Determination of Gripping Forces for Handling Surface-sensitive Objects

Michael Krampe[0000-0003-3996-0255], Michael Miro[0000-0003-2347-7496], Miguel Angel Villanueva Portela[0000-0002-3769-9068] and Bernd Kuhlenkötter[0000-0002-5015-7490]

Lehrstuhl für Produktionssysteme, Ruhr-Universität Bochum,
Universitätsstr. 150, 44801 Bochum, Germany
krampe@lps.rub.de

Abstract. Even for modern robot attached gripping solutions, surface-sensitive object handling remains a challenge. A minimal gripping force is required to grip and handle a surface-sensitive object safely. At the same time, this gripping force should not exceed a certain level to avoid damaging the sensitive surface of the object. Because of this, it is necessary to determine the mostly small range of optimal gripping forces to ensure a safe handling. Therefore, this paper describes an approach to evaluate this range of gripping forces for surface-sensitive objects using by means of chocolate covered marshmallows. For this purpose, a test bench with the same characteristics as a planned gripper is developed. Throughout the project, this planned gripper will be controlled with the help of the detected range of gripping forces. In addition to these static measurements, it is planned, that the gripper will calculate the handling speeds, accomplished by a six-axis industrial robot, with its acceleration forces. The achieved results of this paper will be the starting point for the upcoming measurements with the robot. Furthermore, the influence of the temperature on the range of gripping forces was evaluated, to show the relevance of consistent environmental conditions for the handling of surface-sensitive objects.

Keywords: Gripper, Handling, Force control.

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1 Introduction

In areas like the food industry, robots are often used for heavy load handling, e.g. packaging and palletising. In contrast, the handling of sensitive objects is still a major challenge for industrial robots. Recent articles [1, 2] illustrate the need of a sophisticated control strategy for sensitive object handling in various industries. Furthermore, the acquired sensor data is often used for the handling process alone and not broadcasted towards a MES or CPPS for further process analysis and decision making [3]. Available gripping solutions usually focus on the process of gripping and grasping without taking translational movements during transit into account. Especially sensitive objects are prone to be damaged by dynamic and abrupt changes of acceleration. This can be explained by the corresponding inertia that adds up to the applied static gripping force. As soon as the sum of dynamic and static forces exceeds the object's limits, it is damaged and may no longer be suitable for its designed purpose. In order to provide a suitable solution, the project *Sensitive Robot Based Gripping* (SenRobGrip) aims to develop a cyberphysical gripping system (CPS), which is capable of handling sensitive objects whilst improving the cycle time. To handle surface-sensitive objects, it is required to know the range of optimal gripping forces to handle it safely without damaging it. In some cases, this range can be so small, that even little changes of the environment can affect and lead to a shift of this range. The gripper should include this range of gripping force and the acceleration of the moving robot to optimise the pick-and-place task while transit. The base design of the gripper and the motion planning approach for the robot movements is described by the authors in former publications within the SenRobGrip project [4, 5]. Subsequently, this paper determinates the range of optimal gripping forces using the example of chocolate covered marshmallows and the influence of temperature. These forces are necessary to adjust a later process control with the real gripper. For that, a test bench is developed which covers the same gripping characteristics as the planned cyberphysical gripping system [6].

2 Use Case

The food industry provides many different practical examples for the demand of sensitive object handling. The range of products is varying in consistency, geometry and is often covered by pressure-sensitive surfaces, which break or show signs of maltreatment if not handled correctly. This maltreatment is directly linked to customer satisfaction and may lead to decreasing sales. In order to automate pick-and-place processes for products like these, it is necessary to consider static and dynamic forces within the handling processes. To provide a realistic use case, the developed gripper is designed to be able to handle chocolate covered marshmallows at high velocities and accelerations without damaging the surface. The proposed scenario makes it necessary to develop a handling device for these size variable and extremely fragile products in order to provide a solution for a broader product spectrum. Furthermore, environmental circumstances like temperature and humidity have a distinct influence on the product and therefore have to be monitored throughout the production.

3 Gripper Hardware

The first step is the development of a new and versatile gripper as shown in Figure 1. The design aims to provide high stiffness for an accurate gripping force measurement as well as for being flexible enough to handle various object geometries. The gripper consists of a hollow cylinder to which matching flange adapters for different robot models can be attached. For communication and control purposes, a Raspberry and Arduino are placed inside the cylinder and mounted to a 3D-printed inlay. The finger drivetrains connect to the bottom of the cylinder. To improve stiffness and reduce friction, the fingers are attached to linear motion guides and are propelled by a belt drive.

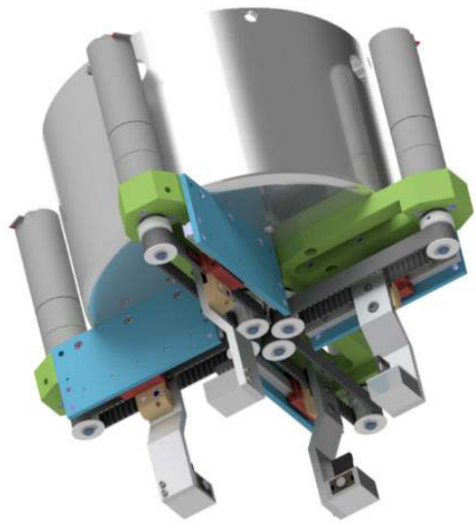

Fig. 1. Gripper hardware design.

Four 24 V DC motors actuate the motion and generate a finger movement speed of up to 0.4 m/s which allows the gripper to close in less than 0.15 seconds.[1] The device is equipped with four exchangeable piezo-resistive force sensors – one in each finger – which provide precise measurements on a scale of 0 to 10 N and an accuracy of up to 0.01 N at 860 samples per second.[2] In addition to this, a 6 degree of freedom (DoF) inertial measurement unit (IMU) MPU-6050 provides the needed information about the robot's movements. Thus, the accuracy of up to 0.598 mm/s^2 for translational motions and 0.0153°/s for rotational movements at 1 kHz allows robot-autarkic control. This enables the manufacturer-independent usage, as no proprietary interface is needed. To monitor environmental influences, a dedicated sensor gathers data on environmental influences like temperature and humidity in order to provide a feedback to the production management system to maintain stable process parameters.

[1] Faulhaber 2250S024BX4 CSD with 1:14 227 gearhead

[2] Honeywell FSG010WNPB with HX711 analog-digital-converters

4 Gripping Force Test Bench

The aim of the gripping force test bench is to simplify the testing using chocolate covered marshmallows and to define the object specific range of gripping force in this example. The general construction is shown in Figure 2. The chocolate covered marshmallow lies on a small podium in the centre of the device and is surrounded by four single grippers. Each of these grippers have its own carriage combined with a rail for the linear movement powered by a servo drive with the help of a belt drive. The gripper jaw is a 30° segment of a circle with a radius of 30 mm and a height of 10 mm made of Polylactide. The podium in the center can be lifted up and down by a seesaw to see if a chocolate covered marshmallow is held safely by the grippers immediately.

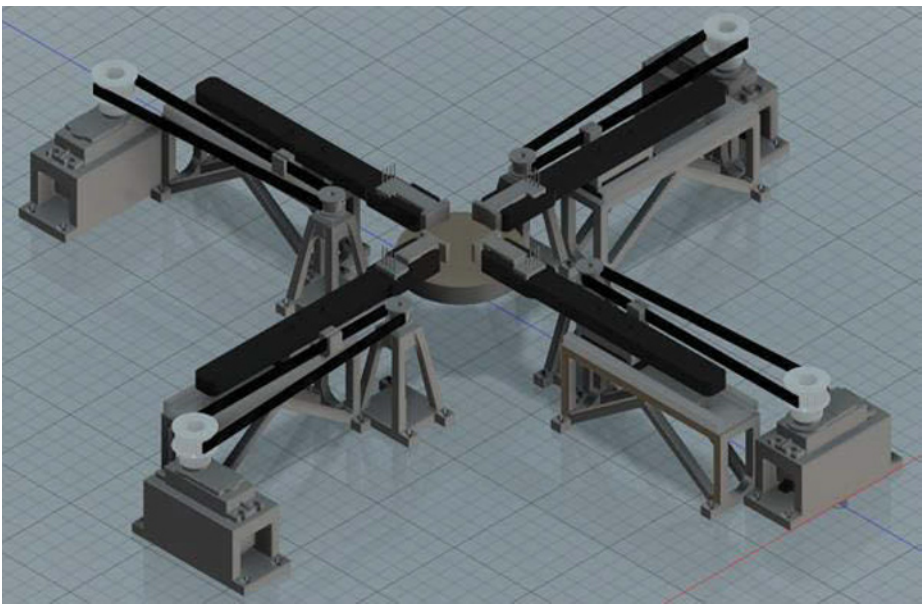

Fig. 2: CAD model of the gripping force test bench

The sensors for force measurement are built into these gripper jaws. To read out the values of the sensors and implement a controller, an analog digital converter is used and connected to an Arduino Due microcontroller by an I2C Bus System.

5 Experimental Design

The main objective of this experiment is to evaluate the range of the gripping force to handle chocolate covered marshmallows without damaging them. This range is limited by the minimal force which is needed to hold the object and the maximum force to hold the object without damaging it. First, the minimal force can be evaluated with the podium and the seesaw in the centre of the test bench. After the gripper is closed around the object, the podium can be lowered to see if the chocolate covered marshmallow stays in position. In a second step, the maximum forces can be evaluated by searching for damages of the sensible chocolate surface. Within the following experiments, the surface damages are divided into five stages. Stage zero represents a not damaged surface and the other four stages describe the level of damaging from a visible light up pressure spot (stage 1), over one crack (stage 2) and many cracks (stage 3) to a complete break of the chocolate (stage 4). These four stages of damage are shown in Figure 3.

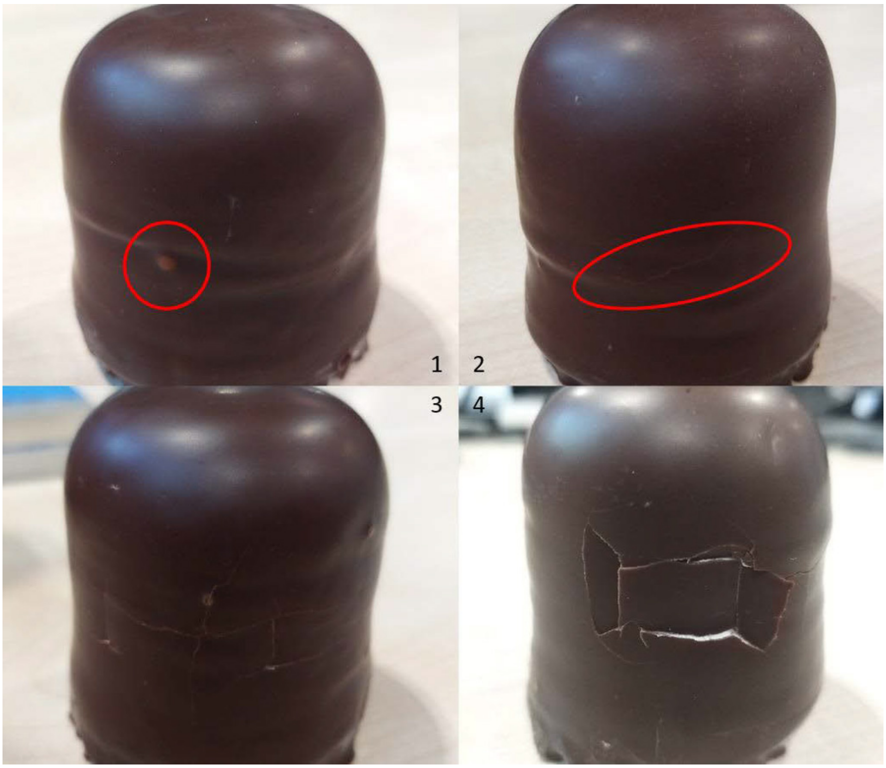

Fig. 3: The four stages of damage

Before explaining the evaluation and showing the first test rounds a technical problem needs to be explained. We identified a random effect of shaking between two opposite grippers. After some adjustments of the controlling and the Arduino software it was possible to nearly eliminate the shaking after some test runs. Afterwards it occured for a few cases only, but it mostly effects the minimum gripper force which is needed to handle the chocolate covered marshmallow. These cases will be marked in the upcoming results. The shaking results from the combination of fast high-end sensors with very high resolution for the measurements and simple motors providing limited step sizes to change the gripper jaws positions. The final gripper with the more expensive motors was already in production so we were not able to use these motors for the gripping force test bench. This leads to problems in the force controlling which is shown by the shaking sometimes. For the final gripper we will not expect these problems thanks to the high-quality motors that will be implemented.

To evaluate the minimum gripping force the gripper is adjusted to test in specific ranges.
The forces are measured when the gripping process is finished, which means that the motors stopped moving and the object is gripped without the podium underneath. After some iterations the range for the minimum gripping force at room temperature (RT) is detected between 0.15 – 0.35 N based on each single gripper. In order to later include the movements of the robot into the calculation, each gripper finger is individually controlled. For the following 30 tests, a three-point controller with the determined range was tested without losing grip at any test. The results are shown in Figure 4. The four values of the individual grippers are combined in the graph to form an overall gripping force for simplification. The developed lower limit for the range of gripping force lies at around 0.88 N.

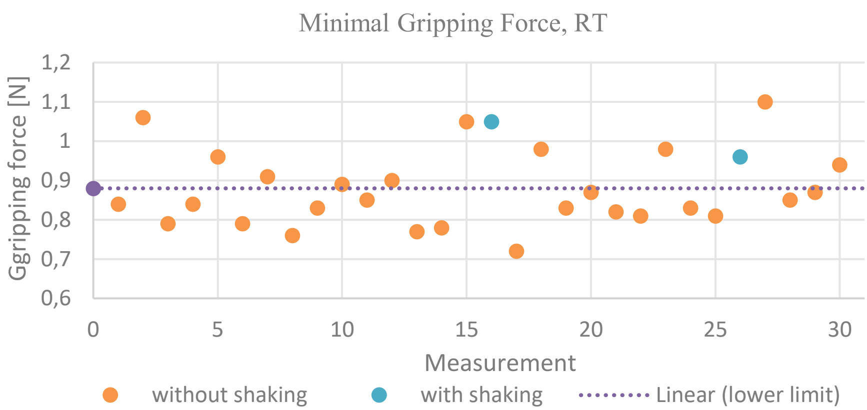

Fig. 4: Measurements for the minimal gripping force at room temperature

To define the upper limit for the range of gripping force every tested chocolate covered marshmallow is gripped twice to ensure that no damage is missed out in the first attempt. After some iterations the range for the maximum gripping force at room temperature is detected to range between 0.8 – 1.2 N based on each single gripper. Again, random force values within this previously determined range were tested. 26 chocolate covered marshmallows are tested twice, which results in 52 measurements. The results are shown in Figure 5.

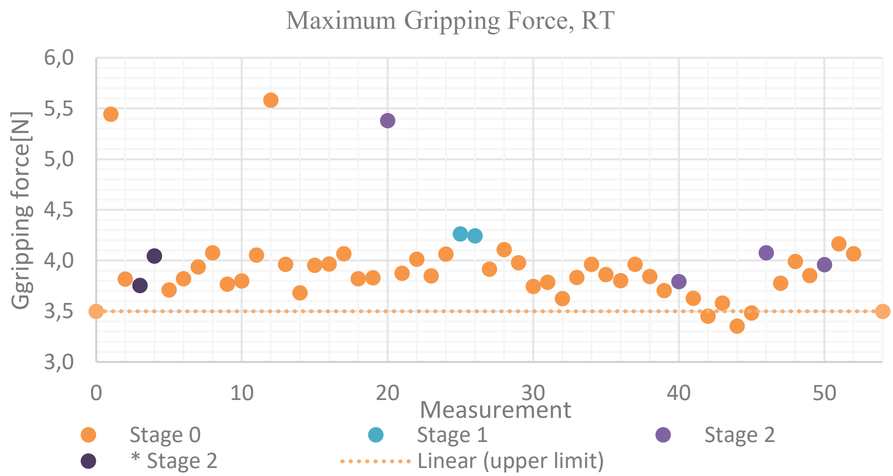

Fig. 5: Measurements for the maximum gripping force at room temperature

Two objects are damaged after the first grasp and four objects are damaged after the second grasp. This leads to eight negative measurements compared to 44 positive ones. The measurements marked with "* Stage 2" are from a marshmallow with a very rough and bumpy chocolate cover, which results in higher pressure peaks. This shows the importance of a good production quality for future handling tasks.

The objects 20 and 25 were damaged at the second grasp. The single gripper forces from the four measurements are shown in Table 1. For object 20 the crack is between gripper 2 and 3. The cause of this crack could be the rise of the gripping force from 1.03 to 1.08 at gripper 2 or 0.88 N to 0.97 N at gripper 3. For object 25 the crack is between gripper 1 and 4. In this case the rise from 1.11 N to 1.15 N at gripper 1 or 0.99 to 1.09 at gripper 4 could be the reason for the crack. This shows the small range of tenths and hundredth of Newton gripping force that can lead to a crack in the chocolate. Because of these small fluctuations the upper limit for the overall range of gripping force is set to 3.5 N as shown in Figure 5.

Tab. 1: Detailed look on two tested objects

			Single Gripper Force [N]			
Object number	Measurement	Grasp	Gripper 1	Gripper 2	Gripper 3	Gripper 4
20	39	1th	0,98	1,03	0,88	1,03
	40	2nd	0,97	1,08	0,97	1,00
25	49	1th	1,11	1,00	0,99	0,99
	50	2nd	1,15	1,00	0,95	1,09

Furthermore, the effect of temperature on the range of gripping forces is evaluated. The chocolate covered marshmallows are cooled down to 8°C and the procedure for finding the range of gripping forces is the same. As shown in Figure 6, the lower limit for the range of gripping forces at 8°C is higher compared to the equivalent limit at room temperature. While testing the maximum gripping forces for the upper limit of the range, the previously mentioned shaking of the test bench is a problem again. This shaking results in some gripping force peaks in Figure 7. Furthermore, some chocolate covered marshmallows got a crack from the temperature differences. Overall, the results shown in Figure 7 lead to an upper limit at around 5 N at 8°C. The different results between the measurements at 8°C and room temperature were expected due to the adhesive and melting characteristic of chocolate.

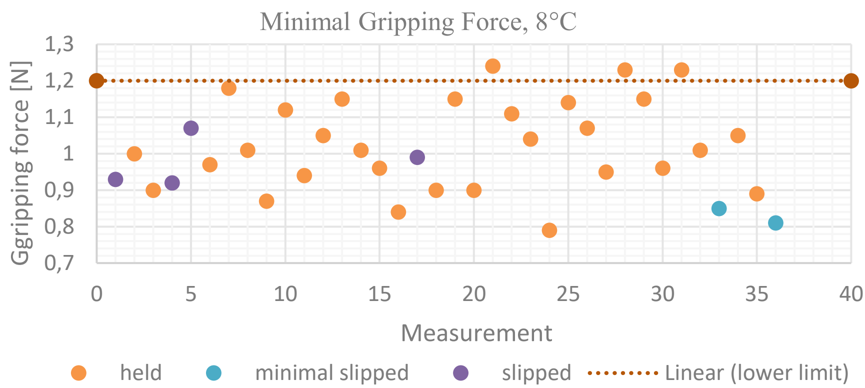

Fig. 6: Measurements for the minimal gripping force at 8°C

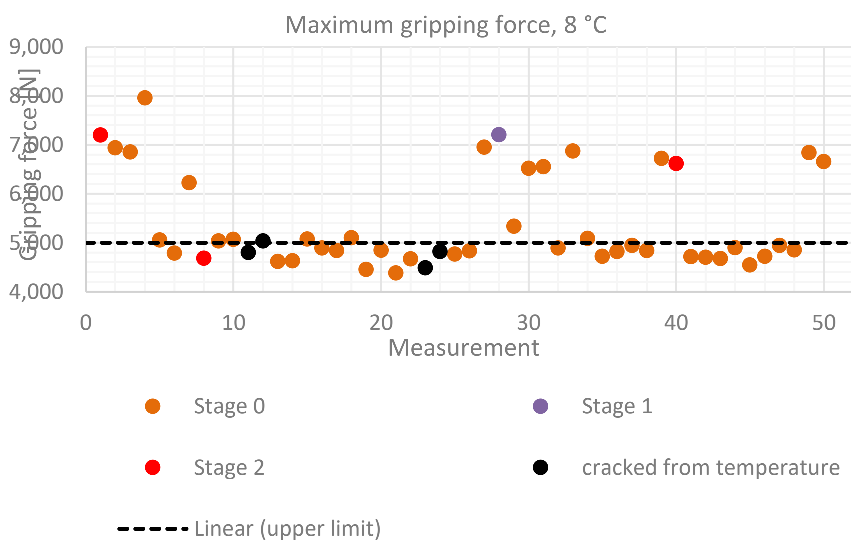

Fig. 7: Measurements for the maximum gripping force at 8°C

6 Results

First of all, the results show that it is possible to determinate the range of gripping forces for surface-sensitive objects like chocolate covered marshmallows. Also, the problems with the shaking grippers will not be expected when using the higher quality motors in the final gripper. Even with the applied cheaper motors for these experiments have shown that the required sensitivity is possible. The evaluated range of gripping force for the example of chocolate covered marshmallows is found between the limits of 0,88 N to 3,5 N at room temperature and 1,2 N to 5 N at 8°C. These results show the limits for the controlling of the surface-sensible gripper developed in this project. The force sensitive object handling needs to determine and actuate the controlling in these defined limits to allow a safe handling of surface-sensitive objects. It should be emphasised that these tests are made on a specific test bench without the acceleration forces of the robot. This will reduce the range of motion and emphasize the importance of controlling the individual fingers. We are currently trying to transfer these results to the real gripper (shown in Figure 8).

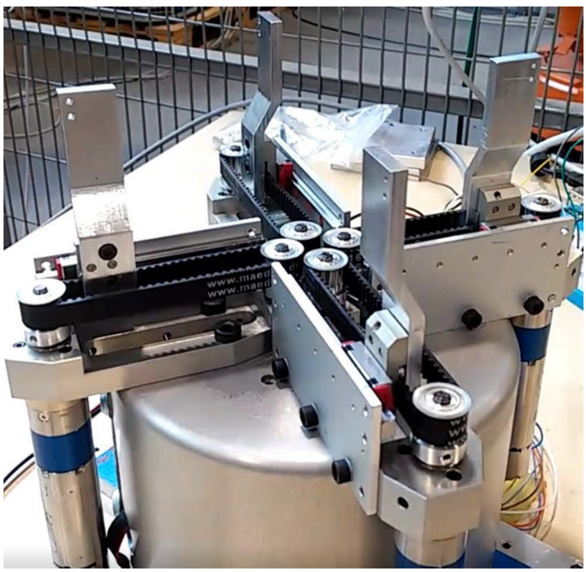

Fig. 8: The real gripper

Furthermore, the results show the importance of the temperature controlling of the product environment. The handling of surface-sensitive objects in winter or summer could make a difference in product quality if the season affects the ambient temperature, yet this paper shows that with some information about the effects of the temperature – and by integrating the measurement into the cyberphysical gripper control - it is even possible to enable a safe handling.

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References

1. Banerji, A.: Development of a Force Sensitive Robotic Gripper. In: Proceedings of Conference on Advances in Robotics - AIR '13. Conference, Pune, India, 04.07.2013 - 06.07.2013, pp. 1–4. ACM Press, New York, New York, USA (2013). https://doi.org/10.1145/2506095.2506096
2. Morita, N., Nogami, H., Higurashi, E., Sawada, R.: Grasping Force Control for a Robotic Hand by Slip Detection Using Developed Micro Laser Doppler Velocimeter. Sensors (Basel, Switzerland) (2018). https://doi.org/10.3390/s18020326
3. Bi, Z., Liu, Y., Krider, J., Buckland, J., Whiteman, A., Beachy, D., Smith, J.: Real-time force monitoring of smart grippers for Internet of Things (IoT) applications. Journal of Industrial Information Integration (2018). https://doi.org/10.1016/j.jii.2018.02.004
4. Spies, S., Kuhlenkötter, B.: Adaptive Online-Anpassung der Roboterbahn zur Reduzierung der am Effektor wirkenden Greifkräfte. Adaptive online adaption of the robot path to reduce the dynamic forces acting at the effector. In: Automation 2018, 03-04.07., pp. 123–133. VDI Verlag GmbH, Düsseldorf (2018)
5. Spies, S., Portela, M.A.V., Bartelt, M., Hypki, A., Ebert, B., Ramirez, R.E., Kuhlenkötter, B.: Force-controlled Solution for Non-destructive Handling of Sensitive Objects. In: Schüppstuhl, T., Tracht, K., Franke, J. (eds.) Tagungsband des 3. Kongresses Montage Handhabung Industrieroboter, pp. 57–64. Springer Berlin Heidelberg, Berlin, Heidelberg (2018). https://doi.org/10.1007/978-3-662-56714-2_7
6. Spies, S., Lenkenhoff, K., Kuhlenkötter, B.: Cyber-Physisches System zur Handhabung sensibler Objekte unter Berücksichtigung der Objekteigenschaften und dessen Verhalten. A Cyber-Physical System for Handling of sensitive Objects with regard to the Objects Parameters and Behavior. In: VDI Verlag GmbH (ed.) Automation 2017 (2017)