In the following we summarize the state-of-the-art of industrial bin-picking systems. Therefore we give a short introduction to the state-of-the-art in the field of tactile gripper application and thus describe the state-of-the-art with regard to common bin-picking systems.

# State-of-the-art of tactile sensor technology in industrial use

From the literature research the following manufacturers and users of tactile sensors are known among other things (There are a lot more manufactures of tactile sensors but generally we do not want to discuss all kinds of sensor technologies ):

Weiß Robotics; Schunk; Fraunhofer IFF, Tekscan;

1. <http://www.weiss-robotics.de/taktile-sensorik/taktile-sensoren/taktiler-sensor-dsa-9210.html>

Weiß Robtics equips different grippers and grip fingers with tactile sensors. “Thereby sensitive grips of different parts are possible”. The tactile sensor can thus be mounted on different object surfaces. The sensor resolution reaches a value of up to 3.4 mm.

1. http://www.de.schunk.com/schunk/index.html?country=DEU&lngCode=DE&lngCode2=DE&r=1

Also Schunk, a great manufacture of grippers, has already attached tactile sensor cells to different types of grippers. Schunk explains that thus the identification of objects is possible. Also the grounds of fragile parts are allowed to be identified on the basis of the tactile feedback.

1. http://www.iff.fraunhofer.de/de/geschaeftsbereiche/robotersysteme/technologien/taktile-sensorsysteme.html Fraunhofer IFF equips grippers and complete robots with tactile sensors, which enables them to interact with the surrounding. For example, a robot can be equipped with the so-called tactile skin, which allows for detection of collisions.
2. https://www.tekscan.com/test-measurement?tab=applications Tekscan uses thin printed foils. They utilize a specific print technology, which allows them to print electrical circuits on flat objects. Additional a thin piezoresistive layer is sandwiched between two printed foils, thus allowing for detection of collisions and forces. The sensor is arranged as sensor matrix.
3. <http://spectrum.ieee.org/automaton/robotics/humanoids/sandia-labs-robotic-hand->

<http://www.sandia.gov/research/robotics/advanced_manipulation/Sandia_Hand.html>

Here a robotic hand is introduced for sensitive object manipulation. On the basis of different sensors, sensitive object manipulation is possible. (There are many other robotic hands, equipped with tactile sensors, and allowing for sensitive grasping of parts)

## Conclusion:

Different manufacturers and users of tactile sensor systems and tactile grippers are known. Mostly the tactile sensor elements are arranged in a matrix structure and the sensor is attached to slightly arched gripper surfaces. The pickit experiment aims for a sensor resolution of up to 1mm (for the two finger gripper) in order to attain as much information as possible from slight object contact, which is necessary for feasible data evaluation. Silicon-based sensors (MEMS, micromechanical systems [8]) are suited for small area application but often lack in terms of flexibility and cost-efficiency. At least one manufacture of tactile sensors, which was already depicted in point (4), called Tekscan, is capable to realize a spatial sensor resolution of up to 1mm, without using MEMS based technology. The piezoresistive material is sandwiched between two printed foils. That way the sensor becomes very thin and flexible and can be attached to large and slightly arched surfaces. Additionally Tekscan uses a method to equilibrate and calibrate the sensor array. This enables the operating tactile sensor array to distinguish between different object shapes, which are given by the output value of the sensor.In most cases this is necessary in order to evaluate the attained tactile information and create a model of the part. In case the visual data is not sufficient to create a complete model of the object, further object exploration can be done through use of tactile object recognition. In order to evaluate collisions properly we intend to cover the whole surface of a thin two finger gripper with a tactile sensor array. In contrast most tactile systems aim to cover flat areas only, which restricts the sensor to detect and locate collisions from all directions. Another advantage of the proposed sensor design is to utilize the inside and the outside area of the gripper for different grasp application as well (spreader gripper).

Only a few tactile grippers are proposed but are not really suited for use in bin picking. The proposed grippers are often utilized for sensitive object manipulation [3, 5, 7, 8, 11]. Most paper focus on anthropomorphic grippers, which are mostly not suited in terms of feasible grasp execution, processing time and costs. Anthropomorphic grippers are designed for gripping parts of different object shape. In contrast to these hands, regarding industrial bin-picking the grippers are designed according to the object and not the other way around in order to reduce the complexity of the system and execute grasps fast and precisely enough.

According to Scape Technology there is no overall sensor technology that can is used for all kind of grippers, in order to verify if a part was gripped or not. A gripper which is not able, to verify if a grip was successful is not suited for use in industrial bin-picking. Our multi-modal approach proposes an overall concept, in which the tactile sensor can be attached to any desirable gripper surface, thus enabling them to detect collisions, verify if an object was gripped or not and last but not least in combination with the camera based system, to verify if a grip was performed as intended.

Supplier and Manufactures of industrial bin-picking systems

**Manufactures among other things are mentioned below:**

Momac: (<http://www.roboter-anlagen.de/Bin_Picking_Griff_in_die_Kiste.html>)

Scape Technology: http://www.scapetechnologies.com/en/

Bsautomatisierung (<http://bsautomatisierung.de/startseite-de/bsautomatisierung/zufuehraggregate/bin-picking.html>),

Fraunhofer IPA <http://www.ipa.fraunhofer.de/en/bin-picking.html>,

3D CPS Bin-Picking: (<https://www.group-cts.de/de/robotics-inmatro/id-3d-cps-bin-packing.html>)

Recognition Robotics (http://recognitionrobotics.com/products/robeye-for-bin-picking/)

Additionally, several system integrators who closely work together with one of the aforementioned manufactures exist however they are often responsible for the design of bin-picking cells.

All the aforementioned bin-picking systems use camera or laser based object recognition systems in order to attain appropriate object data. Up to now, we have not found any manufacture of bin-picking system who utilizes tactile sensors in order to perform grasp monitoring on the parts.

The amazon picking challenge addressed similar problems of bin-picking: <http://www.engadget.com/2015/06/01/amazon-picking-challenge-winner/>

In the amazon picking challenge robots have been equipped with measuring systems (light cut sensors, cameras etc.) to allow for object recognition. These systems recognize, reach and file the objects finally in a box. On this occasion, not the defined grip and positioning of objects are demanded, but to take different objects merely from deposit station to throw them in a box. More precisely, a camera recognizes the objects and the grippers, mostly equipped with force sensors, verify whether the part was gripped successfully or not. However we’d like to extend that idea and aim for the verification of part grasp by determining the part orientation.

Patent Research

We have done some research in DepatisNEt, using term such as “taktil&Greifer”, “bin-picking”, “Griff in die Kiste”. In the following we summarize the patents which seem relevant in this context.

**DE000010319253A1**

Describes a picking system consisting of two cameras which are fastened to the robot in order to verify the grasp process. The cameras are used in order to adapt the component situation in the gripper. Mainly they are used for verification of part gripbut they also detect whether the object orientation changes during transportation or not.

**DD000000254160A1**

This patent describes how grasps are executed with a parallel gripper. The performed grasps thereby are executed according to the object shape.

**DE000010313890A1**

This patent describes a method to monitor gripped components. By that the situation and orientation of the parts can be regulated with the help of a tactile sensor matrix, which is attached to the gripper surface.

**US000004985846A**

This patent describes a multi-modal draught which uses an acoustic sensor and a camera-based object recognition system to take unsorted parts from a box and afterwards the robot brings them into the desired position.

**Assessment of patents according to what the pickit experiment aims for:**

### US000004985846A makes an approach towards a multi-modal bin-picking system. Besides the camera-based data, additional object data is attained through an acoustic sensor. However acoustic sensors lack the ability of high spatial sensor resolution, which makes it difficult to build an object model based on the data. Additionally the intensity of a grasp by means the grip force cannot be evaluated properly, as the sensor is only capable to determine the distance to object structures. This leads to difficulties regarding detection of collisions, which do not necessarily cause the object to change the orientation or position and furthermore to adapt grasp forces based on the object propoerties. Besides the aforementioned drawbacks of acoustic sensor systems, we have not found any commercially available bin-picking system which uses acoustic sensors.

**DE000010313890A1** presents an approach towards equipping gripper surfaces with tactile sensor matrixes for monitoring of the part situation during grasp. The patent says that it is necessary to use closed-loop control architecture in order to hold the grasp strength. Nevertheless, we propose grip arm systems, for instance pneumatic two finger grippers or vacuum grippers which allow for a reliable interpretation of the haptic feedback on the component situation and component orientation, which do not necessarily be used for closed-loop control. The sensor resolution, as well as the succeed rate of the proposed concept are unknown. Furthermore our approach uses camera based data and tactile processed data in combination, in order to monitor the part situation and to verify a grip.

In contrast **DE000010319253A1** presents a system, which uses camera based data for grip verification but also for identification of parts as well. The proposed concept is similar to what we are aiming in the pickit experiment. However, as the concept only includes cameras, the disadvantages of camera based systems to detect objects with shiny, transparent object surfaces cannot be overcome till now. This sometimes leads to small miscalculation of the object position and orientation. Additionally, a method based on the tactile sensors, allows for detection of collisions which do not necessarily lead to a situation change of a gripped part.

In **DD000000254160A1** an exclusively tactile system is presented. Nevertheless, without using camera-based data (or such) no specific and accurate grab can be performed on the object.

# Overall multi-modal bin-picking system

Up to now, we have not found any existing bin-picking system in industrial use or which is described as “idea” in patents and utilizes tactile sensor technology and camera based data simultaneously. The results of the patent research have proven that all presented systems address small problems only but do not focus on an overall concept for bin-picking systems, which combines tactile and visual data and uses them for grasp monitoring, grasp verification or object exploration simultaneously.

One approach towards grasp monitoring was done in [4]. Here a concept is presented, which determines how the object situation can be determined. This is done through evaluation of inertial object parameters like mass, gravity center point during transportation of parts, thus leading to a great reduction of cycle time. This method has proven to determine the object pose and orientation *during* transportation for many different objects very well. Nevertheless this approach deals also with ambiguity of object pose and orientation. This seems to be the bottleneck of this approach, as objects with unsymmetrical mass properties cannot be evaluated properly. Furthermore this concept has proven to deal with some problems regarding structural disturbances from the manipulator. By attaching tactile sensors to the robot surface we introduce a possibility, which is not restricted to the manipulator, which is used.

The impact of shiny objects on the quality of a bin-picking system was analyzed by the authors in [6]. It is the only publication of our literature survey that addresses the same issue as the *pickit* experiment. The author used a promising but complex light source system to improve the object recognition and pose estimation of their system. A further work, in which the light source is optimized, is presented in [2]. The focus here is on a diffuse source that does not cause shiny effects or reflections on objects. However, that approach resulted in complex light source which takes up a lot of space above the bin. An approach for detecting transparent objects is addressed in [10]. The authors used a complex setup consisting of time-of-light camera and a complex scene reconstruction using several image records for detecting a single object in the workspace of a dual-arm robot. Since the resolution of currently-available time-of-light cameras is still inappropriate for precise object detection, the approach is currently considered as not suitable especially for industrial applications. A promising approach has been shown with an upcoming vision sensor that uses a projection of a high-energy light pattern and thermo cameras for detecting transparent objects [1]. Up to now, the sensor is not utilized for bin-picking applications. A slight multi-modal approach is followed by the authors of [9]. Here, the impedance control of a DLR LWR III is used in combination with a time-of-light camera in order to carry out bin-picking operations. Since this configuration is not capable to localize a physical contact, it was not possible to guide the robot gripper towards the target object properly. As our brief survey shows, most of the current solutions to overcome remaining challenges of bin picking focus on improvements of light conditions or vision sensors. Our industrial partner Scape Technologies confirms that such scientific-oriented improvements are not practicable or even realistic for industrial applications, since the available space is in general highly restricted and limited. Only one approach introduces physical contact as a further modality for carrying out bin picking. We can conclude – to our best knowledge – there is no reliable solution available that overcomes any limitation of current bin-picking systems.

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**Multi-modal approach by applying of tactile sensors to the gripper**



