since then the robots have to be programmed only once. However, due to the trend of individualization more flexibility is required regarding fast modifications in the working process. For this purpose the human worker, who can respond immediately to sudden occurring problems or changes, can not completely be replaced by any robot so far. In so-called hybrid manufacturing robots are supposed to support the worker in the industrial sector by taking over particular aspects of his work like handling, holding or mounting the products, while the worker is responsible for more demanding tasks.

Also, in the medical sector the replacing of a doctor or surgeon is not contemplated in near future due to the sameThe term gesture recognition is therefore defined as the process of identifying the user's intention by analyzing his (or her) movements and delivering them to the receiver via a technical interface. A distinction can be drawn between static gestures, better known as a pose or configuration, and dynamic gestures reasons. Robots, though, could for example support the doctor or surgeon by handling the patients during a radiotherapy session or manipulating endoscopes in an endoscopic surgery for more precise cuts.

To enable a direct human-robot interaction and furthermore a collaboration the surgeon or the human worker should be able to control and program the robot without being a trained specialist. Therefore, simply programmable and easily accessible interfaces for intuitive control of robots are necessary during work, which should not interrupt the work process.

Conventional user interfaces for robot control e.g. tablets or keyboards require a tactile interaction with the device. This is not an optimal solution especially for dirty and dusty workplaces, where the information on the display would not be visible after some time or for workplaces with high hygiene requirements such as operating rooms. To avoid direct contact with a control element, gesture recognition and gesture control could depict a suitable and intuitive method for the control of e.g. robots.

In this contribution an attempt of a multiple degrees of freedom gesture control based on dielectric elastomer sensors (DES) is shown. At first appropriate definitions regarding gesture recognition and control and the state of the art of gesture controlling are depicted. After that the technology of dielectric elastomer sensors, the system structure as well as the details on the used components for a demonstration device are introduced. First experiments are described and the results are displayed and discussed. Finally, a conclusion of this work and a brief discussion on the application potentials and the future works complete this contribution.

II. DEFINITIONS AND STATE OF THE ART

In the presented context the term gesture can be defined as a movement which is well-defined [1] and characterized by meaningful information [2], contrary to unintentional movements which do not contain any information for the observer nor for the receiver [3].

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intended movements of the user. However, the receiver

Several current research projects focus on gesture recognition based on visual monitoring of the user’s movement, e.g. with an optical camera [4]. An advantage of this kind of observation is that the user does not have to wear equipment, e.g. cables which can constrain the movements. However, the occlusion of body parts and their movements due to hindrance of line-of-sight by obstacles, external objects and visual barriers is one drawback [2]. Thus, for gesture control in rooms with movable obstacles, e.g. in an operating room, direct gesture recognition via wearable sensors are a promising solution.

For the direct recording of the user’s movement different methodologies have been investigated. E.g. the so-called BioSleeve uses 16 surface electromyography (EMG) sensors to monitor the activity of the user’s forearm muscles [5]. Furthermore, an inertial measurement unit (IMU) of a 3-axis-gyroscope, a 3-axis-accelerometer and a 3-axis-magnetometer can identify the motion and position of the user’s arm. This approach is also able to recognize movements of the fingers since the muscles and tendons responsible for the finger movements are located in the forearm.

The commercially available MYO armband (Thalmic Labs Inc., Ontario, Canada) shows a similar system concept with eight EMG sensors and one IMU. This armband finds its application in various projects, e.g. as an instrument for playing music by motion expression called MuMYO [6] as well as control of an unmanned ground vehicle [7].

Despite the good understanding of measuring muscle activities in combination with arm movements for gesture control, in this paper another technique of direct gesture recognition is presented. This approach is based on capacitance change of dielectric elastomer sensors which are attached to an arm sleeve and hence are independent on muscles currents.

First examples of possible applications regarding movement analysis with dielectric elastomer stretch sensors are the training observation of a golfer, where the elbow’s angle is measured by one single stretch DES [8] and the StretchSense Bluetooth ’finger net’ system of five DES for recognition of finger movements [9], where the captured data is visualized in an visualization app over a wireless Bluetooth connection.

III. SYSTEM SETUP

The presented setup can be subdivided into four components: A) the sensor sleeve with attached dielectric elastomer sensors, B) the analysis circuit with interface to C) the data processing within the software tools MATLAB and ROS (Robot Operating System) and finally D) the robotic system.

A. Arm sleeve with dielectric elastomer sensors

The wearable sensor system consists of an arm sleeve and multiple dielectric elastomer sensors (DanfossPolypower A/S, Denmark) of different lengths attached to it. These sensors can be stretched up to 180 % of its original length without risking damage. The capacity of these sensors approximately ranges from 1 nF to 4 nF, however the exact capacity range depends on the original length of the sensor, small (50 mm), middle (100 mm) and large (200 mm). The developed system consisting of the arm sleeve and the mentioned stretch sensors is shown in Fig. 1.

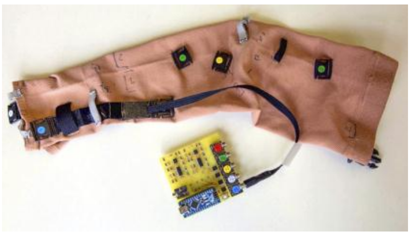

Fig. 1. Sensor sleeve with one attached dielectric elastomer sensor and the sensing circuit as interface to the data processing software.

In order to measure multiple degrees of freedom (DOF) the DES are attached without overlapping each other and are positioned distinct enough to detect only one joint motion.

Dielectric elastomer sensors are based on change of capacity due to mechanical deformation and have several advantageous properties like a lightweight structure, low cost materials, flexibility and a lot of application capabilities [10]. The functional principle of the presented stretch sensors based on DES is sketched in Fig. 2.

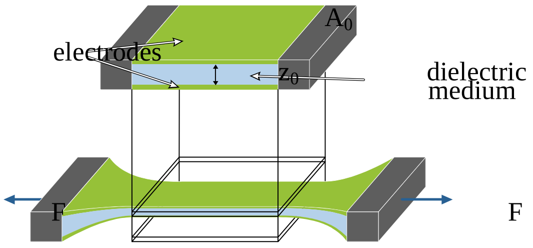

Fig. 2. Principle of a dielectric elastomer stretch sensor.

The structure of this sensor is comparable to a simple plate capacitor with flexible electrodes and an almost incompressible dielectric medium. The capacity C_0 of the undeformedsensor can be calculated with

$$C_0 = \varepsilon_0 \varepsilon_r \frac{A_0}{z_0} , \tag{1}$$

where ε_0 is the permittivity of free space, ε_r is the relative permittivity of the dielectric medium, A_0 is the initial area of the electrodes and z_0 is the initial thickness of the dielectric medium. Since the dielectric medium of dielectric elastomer actuators and sensors is assumed as incompressible its volume remains constant by default [11]. The capacity is then changing to

$$C_1 = \varepsilon_0 \varepsilon_r \frac{A_0 + \Delta A}{z_0 - \Delta z} , \tag{2}$$

where ΔA is the change of area and Δz is the height reduction of the dielectric medium. Since the change in thickness is insignificant compared to the change of area, it is assumed that the capacitance changes linearly with the expansion, thus the measured angle of the joint can be interpolated after calibration of the start and end position by the user. The measured linearity of the stretch sensors are shown in Fig. 3, where small and middle length sensors are tested. The graph shows the capacitance over the longitudinal stretch of the sensors. It can be seen that the sensors of same length also have a quite similar capacitance. The mean relative linearity error as well as its standard deviation is less than 1%. Also, for new sensors no hysteresis effects are detected. However, aging of the sensors lead to creeping effects and slow capacity responses.

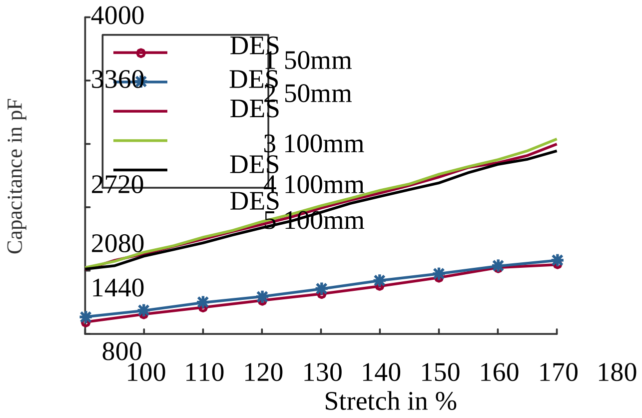

Fig. 3. Stretching the DES results in a linear dependency of the capacity to the deformation with a mean relative linearity error and its standard deviation of less than 1%.

B. Hard- to software interfaces

A first development of the interface between sensing circuit and the data processing software is already shown in Fig. 1. This interface mainly contains of a sensing circuit and an Arduino Nano 3.1 microcontroller board, which is able to communicate with a personal computer. A ROS node reads the data for further evaluation. The interface can process data of at most five sensors. Since the sensing circuit is not specified on one sensor size and is able to survey a wider range of capacitances, the sensors do not have to be of the same original length and can be chosen arbitrarily.

C. Software

In this setup the open source software framework ROS is used. Generally, this meta operating system offers a framework with a simple communication method between different hardware as well as software components. Simplified, this method is based on the interaction between nodes via publication and subscription of so-called topics. Since the input and output of nodes normally are consistently programmed, different hardware components e.g. 6-axis-robots from different manufacturers can be exchanged without new programming of the whole system. [12]

In Fig. 4 the nodes within the presented system are depicted as well as the topics for the communication between publishers and subscribers.

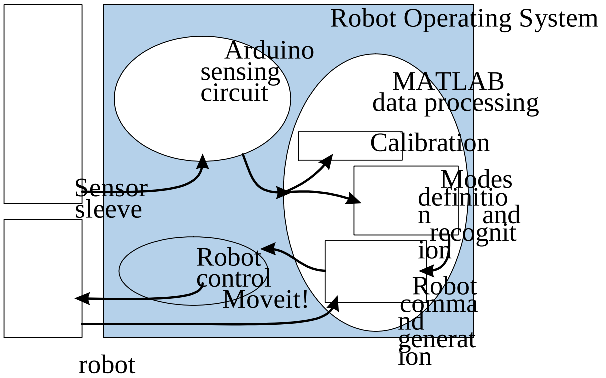

Fig. 4. Within the Robot Operating System, nodes are communicating via topics by publishing and subscribing. Hardware-abstracting nodes allow for including devices such as sensors and actuators.

As shown in Fig. 4 the software MATLAB (MathWorks Inc., Massachusetts, USA) is used for the data processing. A node subscribes the raw data of the sensing circuit published by the Arduino. The data is then processed to detect the joint angles or rotation of the arm. Due to the flexible structure of the arm sleeve, the size and positioning of the arm sleeve however varies slightly every time the sleeve is put on. Therefore, to get meaningful conclusions about the configuration of the arm, a calibration process is necessary before each use, which is realized within a MATLAB function.

After calibration, the capacity values are interpolated to get the angles respectively positions of different DOF and the gesture recognition will be enabled. Once the sensor interface is established a suitable robot request is published. With the help of a path planner RRTConnect within Moveit! arobot path is generated and transferred to the robot controller. For the control of the robot's movement different modes are realized, which are presented later in section IV.

D. Robotic system

In the presented setup a (Universal Robots, Denmark) is used. Since the robot fulfills the safety standards EN ISO 13849:2008 PL 'd' and EN ISO 10218-1:2011, Clause 5.4.3 [13], the can be used for collaboration operations with a human worker. For direct human-robot collaboration, however, the whole system containing the robot and e.g. mounted tools has to be considered for safety evaluation.

IV. IMPLEMENTATION AND EXPERIMENTS

In this section the implementation of the developed system and the procedure of first experiments are described, which show the functionality of the system.

A. Recognizable gestures

To demonstrate the possibilities and functionality of the system the recognition of gestures with three degrees of freedom of the arm is shown. The chosen D determined for all angles to be zero. For the registration of the wrist's palmar-dorsal flection two sensors are used, where one sensor is attached on the palm of the hand and the other sensor is attached on the back of the hand. The reason for this kind of setup is that during the basis configuration the sensors should not be strained yet, otherwise the full amplitude could damage the sensors. With the setup of two sensors measurements of angles between -90° to 90° are possible without the risk of sensor destruction.

To register the elbow flection only one sensor over the elbow is sufficient, because the elbow typically can move around one axis between 0° and approximately 120°.

The torsion of the lower arm is sensed by one sensor which lies diagonal across the lower arm with the ends attached to the wrist's inner side and the elbow.

In the presented experiments different poses are defined, which compose a gesture when executing sequentially. One gesture e.g. is bending the outstretched arm and also folding down the wrist. Another simple gesture could be folding up and down the wrist a few times. The more DOF are observed the more gestures can be predefined.

B. Data processing

Within the software tool MATLAB different functions are developed to perform the data processing of the measured values sent from the sensing circuit. The developed functions are responsible for the calibration process, the pose respectively gesture recognition, the selection of the correct control mode and the generation of a pose vector, which is then sent to a ROS control node for the calculation of the joint angles. Via the ROS tool Moveit! the robot is connected to the system and the controlling of the robot is carried out.

Calibration: The calibration process of the sensors launches automatically after starting the main program. The outstretched arm and hand is set as basic configuration. During the calibration different arm positions are demanded by the process, where the neutral as well as the maximum feasible position of each arm joint are registered. For each position the average of the measured values over three seconds is calculated. Later on, these values are used to scale the measured values and interpolate intermediate positions. Due to the linearity of the sensors as shown in Fig. 3 this calibration procedure is valid. With this scaling the measured values are decoupled from the length of the sensors, which makes an exchange of sensors with different capacities possible. This could be valuable for experiments for finding the sensors' optimal positions and lengths.

Gesture recognition: Since the DES are very sensitive it is important to distinguish between intended and unintended movements. The movement is recognized as intended when the sensor value exceeds a threshold value of the sensor, thus the noise of the sensors can be suppressed successfully.

Within the MATLAB functions a table of possible arm configurations is stored, which also contains the previous described gestures. By comparing the actual values of the sensors with this table the actual poses or gestures are identified.

Afterward, a vector is generated which contains information about the aimed angle positions of the robot and the resulting velocity of the movement. This node also receives the actual joint states and positions of the robot (see also Fig. 4). The information of start and end value of the angles is then received by Moveit!, which executes a path planning for the required movement using all required data and sends the command to the robot, which carries out the received movement commands.

C. Modes and experiments

In the experiment different control modes are developed to show the variety of possibilities to control a robot by gesture or pose recognition. Therefore, to change the mode during experiments an unique initial gesture is implemented, which is not mistakable as well as applicable in each mode.

The modes are classified in two classes, an imitation class and a control class. An overview of the modes is given in Table I.

TABLE I

CLASSIFICATION OF THE IMPLEMENTED CONTROL MODES

Class	Mode	Description
Imitation	Pose mode	Robot imitates the user's arm configuration
Control	Single joint mode	Angle of each joint can be in- and decreased separately
Control	Single coordinate mode	x-, y- and z-coordinate of the Tool-Center-Point can be controlled
Control	Velocity mode	Velocity of gesture defines the velocity of the robot's movement

The test setup is depicted in Fig. 5 where the robot and a user with the sensor sleeve are shown. The sensing circuit is also attached to the arm sleeve and is connected to the computer via USB. The connection to the robot is established via local area network.

The experiments are focused on the proof of principle and the functionality of the whole system. The systemshows the possibility of recognizing more than one degree of freedom with commercial available dielectric elastomer sensors. Furthermore, the analysis of multiple low capacity sensors as well as the communication and the robot control via ROS are considered.

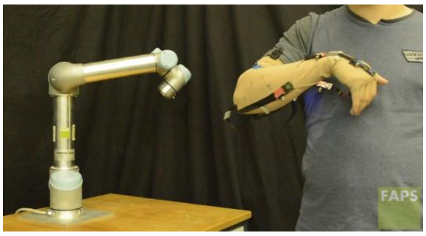

Fig. 5. Test setup with the Universal Robot (left) and the user with the presented sensor sleeve (right).

The rough movements, especially in the control class, base on the used CB1 control box of the. The use of important commands is not supported in ROS, so that a start and end point is necessary to calculate the path of the robot's movement. Considerably improvements and smoother movements of the robot are expected with one of the next versions of the control box. Also other robot systems, e.g. the Robotino, can be controlled with the presented sensor arm sleeve using gesture recognition with ROS providing a framework, where nodes can be exchanged easily.

VII. CONCLUSION

In this contribution a wearable sensor arm sleeve based on dielectric elastomer sensors for an intuitive gesture control of robots is introduced. At first the definitions of gesture control and the basics of dielectric elastomer sensors as well as the setup of the sensor sleeve are described in detail, which contains the four parts of the setup: the sensor sleeve, the sensing circuit as hard- to software interface, the dataprocessing within the software framework ROS (Robot Operating System) and the robot . Furthermore, the recognizable degrees of freedom, the gestures and also the modes, which are used in the experiments are defined. The experiments show the successful implementation and functionality of the presented system for recognizing three degrees of freedom of the user's arm. Further investigations will improve the precision of the system. With the presented technology other future applications are also conceivable like observation of robot arms or as artificial skin of prostheses.

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