6th INTERNATIONAL MULTIDISCIPLINARY CONFERENCE

INTELLIGENT END-EFFECTORS FOR ASSEMBLY ROBOTS

Ferenc ALPEK[1] **& Ferenc SZEKELY**[2]
Budapest University of Technology and Economics, Department of Manufacturing Engineering
[1] A.Prof. Prof.hc.mult. PhD.; [2] PhD student
H-1111 Budapest, Müegyetem rkp.3. Tel:+ 36 1 4632518; Fax:+ 36 1 4633176;
e-mail:alpek@manuf.bme.hu; szekely@manuf.bme.hu

Abstract: Manufacturing automation helps to increase the quality and reliability of products with reduced costs. The Intelligent Manufacturing Systems (IMSs) using robots can realise the advanced automated production. The most important and complicated operation of the robotized production is the assembly. During automated assembly a lot of end-effectors (grippers, tools and special devices) have to be used to make the "final version" of the product. The end –effectors are built into the last robot wrist. During automation the human involvement has to be replaced with sensory systems and advanced control systems realising the monitoring and adaptive control of processes. Intelligent end-effectors (grippers, micro-grippers, tools and gripper and tool changers) are the very important components of the assembly robots.

To replace partly the human intelligence with machine intelligence using intelligent end-effectors is the goal of this development work.

The present paper gives a brief overview about recent developments in these fields, primarily focused on the gripper applications.

Keywords: Robot grippers, micro-grippers, sensory systems, intelligent peripheries, end-effector's changers

1. Introduction

The goal of Intelligent Manufacturing (IM) is to provide simultaneously high-level intelligent automation and intelligent flexibility, rather than to settle for a compromise between the two goals. In some cases it may be easier to intelligently modify the layout, adding workstations or modifying the transport system, than to introduce the corresponding changes in the software. For this reason, although the control software is able to guarantee short-term limited flexibility, it cannot provide flexibility in the longer term [2].

During intelligent manufacturing the effect of different disturbances can be compensated for by using different sensors and advanced data processing systems based on artificial intelligence.

To replace partly the human intelligence with machine intelligence using monitoring is the goal of this development work. Machine intelligence means a number of abilities, for instance:

- To recognise environment,
- To avoid disturbances,
- To diagnose the failures autonomously,
- To replace the human intelligence, etc.

When using advanced control systems the sensory system provides data feedback to the controller of each system components to run the adaptive control happen in real time, thus providing for Machine Intelligence (IM). Based on these abilities the IM's are able to control all operations at the highest level without human inspection and intervention [2; 9].

2. Monitoring robot operations in assembly

The aim of the monitoring is to increase the intelligence and the reliability of the operations, to avoid the disturbances during operations.

The assembly is the last, but the most complicated operation in the production full with a lot of unforeseen events and disturbances. Their elimination needs a couple of sensors and intelligent mechanical robot peripherals.

A variety of sensors can be applied depending on the application, e.g. proximity sensors, force/torque, pressure sensors, CCD cameras, etc. A combination of different sensors provides excellent solutions to control complex operations. Proximity sensors give binary signals, but the other, intelligent sensors give analogue information continuously about the operations and peripheries.

The main intelligent abilities of the mechanical peripheries are the following[2]:

- Detection of the presence of the work piece, tools, etc. in the gripper or clamping fixtures or on the pallet, etc. by using proximity sensors,
- Detection of the position (orientation) of the elements and jaws of the grippers and the fixtures (open-closed-position, etc.) by using proximity sensors,
- Grasping force control and monitoring the grasping and clamping fixtures,
- Automatic changing the jaws of the grippers or fixtures for realizing the reliable clamping and positioning of the cylindrical or prismatic work pieces,
- Other task-oriented intelligent abilities.

2.1. Grasping force control and monitoring the grasping and the clamping fixtures

One of the intelligent tasks is the clamping and the grasping force/torque control and monitoring grippers and fixtures for the robotised production.

The aim of grasping force control is to increase the reliability of clamping operations and to decrease the deformation, damage of thin walled parts, work pieces with sensitive, high quality surfaces. In these cases precision grasp and power grasp system has to be provided.

Pneumatic grippers are frequently used up to the payload of 50-80 kg, where he grasping force is directly proportional to the air pressure, thus making the grasping forces controllable by monitoring and controlling the air pressure. The actual gripping pressure value can be measured by using a suitable strain gauge system, but other technique can also be used. The grasping force can be measured directly by force sensors built into the gripper[8].

There are two solutions available to control the air pressure:

- The air pressure can be controlled in discrete steps (0.5 bar) by using special pneumatic blocks. This system consists of a pressure regulator, a four-way magnet valve, a non-return valve and a pressure switch. The pneumatic blocks can be switched on via the robot control through its Output channels. The application of pressure sensors based on strain gauges can monitor the air pressure.
- The use of stepper motor to control the air supply unit can provide air pressure control. A strain gauge based pressure sensor monitors the actual pressure and the grasping force.

The resolution of the pressure measurement is ± 0,1 bar. In this system a computer controlled stepper motor is used. The steps, speed and torque of the motor are controlled by a purpose built unit complete with a control program in C++. The stepper motor operates the control gear of an air supply unit, which is able to change the air pressure. The pressure value is proportional to the grasping force.

A commercially available strain gauge based pressure sensory device is used to monitor the pressure. Figure 1/a. shows the board model of the control unit with pressure sensor and Figure 1/b the testing of the gripper grasping force monitoring using a strain gauge based force sensor built in the finger[8].

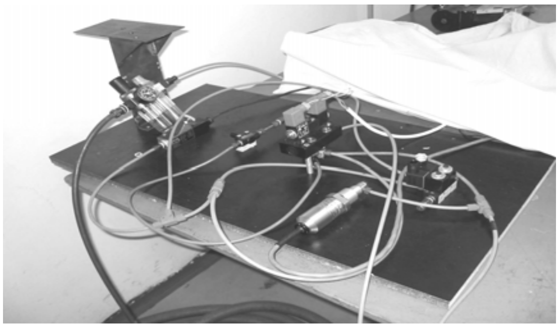


Fig. 1/a The board model of the air pressure control unit with pressure sensor

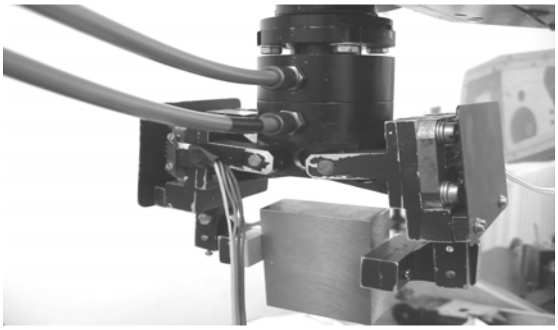


Fig. 1/b Force controlled grasping operation with force sensor built in the finger

2.2. Development of an intelligent end-effector

The aim is to provide in process continuous monitoring of the gripping force and torque values during the assembly. A Puma-760 robot equipped with a special gripper and a 6-axes force/ torque sensor was used in the tests. To measure the force in the robot finger, a strain gauge force sensor was integrated into the finger. The commercial 6-axes f/t sensor was developed by a Hungarian company Kaliber Ltd. Budapest.

2.2.1. Force/ torque sensors used in gripper applications

During the development of the gripper with measuring fingers based on strain gauge technique, several optical stress trials were made to find the magnitude, location and the distribution of the stresses and the direction of the main stresses.

Figure 2 shows this sensory gripper. Two special PC cards are used for data acquisition and signal processing to enable the cell controller to act on the measured force[3].

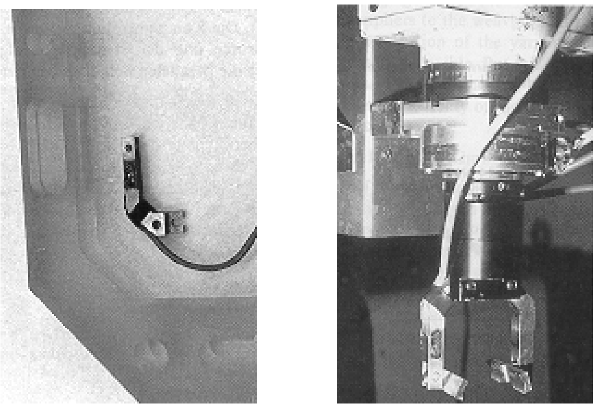


Fig. 2 The model made of plastic and the measuring finger (left) and gripper with measuring finger and 6-axis f/t sensor mounted in the last robot wrist (right)

The grasping force of the pneumatic robot gripper was controlled by air pressure control. The air pressure was controlled in discrete steps of 0.5 bar and it provided satisfactory results. The required level of air pressure is provided by the robot control through its output channels and a strain gauge based pressure sensor can monitor it. The sensor provides the robot control with information about the actual pressure value.

The main technical data of the sensory gripper is as follows:

- measuring range: F= 40 – 70 N (at 6 bar);
- stroke of the gripper: s = 40 mm (30 to 70 mm).

2.3. Development and Application of End-Effector Exchange Systems for Assembly Robots

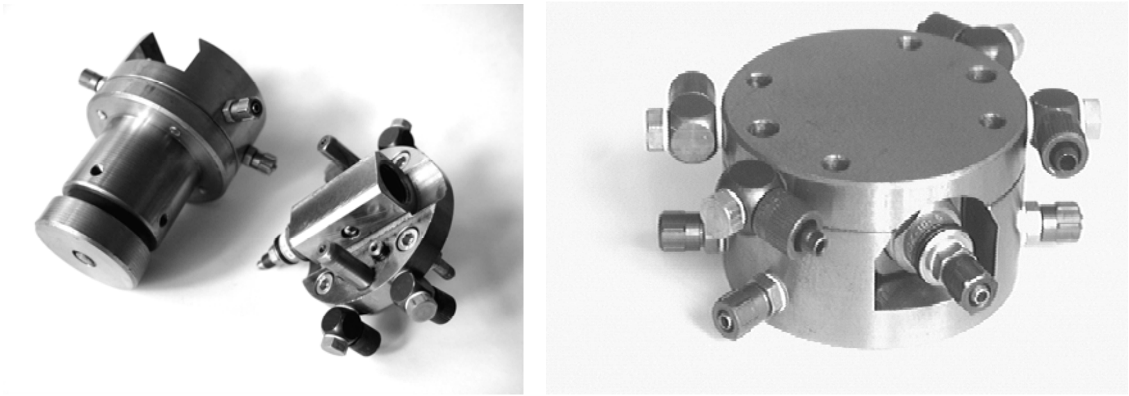
The robotized assembly can be realized by using lot of grippers, tools. These end-effectors have to be changed after the operations by using an automatic changer[1].

When developing changer device three important tasks should be solved:

- locating the two parts of the changers,
- clamping (locking and unlocking) the two parts in a well-defined position,
- signal transmission for power and information.

An end-effector changer consists of two parts. The active part with locked and unlocked mechanism and drive, cylinders, sensors for monitoring, etc. is built into the last wrist of the robot. The passive part is mounted on the end-effectors (grippers and tools). The exchange system can be locked or unlocked automatically by the robot controller. The monitoring of different operations can be realized by sensors (proximity, force, pressure sensors), built into end-effectors generally.

Our research group have developed and built a changer (Figure 3. left).



a.

b.

Fig. 3 Two parts of the tool changer (left) and the changer

For locating the two parts there are two holes with precision bush made of bronze in the active part of the changer. Two pins which are made of hardened steel are used for locating the pair of holes; one of them should be reduced. The two parts of the changer should be pushed together after locating to reach a loss-free connection of the pneumatic and electric channels. An O-ring is used to ensure that the cavity is sealed when contact is made. The solution to the electric signal transmission problem is to use a self made jack plug system (24 V DC, 5 A). The clamping system is based on two balls, which can be moved out by using a cone. The cone can be moved by a pneumatic micro-cylinder (FESTO). The changer has 4 pneumatic and 7 electrical channels to solve the energy and signal transfer between the two parts of the changer. The monitoring of the locking system consists of 2 optoelectrical proximity sensors. The load capacity of the changer is 10 kg.

The Figure 3. shows the changer. The changer was tested by using 3 measuring devices. During testing a cylindrical test piece was mounted on the passive part of the changer (Figure 3.a. left).

The most important measuring data are in the Table 1.

table 1. Measurement results of the testing of the third changer

Direction	Positioning accuracy (μm)	Static stiffness (N/mm)	Resonance frequency f_1 (Hz)	Resonance frequency f_2 (Hz)	Resonance frequency f_3 (Hz)
X	<± 13	3221	189	725	1043
Y	<± 15	451	131	242	908

2.4. Development and application of a sensory pneumatic gripper

For handling the work pieces in a machining cell we developed and built an intelligent gripper. The machining cell consists of a CNC-lathe and a machining centre. This gripper from a pallet can handle the work pieces into a pneumatic vice. For locating and clamping the work pieces the gripper has jaws in form V-block[3;4;9].

Fig. 4 Pneumatic sensory gripper during handling of cylindrical work piece

The Figure 4 shows the gripper during handling. The pneumatic gripper has a built-in optical proximity sensor, a 6-axes force/ torque sensor and a grasping force control unit. The payload is 10 kg and the maximal grasping force value is 150 N.

Nowadays there are a lot of efforts for handling and manipulating of smaller and smaller pieces. Actuations of several instruments in micro-technics are different from applied actuating principles in macro-technique. Since we can not make micro-technique instruments by the support of linear reduction of macro-technique instruments therefore we have to look for other solution. Gravitation by design of traditional robot gripper plays an important part, but by design of micro-grippers it is not so dominant part like frictional losses and adhesive forces. However mechanical grippers in both cases are the most acceptable for several tasks.

3. Micro-grippers and their actuating principles

3.1. Piezoelectric drive

Piezoelectric drive is often applied, which permit fast motion of micro-gripper. Piezoelectric micro-gripper requires high operating voltage and they are able to move just in small movement. However they can produce relatively big force. Frequently piezoelectric micro-gripper are made of silicon and transmission is required because of small movements. Their operating is based on a reversible energy conversion. Mechanical energy and electric energy are transformable back and forth in piezoelectric materials (e.g. $BaTiO_3$) [5]. If you apply voltage on piezoelectric crystal then it will be deformed, but it works vice versa. If you transmit mechanical energy to this crystal then potential difference will appear due to electrical polarization. The Figure 5 shows a piezo-driven micro-gripper and its prototype.

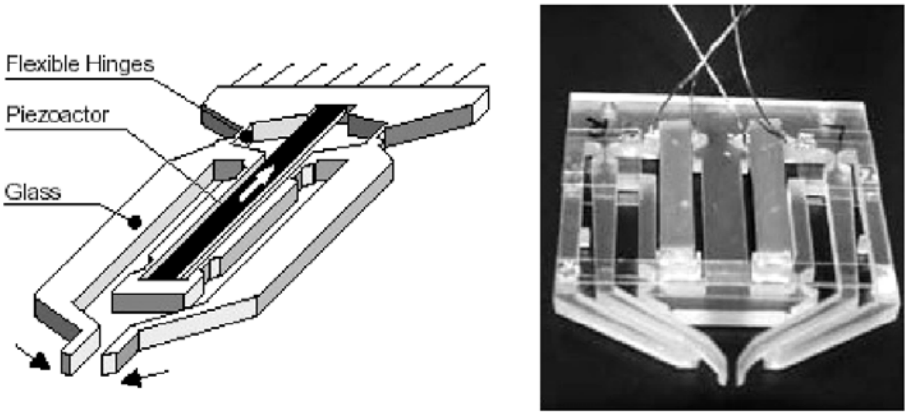


Fig.5 Scheme of piezo-driven micro-gripper and its prototype

3.2 Micro-gripper based on electromagnetic micro-actuator

The working principle of electromagnetic micro-actuator is simply to convert the electrical energy into mechanical action like force and torque. Figure illustrates the flexible micro-gripper (FMG) driven by electromagnetic fashion that was developed by in Suzuki in 1996. It is composed of two cantilever fingers and a body support part. The finger is made of a thin film cantilever silicon nitride and a micro-coil gold on its top.

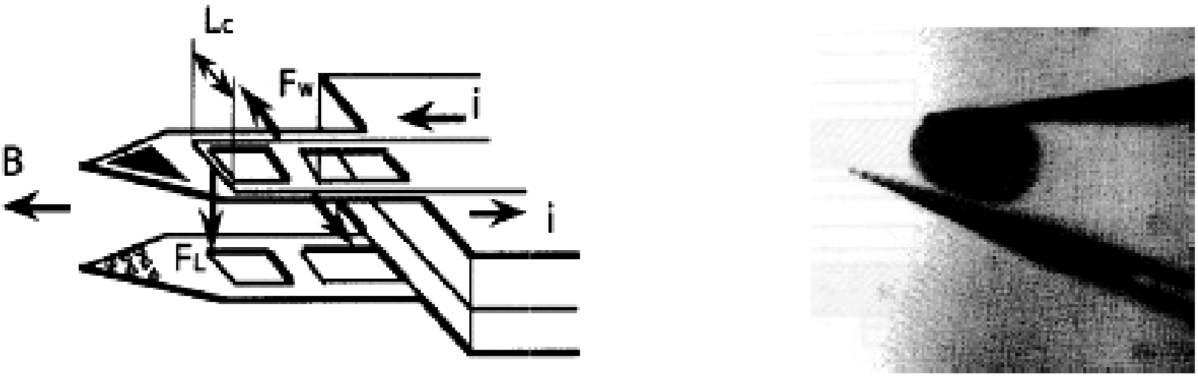


Fig.6 Electromagnetic micro-gripper and the sea urchin egg griping test

During the operation process, the electromagnetic force is generated by the interaction between the electric current of micro-coil and magnetic field of the permanent magnet, thus electromagnetic force F_L is directed perpendicular to the magnetic field to deflect the finger, while the appeared F_W does not affect the bending action. The testing is demonstrated to grip fine particles of polystyrene sea urchin eggs (~100 µm) in water [10].

The Figure 6 shows an electromagnetic micro gripper and a sea urchin egg griping test.

3.3 Drive with shape memory effect

Movement of micro-grippers with shape memory effect is materialized by spring and wire in most cases. These springs and wires are made of Shape Memory Alloy (SMA). Action of these instruments is founded on reversible conversion. Those grippers are made of shape memory alloy and get a permanent shape under a defined critical temperature, after warming-up they change their shape, but after cooling they return to their primary shape. This principle works in vacuum and sterile field too. This type is favourable solution from the point of view of cost thanks to better and better developing material research in industry. This way is especially suitable for actuation of micro-gripper because of big functional path and power of shape memory effect [7]. Disadvantage of these grippers is a relatively big reaction time. This attribute is typical of these solutions because these grippers work under change of temperature and dissipation of heat increases reaction time. The Figure 7 shows a SMA micro-gripper

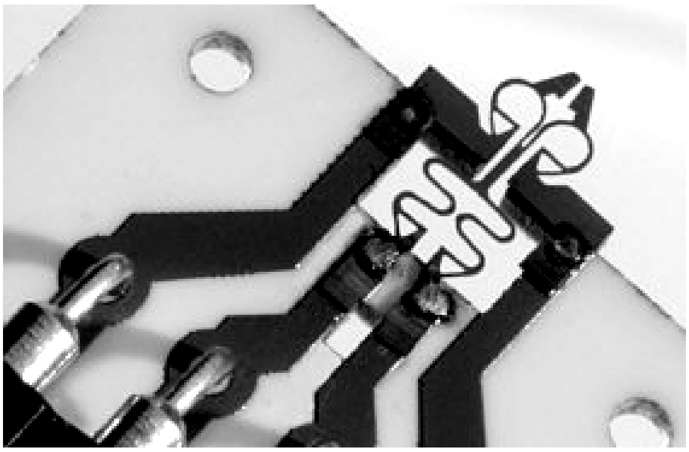


Fig.7 SMA micro-gripper for handling micro-optical components

4. Summary

Automated, robotic systems need a certain degree of intelligence to meet production and quality requirements. These intelligent robotic systems are based on a variety of sensory systems both internal and external to the robot to provide the necessary feedback information to the controller.

A number of sensory robotic system applications were introduced, including the use of various force controlled robot grippers, force-torque sensory intelligent end-effectors, end-effector changer and micro-grippers.

These end-effectors are mostly task-oriented devices, which have to be developed and built by the users in co-operation with expert of this field.

5. Acknowledgement

This R&D work was partly supported by Multi-Material Micro Manufacture: Technologies and Applications, Networks of Excellence (NMP2-CT-2004-500274), the CEEPUS RO-01, CEEPUS RO-104 and CEEPUS A-104 Projects. In the CEEPUS projects the author has been co-operating with other Technical Universities, among others with TU Vienna, TU Košice, Slovak Technical University of Bratislava, Faculty of Material Science and Technology Trnava and University of Maribor.

References

[1] Alpek, F.: Greifer - und Werkzeugwechselsysteme-Steigerung der Flexibilität von Montagerobotern *-e & i,* Wien, Vol.111. 6. 1994. pp. 305 – 309, ISSN 0938-1953

[2] Alpek, F.: Steps Towards Intelligent Assembly – Intelligent Mechanical Robot Peripheries - Academic Journal of Manufacturing Engineering, Vol. 1. Number 1/2003. pp. 10-15. Editura Politehnica University of Timisoara.

[3] Alpek, F.; Kaldos, A.; Radulescu, C.: Increasing the Reliability of Robots using Intelligent Mechanical Peripheries. International Journal „Robotica & Management”, Supplement, 2004. pp. 4-11. ISSN 1453-2069. Romanian Society for Industrial Robotics.

[4] Berkes, G. : Development and Testing a Robotized Assembly Cell. Work on Diploma Thesis. TU Budapest. Dept. of Manufacturing Engineering, 1997. (in Hungarian).

[5] Fatikow, S.: Mikroroboter und Mikromontage; B. G. Teubner Stuttgart Leipzig, (2000)

[6] Hajduk, M.; Alpek, F.: Intelligent fixtures in applied robotics – Steps towards the intelligent manufacturing- Proceedings of 7. ROBTEP Conference, Vyšné Ružbachy. 2004. ISBN 80-073-134-9. pp. 220-225

[7] Just, E.: Entwicklung eines Formgedächtnis-Mikrogreifers; Forschungszentrum Karlsruhe, (2001)

[8] Krys, N.: Methods of increasing the reliability of robot grippers. Work on PhD Thesis. TU Budapest, 2004. Supervisor: F. Alpek.

[9] Velíšek, K.; Alpek, F.: Intelligent Fixtures in Robotized Production and Assembly Automation. Part I. Research Papers, Faculty of Material Science and Technology, Slovak University of Technology in Trnava, Number 14, 2003. pp. 101-108. ISSN 1336-1589.

[10] Wen Shing; Hung.: A study on the design and analysis of micro-gripper for microassembly; National Sun Yat-Sen University, (2003)