Hybrid device for automatic assembly

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Abstract. This paper presents a hybrid device for experimental investigation of the possibilities for enhances of the assembly processes’ quality. The developed hybrid device provides a successful running of the assembly, surmounting certain errors in the positioning of the parts and fending from breakage situations during wedging and jamming of the assembled parts. In the paper is presented in detail the device’s control system as two levels hierarchical structure.

1. Introduction
Till now there is no unified approach for determination of the requirements towards the functional capabilities and the structure of the control systems used in robotic complexes. Two basic methods for functional description with aim of formalisation of those requirements are described in the specialised literature:

1. The first method is related to a description of the control system’s configuration. In that case, basic attention is paid to the composition of technical resources ‘operated’ at the process of control and the option of the information channels between them. All ‘non-standard’ technical equipment and information channels are taken circumstantially.

2. The second method is related to the algorithm of the control system. The circulation of instructions, commands and signals in the complex ‘operator – control system – measurement – executive mechanisms’ supports the control process, while the variety of language resources used for those reasons, admits the functional possibilities of the control system to be estimated.

The basic task of the hybrid accommodation device is the increase of the quality of the assembly process providing successful running and continuation of the assembly, surmounting certain errors in the positioning of the parts. The hybrid device consists of: Force/Torque sensor; Device for passive accommodation with remote centre of compliance (RCC); Block for active accommodation; Control system.

In this paper is presented in detail the control system as a hierarchical structure with two levels of control: Level of ‘elementary movements’, controlling the movements of the hybrid device’s manipulators and measuring the forces and the torques acting in the gripper and the Level of ‘logical control’, estimating the condition of the assembly process and providing control decisions for its continuation and eventual adaptation.

2. Apparatus structure of the control system
Nowadays preference is given to parcelled control systems. This definition describes the universal standard apparatus part, consisting of ‘intelligent’ modules on which the control program is based. The
functions are distributed on the separate modules in this program. The use of ‘intelligent’ devices – possessing their own microprocessor and operating system, capable of executing specific control tasks, shortens the term for development of the control system and allows the achievement of an optimal correlation price/possibilities. The control system of the hybrid device (Fig.1) is combined of the following equipment [1]:

1.1 Intelligent Dual axis DC Servo Controllers - (SB-212-I-SERV-2) including:

- Power supply and drives:
  - Two drives for DC BRUSH MOTORS
  - Built-in 330VA transformer.

- Built-in Safety equipment:
  - Error Handling Routines;
  - User defined automatic Error routines;
  - Hard wired Limit and Emergency switches;
  - Soft travel limits and programmable error limits.

- Position Measurement system:
  - Built-in Encoder interfaces - two for closed loop operation, or one for closed loop operation and one for Master-Slave operation.

- Position Controller providing the following motion modes:
  - Positioning with capability for linear and circular interpolations;
  - Regular speed (velocity);
  - Master - slave following;
  - Continuous path;
  - Arbitrary path composite of up to 1024 points.

- Command interpreter based on a high level ACSPL programming language, enabling the user to implement complex motion-time-event sequences and programs.

- Two data communication interfaces:
  - Programming unit interface - RS232C. Up to 8 controllers can be chained via the same

**Figure 1.** The control system of the hybrid device
serial link;
- Programmable controller (PLC) interface - The I/O port (16 uncommitted outputs and 14 to 16 uncommitted inputs).

1.2 Intelligent Multi-axis Force/Torque Sensor system including [2]:
- F/T Transducer, that converts forces and torque into analogue strain gage signals to the F/T controller. The transducer is commonly used mounted between the robot and the robot end-effector.
- Intelligent F/T controller with factory - installed F/T software:
  - The primary function of the F/T controller is to convert strain gage data to Cartesian force/torque components. Communication can be executed through the serial I/O (RS 232), the discrete I/O, or the optional parallel port.
  - The software allowed program to the F/T controller to monitor force and torque thresholds. The thresholds are programmed in statements (monitor conditions) that are stored in non-violate memory. The discrete I/O is used to select the monitor conditions to be scanned and output the programmed thresholds.

1.3 Programmable Logical Controller (PLC) [3] Simatic S5 95U
It configuration (number and type of in/outputs, CPU) depends on the specific task for co-ordination of the communication processes between the components of the system and its position of a logical controlling system able to make decisions for the priority of one or other elementary operations during the execution of the controlling program.

1.4 Standard Personal Computer (PC)
Uses the benefits of the standard computers for supply and control of a typical data base and hardware and combined with the simplicity of the Windows technologies does the work of the operator more comfortable in analysing the archive data, modelling the behaviour of the control system and the whole equipment and also in modification of the program.

![Hierarchical structure of the control system](image)

**Figure 2.** Hierarchical structure of the control system
The control system including the mentioned technical resources could be considered as a hierarchical system with two levels of control (Fig. 2):

- **First level** – level of ‘elementary movements’, including the servo controllers and the force/torque sensor, controls the movements of the manipulators of the device (axis Z – gripper, and axis X, Y – active accommodation) and measures the reactions of the forces in the gripper.
- **Second level** – level of the ‘logical control’, including the logical controller and the PC is connected with the estimation of the assembly process condition, the ruling decisions for its continuation, archivation of the conditions and possible adaptation.

As it is obvious from Fig. 2, the two control levels in the hierarchy are connected with specific information flows. Different circumscriptions defining the levels of competence of the active elements are clearly visible. The information exchange between the servo controllers and PLC, done in the same way as that between the force-torque sensor and PLC is based on the digital input and output of the devices and defines the configuration of the PLC. The existence of horizontal connection between the logical controller (PLC) and the personal computer (PC) shows a certain functional redundancy of technical resources in the second level of the system. In this situation a question arises – Is it possible all control functions of this level to be charged to only one device?

In the general case the logical control could be charged only to the PLC, which is adapted for conditions of manufacture and has the resources for information connections to the control systems of the external equipment – the assembly complex. In this particular case, the considered device (and to be more exact its control system) has experimental research character and all control algorithms could be partly modified. Therefore some extra algorithms and technical equipment for adaptation, collection of data for the development of the control process, creation, modification and set up of the existing algorithms of the control must be provided in the control system. And that is why the PC should be accepted as an optional device to be used in the experiments only.

### 3. Algorithmically structured control system

Generally the tasks for synthesis of control algorithms in complex systems use the hierarchical method, which successfully applies support of a clear structural organisation of the program supply, based on the technical resources included in the composition of the control system.

Four hierarchical levels of the control system functions could be defined (Fig. 3):

- **Level of planning** – including tasks connected with the formulation, editing and the setup of the different algorithms from the structure of the control system (control program). The resources for determination of these class tasks comply with the traditional resources for programming.
- **Level of co-ordination** – the algorithm for control of the technological process is interpreted as control instructions for:
  - Formation of elementary cuts of the working parts movement trajectory;
  - Change of the devices’ working modes (automatic, manual, transformation of the co-ordinate systems);
  - Change of the external equipment’s working modes – suspension/permission of the conveyer’s and the assembly robot’s work.

The instructions formulated on this level are the information input for the next level.

- **Level of elementary operations** – the received instructions are transferred into commands for control of the executable elements (servo movements). During the formation of those commands, the laws of manipulators’ movements must be synthesised (interpolation of the elementary segments and transformation of the co-ordinates).
- **Level servo-control** – last and lowest level in the hierarchy. It is formed from the control tasks of the movements of the different links, whose combined motion provides the required translation of the peg towards the bush.

The servo-modules are specialised equipment and in this concrete case development of algorithms for servo control level is not required. In the process of primary set up, during the connection of the
module to the mechanical system for movements a set-up of the coefficients of the positioning regulator is done using the program ACSI distributed by the manufacturer.

An essential feature of the device is the considering of the positioning control of the motion (positioning in point). In this case the target of the control is not a compensation of the errors caused by the current elementary movement, but a compensation of the summarised error provoked by the positioning of the assembly robot and a decrease of its influence towards the assembly process.

As it was previously mentioned, the experimental research character of the hybrid device requires the inclusion of accessory algorithms for adaptation and data collection of the controlled process. The algorithm for adaptation could be assumed to be a part of the co-ordination level. This algorithm works up the information of the force/torque sensor (indirection measurement of the relative position of the parts during the assembly process), and formulates an operator for corrections (a value of the elementary motions on the different axis), which during the process of calculation of the current fragment of the control program remains unchanged. By this method the processes of the sensor’s information work up and self-adaptation (correction of the program depending on the state of environment) are separated in time.

![Hierarchical levels of the control system functions](image)

Figure 3. Hierarchical levels of the control system functions

To the same level could be assumed also the algorithm for archivation of the position of the working devices and the balance of the forces and the torque in all stages of the control process, with an intention for development of adequate model for the reasons of the adaptation and the following generation of the control system. To a considerable extent the character and the content of the different program modules are defined by the type and the capabilities of the technical equipment that is included in the structure of the system for control. The force/torque sensor is special equipment. Its programming for the control reasons is included in the definition of the constrains of the forces’ value on the axis X, Y and Z and the conditions for their statement coding. A typical feature in this coding is the direct use of the testimonies as commands for the direction of the movements (the indication of the movement sent by the PLC directly in the registry for direction, in automatic mode of movement).
4. Development of test method and conducting experiments
The goal of the experiments to be carried out is to prove the functional applicability of the developed hybrid device for automatic assembly.

♦ analysis of the process for decreasing axes misalignment until reaching the necessary minimum for successful assembly;
♦ study of the assembly process between cylindrical surfaces with clearance comparing assembly processes with or without correction movements of the assembled parts;

The hybrid device and the chosen samples define a few changeable factors, which will vary during the experiments as:
- The material of the assembled parts for all experiments is: anneal steel for the pegs and anneal steel, aluminium and bronze for the bushes;
- The experiments are conducted with clearance among the assembled surfaces: 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09 and 0.1 mm;
- The initial axes misalignment $\varepsilon$ of the assembled surfaces can be set through the linear motion modules step $\Delta$, with an accuracy $\pm 0.0001$ mm;

![Figure 4. Fx variation during assembly process](image)

The $F_x$ variation during assembly process with passive and active accommodation is presented in Fig. 4. Force change during the chamfer crossing is the same because the RCC device does the correction.

5. Conclusion
The hybrid assembly device presented in this paper gave a possibility for complete investigation of the assembly process between round parts with clearance. It gives an opportunity for monitoring the force/torque conditions and the accommodation movements during the assembly process.

References
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