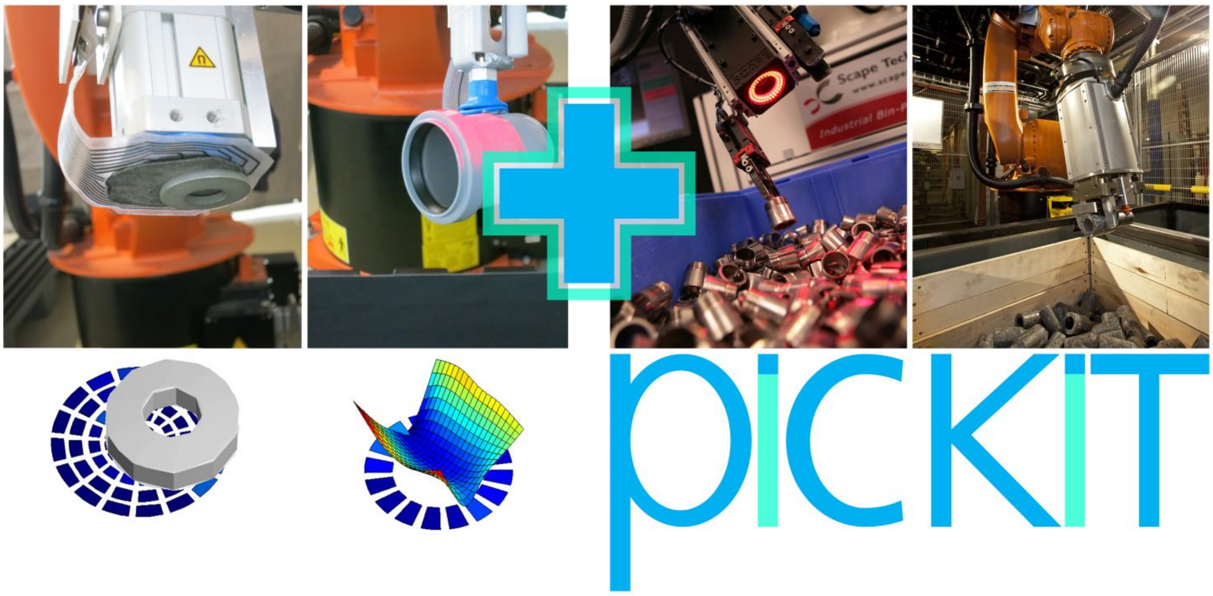
The European Co-ordination Hub for Open Robotics Development

Pickit



Fraunhofer IFF

Scape Technologies A/S

Final Report

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Section 1: Executive summary

- Bin-picking systems often suffer from being unable to grip parts with challenging surfaces e.g. shiny objects reliably. The objective of the *pickit* experiment was to improve common bin-picking systems with the help of the tactile feedback. Within the project we address general bottlenecks of such camera-based bin-picking systems. That's why we aimed to reduce the reject rate and detect such challenging parts. Therefore, we propose a highly sensitive, robust tactile sensor attached to differently shaped grippers. Thus we can measure the pressure distribution and determine the object pose in the gripper.
- We demonstrated how to use this method to reduce the cycle time by 36% of a common industrial bin-picking system. Additionally, we have shown how to detect collisions while picking parts from the bin. This includes the detection of a successful part grip after conducting a pick etc.. The integration of tactile sensors into the magnet gripper thus allows using this gripper in a common bin-picking system. Furthermore, we are able to determine distinguishing object features from the tactile feedback. This e.g. can be small object curvatures which are detectable with a reliability of 90%. The 3D camera system is not able to detect those features. The results achieved in the project can be easily transferred to any industrial grip application.
- Since our experiments regarding the determination of part pose from conducting unspecific touches with the tactile gripper on a part almost always change the part pose, we had to adapt the objective of the project. Nevertheless, our detection algorithm is able to detect parts from a single grip which should be easily transferable to any other application.

Section 1.1: Milestone overview

	Description	status
M1	Integration of tactile sensor	Achieved
M2	Integration of an optimal support strategy	Achieved
M3	Final experiment result	Timely achieved

- M2: The sensitivity of the tactile sensor is not sufficient to detect object shapes through sequential touch without changing the object poses. This is why we had to change the objective by determining the object pose in the grippers.
- M3: We have tested different parts with different grippers and different tactile approaches

Section 1.2: Deliverable overview

#	Description	Status
D1.1	Story Board incl. the results of Task 1 to 3	submitted
D1.2	Multi-Media Report	submitted
D1.3	Report on RIF visit outcome (The report will summarize the impressions, experiences and results of the RIF visit)	Deviated
D1.4	Integrated hardware for multi-modal bin-picking (Video report of the integrated system including a model-based visualization of acquired and processed sensor data)	submitted
D1.5	A suitable approach for multi-modal bin-picking (Research report on how visual and tactile modalities can be combined and then used for bin-picking)	submitted
D1.6	Multi-modal bin-picking system (Video report of the final demonstrator which will be used for system and TRL evaluation)	submitted
D1.7	Final report of the pickit experiment (Report on the entire experiment and its results)	submitted

D1.3: Unfortunately we could not visit the RIF because we had a timely intersection with the preparations for the Automatica 2016.

Section 1.3: Technical KPIs

#	Description	status
1	TRL gate review	Achieved
2	Object reject rate	Achieved
3	Success rate of determining the position of objects with challenging surfaces (dark, shiny, etc.	Achieved
4	Reduction of cycle time through recognition of objects properties based on tactile feedback	Achieved

Section 1.4: Impact KPIs

#	Description	status
1	Decreasing the reject rate of SCAPE's current bin picking system significantly	Achieved
2	The ability to manipulate objects with dark, shiny, or semi-transparent surfaces with a single general-purpose bin-picking solution leads co new product classes of bin-picking systems.	Achieved
3	The long-term success indicator may be enabled by how long it took to bring the first products with pickit capabilities on the market.	

2: So far, we have tested the detection of the washers based on a single feature, which is not sufficient detecting the complete object pose with a camera. Whenever a part is gripped, the tactile sensor allows for detection of the part pose in the gripper.

Section 1.5: Dissemination KPIs

#	Description	status
1	Website, LinkedIn	Achieved
2	IFF Wissenschaftstage 2016	Achieved
3	IFF Wissenschaftstage 2017	Upcoming
4	Youtube Video 1[1]	Achieved
5	Youtube Video 2	Deviated
6	ICRA 2016 submission	Deviated
7	IROS 2016 submission	Deviated
8	IFF Jahresbericht	In progress
9	ICRA 2016	Deviated
10	IFFocus	In progress
11	Automatica 2016	Achieved
12	IROS 2016	Deviated

5: Currently, we are not satisfactorily sure on what extent we'd like to publish everything due to some legal aspects.

Section 1.6: Additional (unplanned) achievements

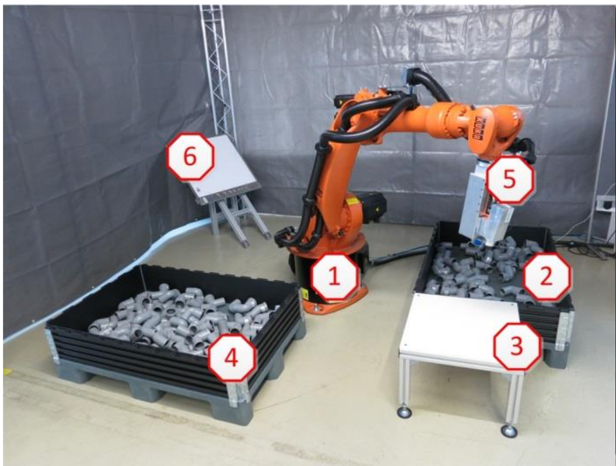
- The *pickit* project addresses a quite popular issue in the field of robotics by means using tactile feedback and camera data at the same time to validate grips. (see article e.g. http://spectrum.ieee.org/automaton/robotics/robotics-hardware/why-tactile-intelligence-is-the-future-of-robotic-grasping).
- We still have an increasing interest of our customers in purchasing the flexible tactile sensor.
- At the ISR conference we had a discussion with EC officials who expressed special interests in our results and experiments of the pickit project.
- There was one costumer of bin-picking systems at the Automatica who "will be thinking about a test study on using a specific bin-picking application" testing our approach in respect to a reduction of cycle time.

Section 2: Detailed description

Section 2.1: Scientific and technological progress

In the following, we outline the scientific results achieved during the complete runtime of the pickit experiment.

[1] https://www.youtube.com/watch?v=xA92uIuF-3U



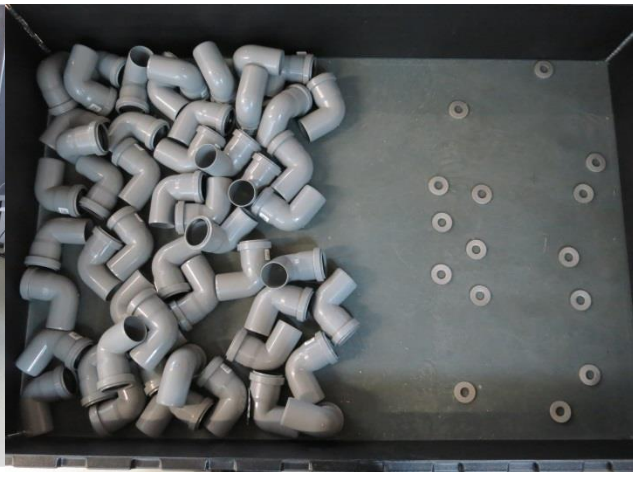


Figure 1 Set-up for multi-multimodal bin-picking at Fraunhofer IFF. Robot with tool mounted unit from Scape Technologies: robot KR 16 (1), supply bin with randomly stored parts (2), Handling Station for additional orientation control of the part (3), deposit bin (4), Tool mounted camera (5), Calibration Station for calibration of camera and Grid Scanner (6)

Figure 2 Randomly stored parts in a bin (left: angle tubes, right: washers)

Task No.	Task title	Lead Participant (short name)	Start month	End month
T1	Technical specification	IFF, Scape	1	2
T2	Tactile sensor for bin-picking	IFF, Scape	2	4
T3	Design and installation of experimental setup	IFF, Scape	3	4
T4	Modeling of the tactile gripper	IFF	5	6
T5	Development of tactile bin picking strategies	IFF	6	11
T6	Integration of the tactile mode in bin picking	IFF, Scape	11	14
T7	Verification of multi-modal bin-picking	IFF	15	17

T1: We agreed on using a vacuum gripper and a magnet gripper to test the possibilities of our multi-modal approach. We further decided to attach a sensor with a spatial resolution of less than 1mm resolution to a thin rigid-two finger gripper with a complex surface. This sensor covers the complete surface of the finger gripper. There is still some work to do in order to prevent the sensor from crosstalk between neighboring sensor cells properly. However, to our best knowledge, there is no such sensor capable to cover a complete surface of similar (mostly thin) objects since most tactile sensors lack the flexibility to be attached to such complexly shaped surfaces.

T2: The design of the tactile sensor, which can be attached to differently shaped surfaces, poses some strict requirements on the manufacturing process since the tactile sensor for the vacuum gripper needs to be flexible, whereas the tactile sensor for the magnet gripper requires withstanding high pressures. In order to attain sufficient data about the object shape when gripping, we could further improve the spatial sensor resolution of the sensor down to 1mm. Since the objectives, worked out in T1 posed some burdens, this took us a few more months longer than originally planned.

T3: The experimental set-up includes the integration of a specific tactile sensor to the grippers and the commissioning of all components of the bin-picking system. We used a KUKA robot KR 16 communicating via KRL XML to integrate the tactile modality into Scape’s bin-picking system. That also makes the system adaptable to changing objectives and integration of additional sensor modalities to Scape`s bin-picking system.

T4: We successfully modelled the tactile data attained from the tactile sensors of the vacuum gripper and the magnet gripper (see Figure 3). Based on the modelled data, which equal forces on every sensor cell on a predefined location of the sensor matrix, we are able to determine the object shape and location of the gripped part in the gripper. That way we can directly place the parts accurately without using an intermediate step for orientation control.

T5: At the end of the project we could determine the pose of objects made of transparent material (here a glass) through sequentially carried-out contacts. The object detection via tactile exploration is basically possible but is generally subjected to the fact that the object pose can change due to the application of contact forces. Furthermore, tactile object recognition increases the cycle time, which isn’t acceptable in most cases. Besides this approach, we have successfully demonstrated how to recognize objects and determine their poses in a gripper. That should be done if object data acquired by the camera system is insufficient or to monitor if an object was gripped as intended. Our complete approach and the tasks which have been utilized are described in D5.1.

T6: The introduction of a tactile modality in bin-picking applications offers new perspectives (as realized in the project):

1. Detect whether a part was gripped or not
2. Detect collisions with transparent parts during pick
3. Determine the object pose in the gripper
4. Detect whether the gripped part was accurately placed (When the part was not placed accurately, there is still a tactile feedback from clamping the part, thus the robot re-grips the part and runs the recognition again)
5. Detect inconspicuous object features like small curvatures
6. Sometimes we can also detect that two parts have been gripped at the same time

Our approach has proven to be reliable with respect to detecting the loss of a transported part. We have tested this characteristic 20 times in a row for the magnet gripper. In all cases, we removed the gripped washers after pick so that the robot conducted a new pick. The detection of collisions was tested on a transparent glass. When the camera system detects a part, close to a transparent obstacle (here the mentioned glass), the robot may collide with that part during a pick operation. Right after a collision occurs, the robot initiates a protective stop immediately. In this case the tactile sensor output of a few sensor cells rises above a certain predefined threshold. This functionality was not yet integrated into the process but showed sufficient results in raw laboratory conditions.

The detection of object pose after conducting a grip with the magnet gripper has been demonstrated for the mentioned washers. In almost all tests, the object situation was determined precisely and allows for placing the washer on a bolt. The use of the tactile feedback reduces the cycle time by 36%. The presented approach can also be applied on other objects with distinguishing features like holes, edges or rounded surfaces for instance. In 95% of the experimental tests the system was able to differentiate if the washer was gripped at its concave or convex side. This feature can especially be used in tasks where sorting material is needed and in which the camera data is insufficient for proper object recognition.

The reconstructed surface model used for the tactile feedback of the vacuum gripper has also been used for detection of transparent object shapes.

T7: Our sensor has proven to work properly for the vacuum gripper and the magnet gripper. In case of using the vacuum gripper, the tactile sensor did not reduce the suction power essentially. The vacuum gripper allows for determination of depth information (surface model) on the object, which was also used for tactile object exploration. Furthermore, we achieved a high spatial sensor resolution which allows for covering the entire surface of a two finger gripper.

Section 2.2: Scientific and technological achievements

One of our main achievements in this project is the design of high resolved tactile sensors and the development of a new fabrication method of a flexible, equilibrated tactile sensor, which is adaptable to different object shapes. We intend to present the results of the sensor design, functionalities and use on different grippers at the next IEEE sensors conference (2017). The tactile sensor seems to be of some interest to manufactures of grippers, which often lack sensor technologies attaining sufficient information about the current grip condition. Our future developments of the tactile sensor also focus on measuring precise force values (by means calibration of tactile sensors), which might be a competing technology to common, industrial force sensing devices like TEKSCAN.

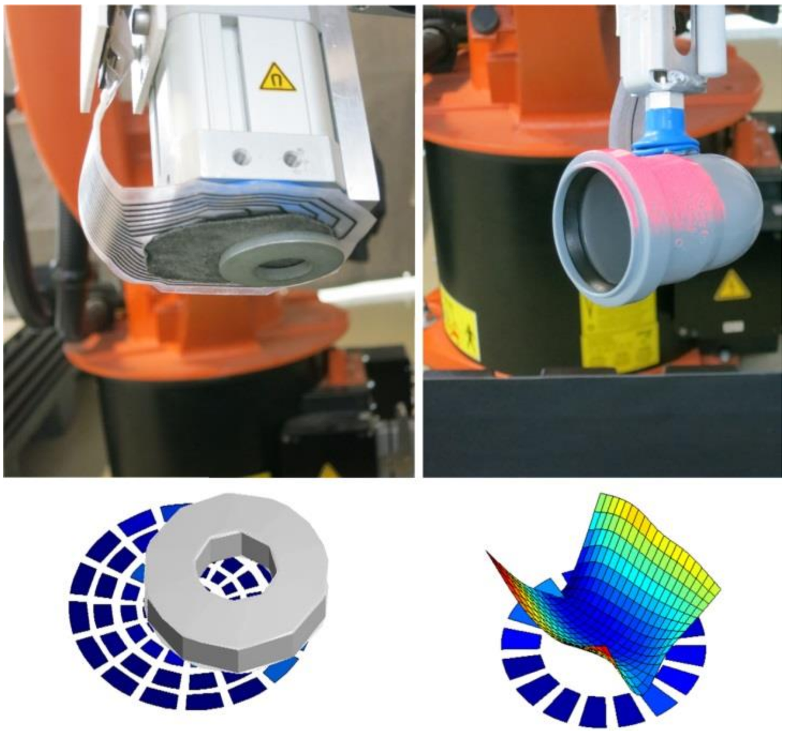


Figure 3 Pressurized sensor array for the magnet gripper with estimated object position (left), gripped angle tubes and reconstructed object surface using the vacuum gripper (right)

Further achievement:

- ➔ Additionally, we developed an object detection algorithm using the tactile sensors for circular object contours. We are aiming to improve the algorithm to make it applicable for different object features (not just circular edges) so that it can be used on any desirable object, gripper and application.
- ➔ We have published one paper regarding Sensor Calibration and one paper regarding the results of the bin-picking application (see table below).
- ➔ From our analysis of the system and gripping application (TRL report), the TRL of our sensor application for the grippers can even be increased by 1, raising the TRL of the gripper application to 7. Scape's bin-picking system has already TRL 9.
- ➔ Through use of the tactile sensor on a magnet gripper, we made a step change by introducing this gripper in an industrial bin-picking application. So far, the magnet gripper could not be used in real applications since the detection of lost parts and the verification whether a part was gripped or not is essential in bin-picking. The use of the magnet gripper can improve the system in terms of cycle time and reliability for specific parts.
- ➔ The cycle time of the bin-picking application can be reduced by 36%. This is due to direct determination of object pose in the gripper after gripping the part directly out of a bin. That

way the part pose can be verified in the gripper and thus placed in the deposit bin without placing it in an intermediate step on a table and conducting additional orientation control.

- ➔ We are able to measure collisions of the grippers with parts (e.g. detect a collision with a transparent glass) that are not supposed to be in the bin. According to Scape this functionality is sometimes used in unstructured environment where people have easy access to the system. So far, this algorithm cannot be used in real-time application, since we are using KUKA KRL XML
- ➔ We can use our sensor on a flexible vacuum gripper. So far, it is not reported that any one besides us has done this before. In another student project we have even successfully investigated the use of the sensor on a FinRay gripper (from Festo).
- ➔ In a student project, we successfully tested a 3D-Hall-Sensor for determination of object curvatures on ferromagnetic objects.
- ➔ We have developed a two-finger-gripper with one finger completely enclosed in a tactile sensor with about 1600 sensor cells. The spatial sensor resolution is 1mm.

Section 2.3: Socio-economic achievements

- ➔ ***Decreasing the reject rate of SCAPE's current bin picking system significantly.*** Through use of tactile sensors, we introduce a new modality to bin-picking. Thus the system can be improved e.g. in regard to conducting grips on object features only. As a consequence, more parts can be gripped out of the bin (Figure 4) and identified in the gripper. This also applies for e.g. partly transparent glasses (Figure 5). *Examples: The tactile suction cup is used to grip a glass. Based on the tactile feedback we determine the center of gravity of the part and deposit it accordingly, whereas the magnet gripper identifies the part pose of washers.*
- ➔

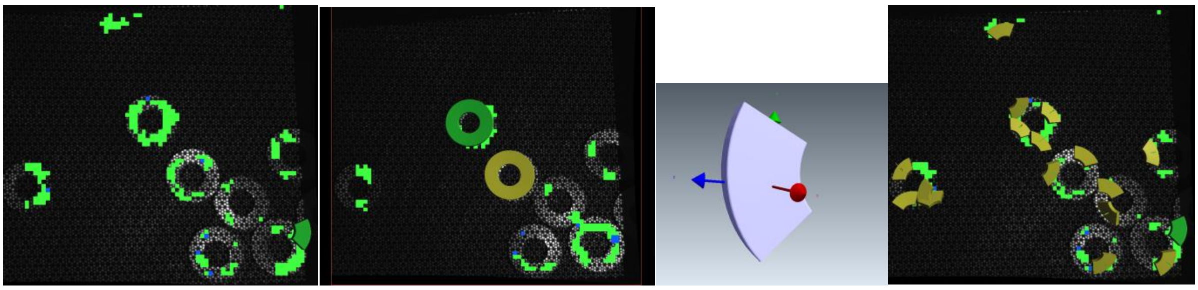


Figure 4 left: Detected object features (green points); left middle: Estimated object pose of a complete 3D-CAD model of the washer; right middle: CAD- model of simulated "object feature" (e.g. part of washer); right: Increased recognition score due to more object matches.

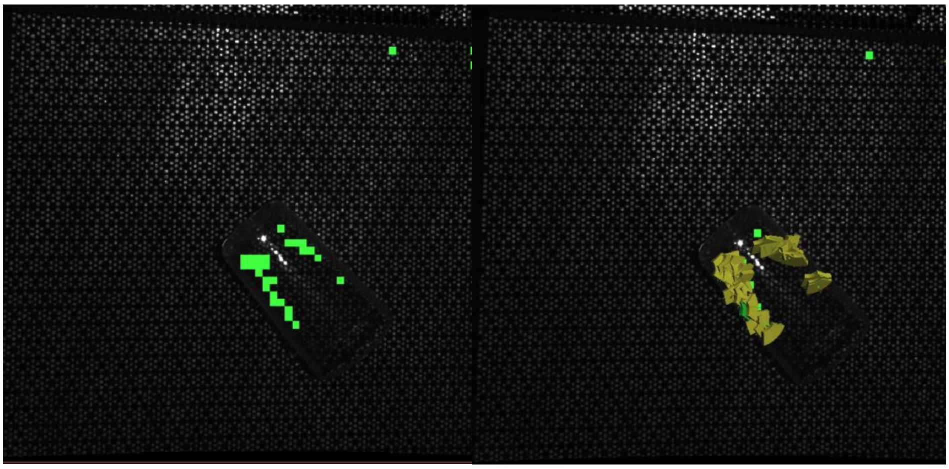


Figure 5 Glass, deposited in a bin; Example of acquisition data (green points), This allows conducting single-purposed grips on the transparent object (increased success rate of picking a part). Afterwards, the part situation can be determined from the tactile suction cup gripper.

- ➔ ***The ability to manipulate objects with dark, shiny, or semi-transparent surfaces with a single general-purpose bin-picking solution leads to new product classes of bin-picking systems.*** We tested different multi-modal bin-picking approaches which allow identifying the part situation in the gripper (washers are gripped by the magnet gripper and the cylindrical glass is gripped by the suction cup). With our multi-modal bin-picking system, we could enable the system to even grip transparent objects like glass and black objects like blackened washers. So far the camera system and the Grid Scanner did not attain sufficient information on such objects, in order to detect them reliably.
- ➔
- ➔ ***The long-term success indicator may be enabled by how long it took to bring the first products with pickit capabilities on the market.*** Scape is still interested in the tactile magnet gripper. Nevertheless, there is still some work, which needs to be done before the tactile sensor is suitable for industrial gripping application. This includes putting the sensor in a proper shell, which protects it from environmental impacts. The sensor may further be used in a completely different application. We submitted some proposals aiming to improve the results of the pickit experiment (algorithm and grippers) and use it for new application areas (e.g. mobile robot units).

Section 2.4: Dissemination activities

- ➔ We published one paper "A New Multi-Modal Approach Towards Reliable Bin-Picking Application" and presented it at the ISR conference summarizing the results of the *pickit* experiments in regard to grip monitoring.

TABLE 1: LIST OF SCIENTIFIC PUBLICATIONS AND DISSEMINATION ACTIVITIES								
N.	Type of publication/ event[2]	Title of the article/presentation/ demonstrator	Partners involved	Title of the periodical/series/ conference/book/Event	Place	Date	Vol. and pages	Is/Will open access[3] provided to this publication?
1	*Conference presentation*	*Sensor Design and Calibration of Piezoresistive Composite Material*		*2015 IEEE sensors*	*Busan (KOR)*	*Sept., 2015*	*Vol. 2, pp. 1 –4*	Yes
2	*Poster presentation*	*A new Multi-Modal Approach towards reliable Bin-Picking Application*	*Scape Technologies A/S*	*2016, ISR Conference*	*München (D)*	*Jun. 2016*	*pp. 1 –7*	Yes
3	*Exhibition*	*Presentation of objectives of our multi-modal bin-picking approach*		*2015 Wissenschaftstage IFF -Technikumsrundgang*	*Magdeburg (D)*	*Jun. 2015*	*N/A*	*N/A*
4	*Exhibition*	*Presentation of multi-modal bin-picking system*		*2016 Lange Nacht der Wissenschaften at Fraunhofer IFF*	*Magdeburg (D)*	*May 2016*	*N/A*	*N/A*
5	*Exhibition*	*Presentation of multi-modal bin-picking system*		*2016, Automatica*	*München (D)*	*Jun. 2016*	*N/A*	*N/A*
6	*Video*	*First media report*	*Scape Technologies A/S*	*Youtube*	*Magdeburg (D)*	*Oct 2015*	*N/A*	*N/A*
7	*Newspaper*	*Ferngesteuert (KUKA Übernahme von Midea)*		*FAZ*	*Germany*	*Jule 2016*	*N/A*	*N/A*

➔

Section 3: Resource usage summary

TABLE 1: LIST OF RESOURCE USAGE	
Matter of expense	**Costs in EURO**
Personal costs	**314.001**
Material/Travel etc. costs	**8.466**
Technical equipment	**36.075**
Overall costs	**358.542**

➔

Section 4: Deviations and mitigation

➔ We had a small time shift since a colleague left our team and we had to come up with another team member to fill the gap.

[2] Indicate the type of publications/events, e.g.: journal paper, conference presentation, technical report, abstract, book chapter, exhibition, other. In case of a submitted publication, please include the symbol “(S)”.

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

- ➔ Furthermore, we often had to repair for instruments. This started, when we first received the camera system. This was when we realized that the grid scanner was broken.
- ➔ We had to adapt the objective of the experiment since the object detection through sequential contact force was not suitable. From this we concluded detecting part poses in the gripper is the most suitable approach here.

Section 5: Future work

- ➔ The presented results will be used for the PhD thesis of Veit Müller and further development of object classification algorithm using the tactile feedback. Currently, we are working on a follow-up project tender to use this tactile grip modality on mobile robot units. Even the University of Magdeburg, where our BA student Mr. Lam graduated, has proposed a joint project using the new sensor as a force sensing device.
- ➔ More publications about pickit results are currently planned, in particular about the design of the tactile sensor used for the two-finger gripper and the surface recognition algorithm of the tactile vacuum gripper and the recognition algorithm for picking transparent parts.
- ➔ Currently, we are preparing a BMBF project using our tactile sensors and our multi-modal approach to incorporate them into autonomous mobile robot units to carry out different tasks in the Life Science field.

  At the moment we are not planning to bring the technology or software algorithm to market since there are still some burdens to take here.

Section 6: Lessons learned (optional)

- ➔ The planned time horizon for the pickit project was challenging. First of all, we have done quite a lot of work figuring out a suitable approach. The most promising approach is to pick known parts by chance using sole feature data of the camera system without using a complete recognition algorithm.