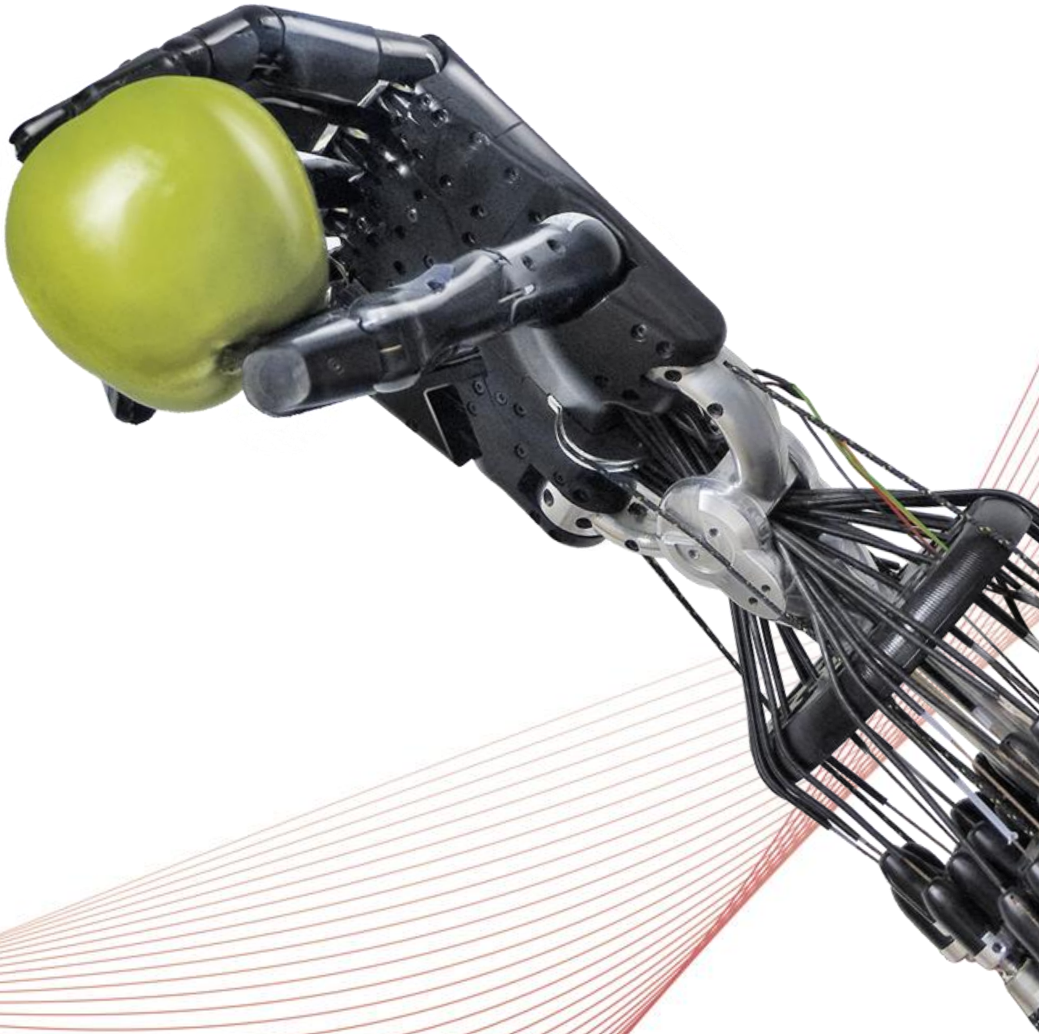
Robot Hand with a Sensitive Touch

LDS Tactile Sensors for Sensorimotor Skills



LaserMicronics

MICROMACHINING SERVICES

Complex task, complex structures

CITEC uses compact LDS component as sensor array

Helpful humanoid robots – already a reality in the movies – are inspiring a lot of research in a wide range of scientific disciplines. More than 200 scientists from engineering and life sciences collaborate within the interdisciplinary "CITEC" (Cognitive Interaction Technology) research cluster at Bielefeld University. At the start of 2014 a major step was taken with the development of a tactile sensor in the form of a fingertip for use in artificial hands – this key sensor limb is a complex LDS component.

Unscrewing a bottle cap, turning on a light in the dark, or grasping a glass tightly enough so it doesn't fall out of your hand doesn't present much of a challenge for many people. However, these actions all require complex sensorimotor skills as well as the ability to interpret sensory information (perceptions).

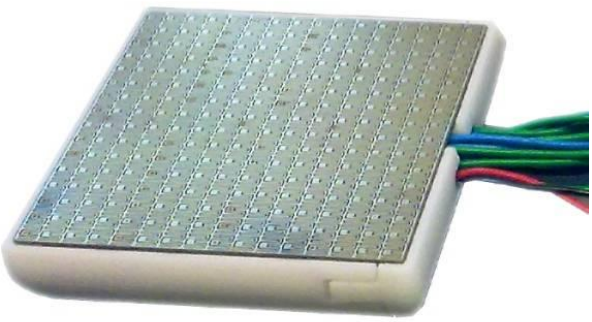
Intelligent motions and actions

One of four core research fields in the CITEC Center of Excellence, "Motion intelligence" has the aim of combining perception and action in robots to enable smooth human-robot collaboration, even in unforeseen environments.

The modern CITEC building at Bielefeld University: home to an interdisciplinary collaboration between engineering and life scientists

To this end, cybernetics, biology, and neuroinformatics experts take an integrated approach to derive the required skills from the underlying sensorimotor interactions between the robot and its environment. Four main aspects are involved in the research: intelligent motion, attentiveness (robot-human), situation-based communication, and memory and learning processes. If robots are to be useful, they have to interact sensitively with the environment and utilize unknown objects safely in unstructured environments.

Already in 2007 the university created two highly flexible, human-sized robot hands with 20 degrees of freedom and 24 joints. The hands were installed on a seven-jointed industrial robot and represented a unique setup for research on bimanual grasping motions.



The first prototype: the "Myrmex" flat sensor array

Flat tactile sensor systems

The first phase used the "Myrmex" tactile sensor that had been developed in-house. This sensor has an array of 256 high-resolution sensing elements on an area of 80 x 80 mm and integrated electronics providing for a frame rate of 1.9 kHz. It primarily captures normal forces but also delivers a powerful basis for algorithms for slip detection and contour tracing.

The artificial hand

Transferring these sensory abilities to the complex system of an artificial hand was the objective of an ambitious project. The technological highlight was a tactile sensor of the same shape and size as a human fingertip made using the LDS process.

Compared with the flat tactile sensor systems, this project had a number of added requirements in the advanced development stage:

- The fingertips had to be extremely sensitive.
- There was only a small volume available to accommodate the sensor system. The compact analysis electronics had to be integrated into the sensor assembly.
- The sensor had to take the form of a human fingertip, i.e., a curved form.
- High spatial resolution – the sensor had to be able to determine the intensity and direction of applied pressure and supply the database for dynamic processes.

These properties could not be achieved with the required precision using conventional planar components – a three-dimensional acquisition technique was needed.

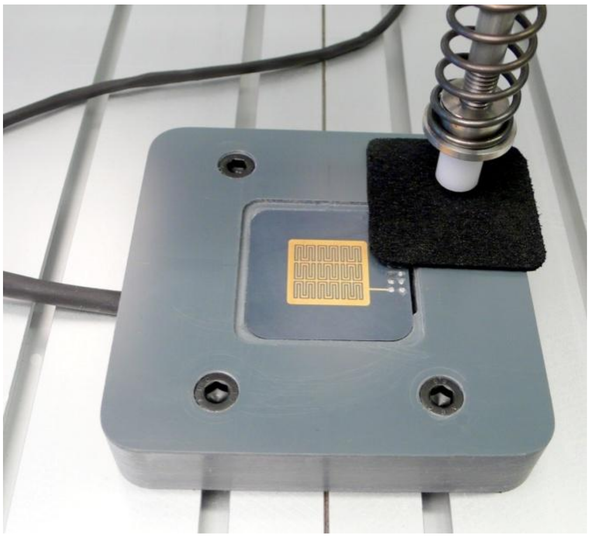
Three-dimensional molded interconnect devices

MID stands for "molded interconnect device," an injection-molded three-dimensional substrate with integrated circuitry. Various methods have been successfully used to manufacture them on an industrial scale.

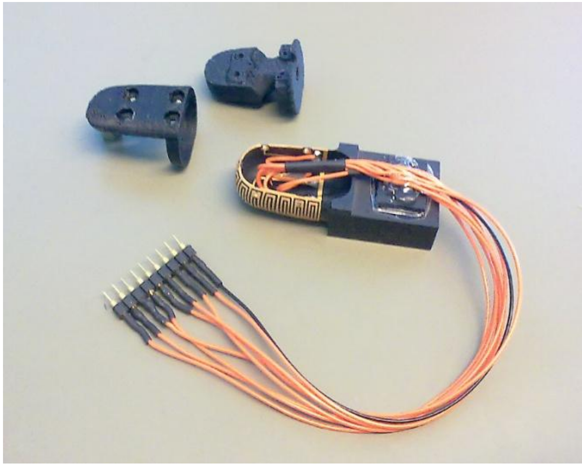
The most flexible MID manufacturing process was chosen. With Laser Direct Structuring (LDS), conductive traces are applied to three-dimensional plastic parts. The base part is made by injection molding a plastic containing an LDS additive. The laser then writes the conductor structures on the part, activating the additive in the patterned regions at the same time. In electroless metallization baths, metal layers are then built up on the structures. LDS MIDs are extensively used as antennas in smartphones and tablet computers, as well as in the automotive industry, medical technology, and consumer electronics.

Through the use of a laser, structures down to the fine pitch range (75-µm trace and 75-µm space) can be produced. The conductor structures can be modified simply through modification of the layout data. This proved to be helpful in the iterative adaptation of the sensor structures on the fingertip.

LDS (left to right): The injection-molded part (1) is structured by laser (2) and then metallized (3).
Components and contacts can be mounted on the metallized surface (4).



The first LDS sensor was made as a functional prototype on a prototype board.



Milled out of solid material and excluding analysis electronics: with the first prototype, the basic functionality of the fingertip layout could be confirmed.

Demands on the LDS part

To ensure the spatial resolution capabilities of the tactile sensor system at least six sensors were required. The circuit used allowed for a maximum of twelve sensor cells. The integrated analysis electronics had to have a frame rate of greater than 1 kHz to ensure surface recognition and slip detection.

The base part was preplanned in terms of geometry (3D sensor surface), construction (fastening via threaded dome to the hand skeleton) and electronics (linking to the hand's SPI bus). The volume limitations necessitated a double-sided layout: the outside surface housed the sensor electronics, and the interconnection network was arranged on the inside of the fingertip and equipped with the analysis electronics. Vias were required to connect the two sides and were through-plated by the metallization step in the LDS process.

The spatial sensor relies on the measurement methods and analysis electronics of the proven Myrmex sensor. A closed-cell, conductive foam changes its electrical resistance as a function of the applied pressure. Coupled with a fixed resistance, this foam changes the applied voltage as a function of the pressure normal to the sensor cell. This voltage is supplied to the A/D converter of a microcontroller, analyzed, and transmitted to the control components.

Ultramid prototype

There are already pre-made plastics containing LDS additives available for the LDS process. BASF supplied solid material for production of the first prototype, which was machined by milling to the desired shell structure. The manufacturing service provider LaserMicronics assumed the LDS structuring task as well as the subsequent metallization with a layer structure made up of copper, nickel, and gold.

The first prototype was produced in a simplified version without analysis electronics for the purposes of investigating the feasibility of the three-dimensional sensor array. The feasibility was confirmed.

Optimization and manufacturing of mass-produced part

The experience gained with the first functional prototype was the inspiration for further development leading up to mass production. Manufacturing the "fingertip" using injection molding enabled complex geometrical requirements to be met. The decision was made to use liquid crystal polymer (LCP) Vectra 840i LDS from Celanese.

LCP has a special property in relation to the LDS process: it can be drilled by the laser in the structuring process and is activated through this action. This makes through-hole plating especially easy – the drilled holes are automatically through-plated during metallization.

Subsequent CAD design was laborious. The complete process (including routing of the conductor structures) was performed in a CAD design program. Trace distortions arising from projection onto the three-dimensional surface were iteratively corrected. A key criterion in this phase was the arrangement of the electronic components. The possibility of manual assembly – accessibility by the soldering systems – is a prerequisite for integrated analysis electronics.

An experienced partner (König Kunststofftechnik) was also called in for injection molding. In the design, it was important to comply with the molded part geometry requirements imposed by the LCP (roughness, wall thickness, yield points) and with LDS specifications:

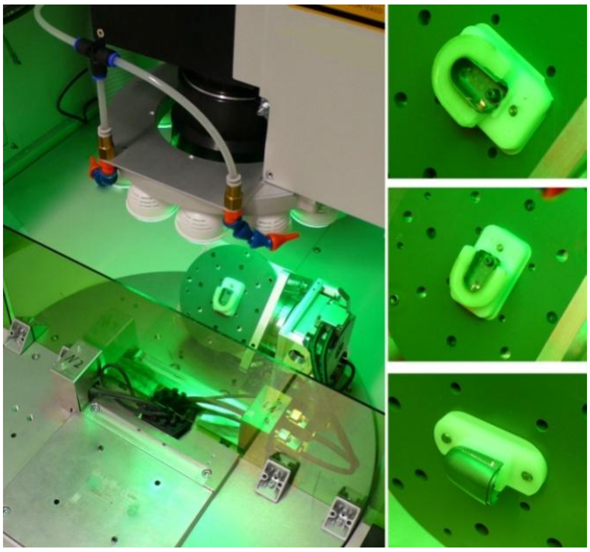
- Minimum angles of incidence, shadowing, and accessibility by the laser
- Maximum wall thicknesses of vias
- Minimum radii of the conductive traces
- Positioning of the ejector pins

LDS production

LDS production, i.e., laser structuring and metallization, was done at LaserMicronics. Use of a single-head laser system made it necessary to use 20 positions for double-sided LDS processing. In practice, structuring from five different spatial directions is required. The laser process was very capable of handling this complexity because it allowed for seamless stitching of the 20 substructures, despite production tolerances.

The metallization process, on the other hand, was standard. First a copper layer about 15 µm in thickness, then a nickel layer, and finally a gold finish was built up chemically in an electroless bath. Conductor structures generated in this way adhere extremely well to the substrate and are protected from environmental factors.

Production at LaserMicronics went hand-in-hand with in-process optimization of the existing CAD routing. This resulted in an extremely compact sensor component acting as an interface between the robot, the software, and the outside world.



The traces in interior and exterior positions and their spatial distribution required structuring in 20 positions. The LDS process can lay traces next to each other without any overlap.

The laser-structured components can be chemically metallized in an industrial-scale process or – as shown here – in cascading beakers. A base layer of copper and a finish layer of nickel/gold are standard.

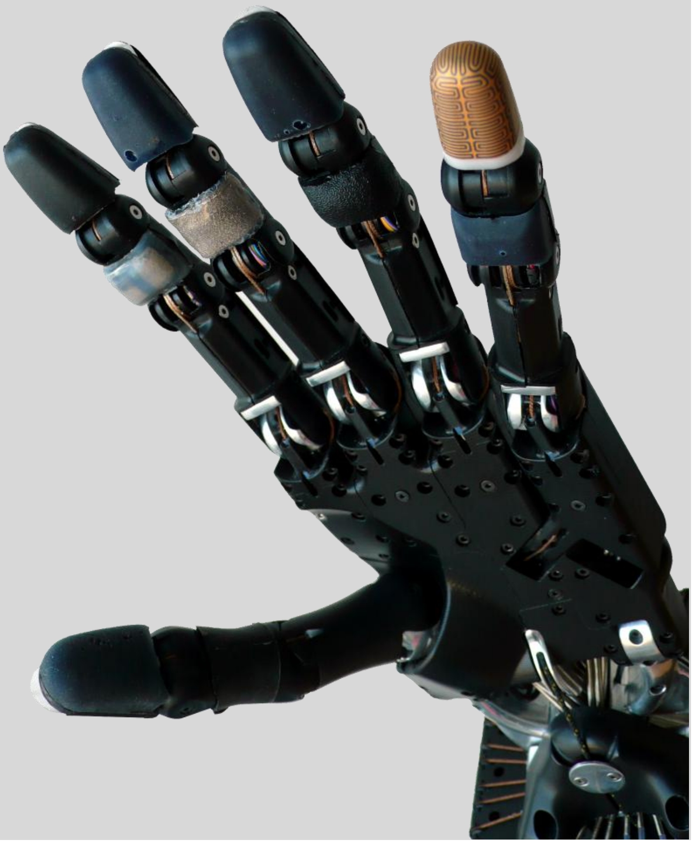
Grasping with a delicate touch

The researchers demonstrate the result using a practical example: the robot hand grasps an empty plastic cup and holds it securely, even when a liquid is poured into it.

The sensor array delivers not only individual pressure values but also values pertaining to the fingers' grip on the object – the slip detection system continuously adjusts the gripping force during the manipulation and holding processes.

Twelve sensor cells at various angular positions (normals) are implemented on the surface of the fingertip. The complete analysis electronics system is soldered directly on the inside surface of the fingertip. The force vectors are determined and transmitted to the robot control system via the SPI bus.

A conductive foam coating lends the sensor its function: compression of the foam causes the individual sensor cell resistances to change.



Project participants

Bielefeld University, Neuroinformatics Group CITEC

LPKF Laser & Electronics AG
- LDS process consulting
- Assumption of costs for LDS production

LaserMicronics GmbH
- LDS process consulting
- LDS production
- Metallization

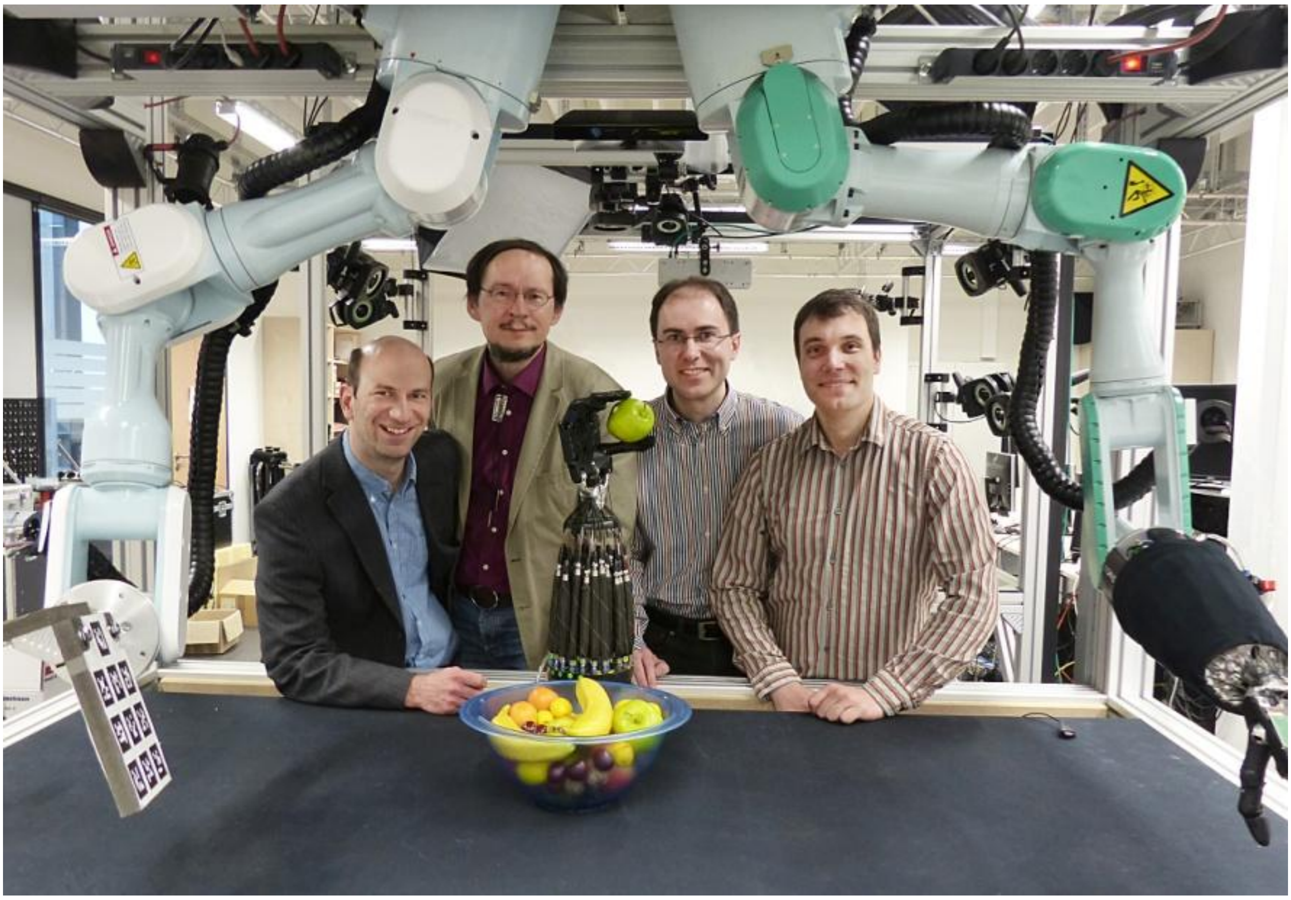
König Kunststofftechnik, Bad Salzuflen
- Moldmaking consulting
- Production of injection-molded parts

BASF
- Supply of Ultramid solid material
- LDS process consulting

Ticona / Celanese
- Supply of LCP material “Vectra 840i LDS”

Additional Information:
IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2013)

A highly sensitive 3D-shaped tactile sensor by R. Kõiva, M.Zenker, C. Schürmann, R. Haschke and H.J. Ritter, Bielefeld University / CITEC



The CITEC project team involved in the development of the sensitive robot (left to right):
Dr. Robert Haschke (Head of Robotics Group in Neuroinformatics Working Group), Prof. Dr. Helge Ritter (Chair of Neuroinformatics at Bielefeld University and CITEC Coordinator), Risto Kõiva (Scientific staff member CITEC with concentration on tactile sensor systems and intelligent objects), Matthias Zenker (coordination and production of LDS fingertip)

Cognitive Interaction Technology (CITEC) Center of Excellence

The Cognitive Interaction Technology Center of Excellence was established in 2007 at Bielefeld University within the framework of the Excellence Initiative of German federal and state governments. CITEC targets the key functions of cognitive interactive systems with its four core research areas of motion intelligence, attentive systems, situation-based communication, and memory and learning.

The Bielefeld Center of Excellence comprises 31 research groups, 15 of which moved, with 260 scientists in informatics, biology, linguistics, mathematics, sport sciences, and psychology, to a newly erected research building with a floor space of 5,300 square meters, including 1865 square meters for 35 labs, in mid-2013.

CITEC runs its own graduate school, currently with 100 doctoral students, and has an annual budget of six million euros, provided through the second funding phase of the German Excellence Initiative.

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LPKF Laser & Electronics AG

LPKF Laser & Electronics AG produces machines and laser systems that are used in electronics manufacturing, medical technology, the automotive industry, and solar cell manufacturing. The international Group combines competencies in laser technology, optics, and drive and control technology with comprehensive know-how in laser micromaterial processing. Around 20 percent of the workforce is engaged in research and development.

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LaserMicronics GmbH

LaserMicronics GmbH was founded in 1989 as a service provider for laser-based manufacturing. The laser micromachining specialist provides assistance to customers in tasks ranging from process evaluation and optimization to make-to-order production, as well as offering capabilities in ramp-up production and peak demand accommodation. At the Garbsen and Fürth locations, LaserMicronics has a wide range of offerings in UV laser machining, laser plastic welding, LDS technology, and micro-cutting elements.

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