International Journal of Industrial Engineering and Management (IJIEM), Vol. 3 No 3, 2012, pp. 121-131
Available online at www.iim.ftn.uns.ac.rs/ijiem_journal.php
ISSN 2217-2661

UDK 621.88

Bionic Assembly System: working modes, control and scheduling

Branko Katalinic
Vienna University of Technology – Intelligent Manufacturing Systems Group, Vienna, Austria,
katalinic@mail.ift.tuwien.ac.at

Valentin E. Pryanichnikov
International laboratory "Sensorika", KIAM, Russian Academy of Science, Moscow, Russia,
val-rover@rambler.ru

Kanji Ueda
National Institute of Advanced Industrial Science and Technology (AIST) and the University of Tokyo, Tokyo, Japan, k-ueda@aist.go.jp

Paulina Cesarec
Vienna University of Technology – Intelligent Manufacturing Systems Group, Vienna, Austria,
cesarec@mail.ift.tuwien.ac.at

Ilya Kukushkin
Vienna University of Technology – Intelligent Manufacturing Systems Group, Vienna, Austria,
kukushkin@mail.ift.tuwien.ac.at

Roman Kettler
Vienna University of Technology – Intelligent Manufacturing Systems Group, Vienna, Austria,
kettler@mail.ift.tuwien.ac.at

Received (4 June 2012); Revised (18 September 2012); Accepted (23 September 2012)

Abstract

Innovations in the field of assembling systems are going in many directions. One of them is a creation of a new generation of automated assembly systems, based on natural phenomena. Bionic Assembly System (BAS) is a new concept of advanced assembling system, which combines two basic control structures and principles: centralized control system, based on the hierarchy and self-organizing control system, based on the heterarchy. This paper describes hybrid control structure, working scenarios, scheduling, reconfigurations and logic of working cycles during the assembly of one unlimited sequence of assembly orders. These systems have some additional possibilities for minimization of assembling time using system and layout reconfiguration. Different possibilities of the reconfiguration of BAS are shown in this paper.

Key words: *assembling, bionic assembly system, hybrid control structure, layout, reconfiguration, scheduling, self-organization*

1. INTRODUCTION

Migration of the products from the developed to developing countries is one of the main characteristics of modern time. One of the main reasons for this migration is labour low cost in developing countries. The products with an intensive human work are the best candidates for this migration. Typical approach of production of products in developing countries is divided in many simple steps. Developed countries are fighting against this migration in different ways, but the main are innovation and production automation.

Production of the products can be divided in following tasks: design, process planning, machining of parts, assembly. The complexity of those tasks and actual level of automation are very different. Assembly has the highest complexity of task and the lowest level of automation. This fact makes the products with intensive assembly value and time to the best migration candidates.

Innovation in the field of assembling is going in many directions. One of them is a creation of a new generation of automated assembly systems, based on natural phenomena, such as self-organization. There is a new concept of assembly system, proposed by Katalinic under the name “Bionic Assembly System”. The description of working elements, the system layout, functions and working scenarios and strategies are given in [1], [2] and in [6]. This is a hybrid type, which combines two basic control structures and principles: centralized control system, based on the hierarchy and self-organizing control system, based on the heterarchy.

The first one concept is well-known and it is the most used control concept in the industry up till now. The other one is very present in the nature, but almost not used in the industry.

There are many definitions of self-organization, [3], [4] and [5]. As told in [10] “The self-organization is one of the main patterns of the organization of material, energy and information in the nature. It is a present in inanimate and in the biological systems. The self-organization phenomenon is a present in the whole range of the size from less than atom till the whole universe. The self-organizing is a very complex phenomenon with many different phases. At the moment there is no one unique definition of self-organizing. But there are many definitions which are describing particular characteristics, affects and forms of self-organizing.”

Combination of those two concepts brings out the hybrid system. As shown at Fig.1. Basic control structures: hierarchy, heterarchy and hybrid.

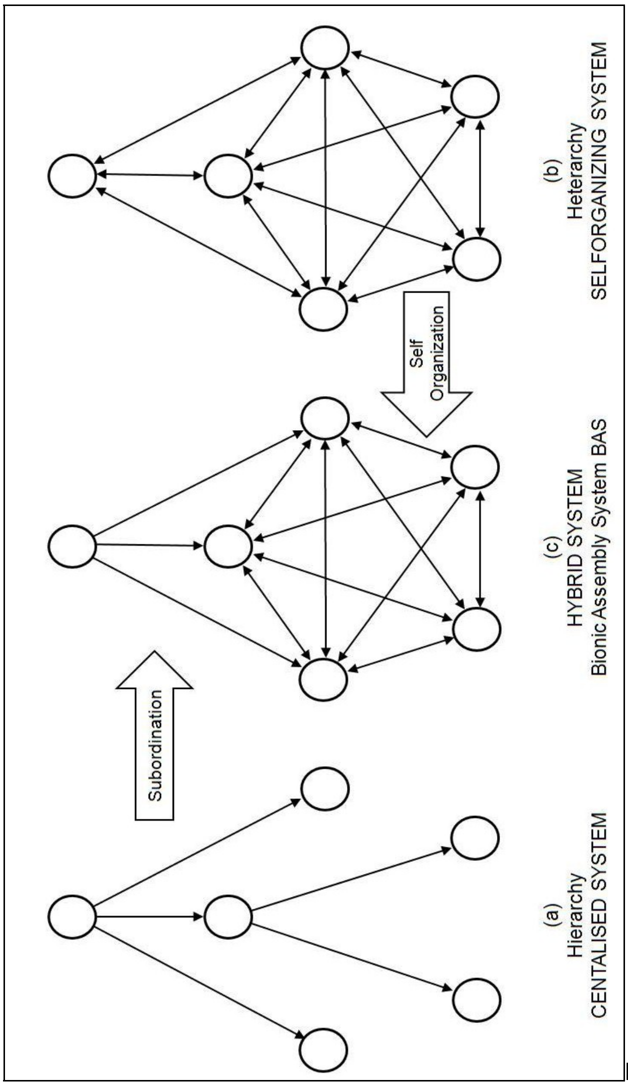
Actual design results of continuous research focused on the development and implementation of the next generation of assembling systems are presented in this paper.

2. RECONFIGURATIONS

Assembly stations and mobile robots are the key elements of kernel part of this system (Fig.2.). Assembly stations are machines which can complete one or more assembly operations on one or more different products. There can be more alternative assembly stations for the same assembly operation. Assembly station can be in one of three basic states: “working” (able to work and used), “passive” (able to work but not needed) and “out of function” (unable to work for any kind of reasons). Change of state of one or more stations “to working state” or “from working state” change the number of working stations and production abilities of assembly system. Changing of number of working stations in the system will be called “system reconfiguration”.

In the concept of bionic assembly system the assembly stations can be moveable in the shop floor ie the station can change its position and orientation, this change in layout of system here will be called “layout reconfiguration”. Layout reconfiguration changes the distances between stations and trajectories of mobile robots and time which is needed to complete transport order. Layout reconfiguration is in classical systems almost impossible, but in the future systems this ability is very welcome and very often studied system improvement.

Layout reconfiguration opens totally new possibilities and new ways in the optimization of production. Layout reconfigurations are bringing dynamic changes of layout and open variety of different possibilities how to complete one assembly system order.



FF

igure 1. Basic control structures: hierarchy, heterarchy and hybrid

Assembly of the product is completing step by step on assembly pallet, which is carried by mobile robot, from one to the next stations. In the comparison with the classical assembling systems this system has some additional possibilities for minimization of time for assembling one product and for assembling of one run. This can be achieved through the rearrangement of the queues for the first case and reconfiguration of layout, during the assembly for the second case. These two possibilities are investigated and presented in this paper.

3. DIFFERENT MODES OF ASSEMBLY PROCESS

3.1 Normal working mode

Each mobile robot gets an assembly order. It means to assemble one piece of one product. It follows step by step assembling plan of product to complete this order. Robot communicates with all assembly stations to find out, which station is able to complete next assembly operation. If there are more candidate stations, it is choosing station with the shortest completing time of operation.

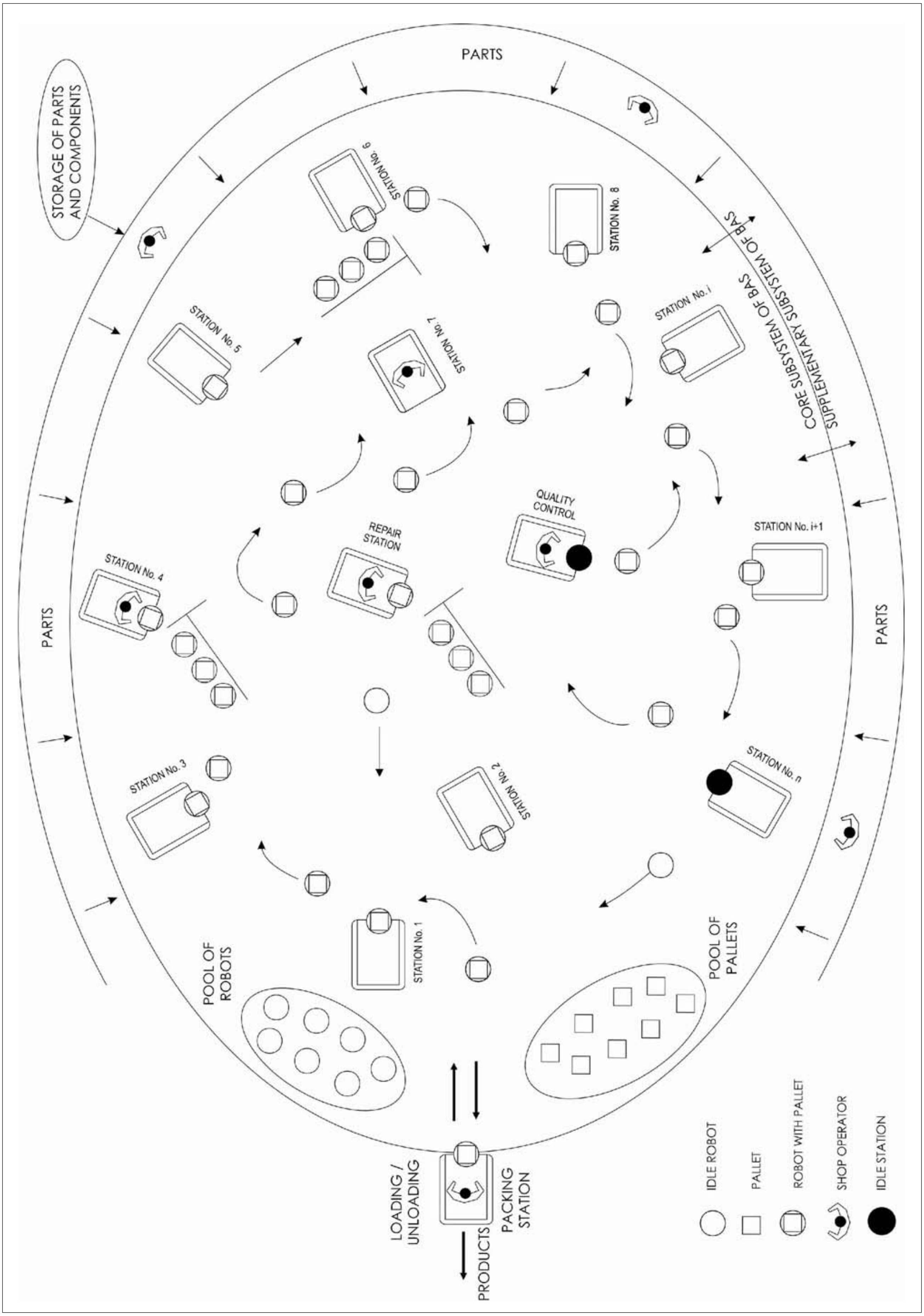


Figure 2. Layout of a Bionic Assembly System

It is very typical for assembly stations that there are waiting robots in the queue in front of the station as shown in (1).

$$ {}^{O_i}_{P_m}S_1 : \blacksquare\, {}^{O_i}_{P_m}R_1 \;\blacksquare\, {}^{O_i}_{P_m}R_2 \ldots \blacksquare\, {}^{O_i}_{P_m}R_{last} \qquad (1) $$

In front of the station S number one for operation i-th on m-th product are waiting robots on i-th operation in the assembling of m-th product, numbered from one till the last.

There are 3 priorities of orders (1 – high, 2 – normal, 3 – low). Typical situation in front of the one station is described at (2) and shown at Fig.3.A.

$$ {}^{O_i,O_j,O_k}_{P_m,P_n,P_l}S_1 : \blacksquare\, {}^{O_i}_{P_m}R^1_1 \;\blacksquare\, {}^{O_i}_{P_m}R^1_2 \ldots \blacksquare\, {}^{O_i}_{P_m}R^1_{Last} \;\blacksquare\, {}^{O_j}_{P_n}R^2_1 \;\blacksquare\, {}^{O_j}_{P_n}R^2_2 \ldots $$
$$ \ldots \blacksquare\, {}^{O_j}_{P_n}R^2_{Last} \;\blacksquare\, {}^{O_k}_{P_l}R^3_1 \;\blacksquare\, {}^{O_k}_{P_l}R^3_2 \;\ldots\; \blacksquare\, {}^{O_k}_{P_l}R^3_{Last} \qquad (2) $$

In station S it is possible to make i-th operation on m-th product, j-th operation n-th product and k-th operation on l-th product. The queues of the robots in the front of the station with the respect of priorities are formed in following sequence.

In front of the station S number one for i-th operation on m-th product, j-th operation n-th product and k-th operation on l-th product, are waiting robots on i-th operation in the assembling of m-th product, with the first priority, numbered from one till the last. Then, following robots on j-th operation in the assembling of n-th product, with the second priority, numbered from one till the last. The last in the queue are robots on k-th operation in the assembling of n-th product, with the third priority numbered from one till the last.

Shortest completing time of operation is a sum of waiting time in the queue in front of the station and assembling time at the station. All the robots in the system are following the trajectory based on the criteria of the “smallest time resistance” for next assembly operation. For the operation, which can be completed on more assembly stations it is necessary to solve the problem of changing a number of working stations.

3.2 Working mode after introduction of new alternative station

In the case of introduce of new stations it is necessary to rearrange the queue from the robots, waiting in front of the other station, as shown in (3).

$$ {}^{O_i,O_j,O_k}_{P_m,P_n,P_l}S_1 : \blacksquare\, {}^{O_i}_{P_m}R^1_1 \;\blacksquare\, {}^{O_i}_{P_m}R^1_2 \ldots \blacksquare\, {}^{O_i}_{P_m}R^1_{middle} \;\ldots\; \blacksquare\, {}^{O_i}_{P_m}R^1_{last} $$
$$ \blacksquare\, {}^{O_j}_{P_n}R^2_1 \;\blacksquare\, {}^{O_j}_{P_n}R^2_2 \ldots \blacksquare\, {}^{O_j}_{P_n}R^2_{middle} \ldots \blacksquare\, {}^{O_j}_{P_n}R^2_{last} $$
$$ \blacksquare\, {}^{O_k}_{P_l}R^3_1 \;\blacksquare\, {}^{O_k}_{P_l}R^3_2 \;\ldots\; \blacksquare\, {}^{O_k}_{P_l}R^3_{middle} \ldots \blacksquare\, {}^{O_k}_{P_l}R^3_{last} \qquad (3) $$

$$ {}^{O_i,O_j,O_k}_{P_m,P_n,P_l}S_2 : \text{Ready for the assembling} $$

The result of rearrangement of the queues is:

$$ {}^{O_i,O_j,O_k}_{P_m,P_n,P_l}S_1 : \blacksquare\, {}^{O_i}_{P_m}R^1_1 \;\blacksquare\, {}^{O_i}_{P_m}R^1_2 \ldots \blacksquare\, {}^{O_i}_{P_m}R^1_{middle} \;\blacksquare\, {}^{O_j}_{P_n}R^2_1 \;\blacksquare\, {}^{O_j}_{P_n}R^2_2 \;\ldots $$
$$ \ldots \blacksquare\, {}^{O_j}_{P_n}R^2_{middle} \;\blacksquare\, {}^{O_k}_{P_l}R^3_1 \;\blacksquare\, {}^{O_k}_{P_l}R^3_2 \;\ldots\; \blacksquare\, {}^{O_k}_{P_l}R^3_{middle} $$
$$ {}^{O_i,O_j,O_k}_{P_m,P_n,P_l}S_2 : \blacksquare\, {}^{O_i}_{P_m}R^1_{middle+1} \;\ldots\; \blacksquare\, {}^{O_i}_{P_m}R^1_{last} \;\blacksquare\, {}^{O_j}_{P_n}R^2_{middle+1} \ldots $$
$$ \ldots \blacksquare\, {}^{O_j}_{P_n}R^2_{last} \;\blacksquare\, {}^{O_k}_{P_l}R^3_{middle+1} \ldots \blacksquare\, {}^{O_k}_{P_l}R^3_{last} \qquad (4) $$

In front of the station number one for i-th, j-th and k-th operation on m-th, n-th and l-th product are waiting robots on i-th operation in the assembling of m-th product, with the first priority, numbered from one till the middle. Then, following robots on j-th operation in the assembling of n-th product, with the second priority, numbered from one till the middle. The last in the queue are robots on k-th operation in the assembling of n-th product, with the the third priority numbered from one till the middle.

In front of the station number two for i-th, j-th and k-th operation on m-th, n-th and l-th product are waiting robots on i-th operation in the assembling of m-th product, with the first priority, numbered from middle+1 till the end. Then, following robots on j-th operation in the assembling of n-th product, with the second priority, numbered from middle+1 till the end. The last in the queue are robots on k-th operation in the assembling of n-th product, with the the third priority numbered from middle+1 till the end, as shown in (4) and at Fig.3.B.

3.3 Working mode after failure of one alternative station

In front of the stations number one and two for i-th, j-th and k-th operation on m-th, n-th and l-th product are waiting robots on i-th operation in the assembling of m-th product, with the first priority, numbered from one till the last. Then, following robots on j-th operation in the assembling of n-th product, with the second priority, numbered from one till the last. The last in the queue are robots on k-th operation in the assembling of n-th product, with the third priority numbered from one till the last as shown in (5). In case of failure of the station number 2 mobile robots are moving to the station 1 in the following way:

Robots on i-th operation in the assembling of m-th product, with the first priority, numbered from one till the last are coming to the end of the queue of i-th operation in the assembling of m-th product, with the first priority, on the station two. Then, following robots on j-th operation in the assembling of n-th product, with the second priority, numbered from one till the last are rearranged with the same rule. The last is the rearrangement in the queue of robots on k-th operation

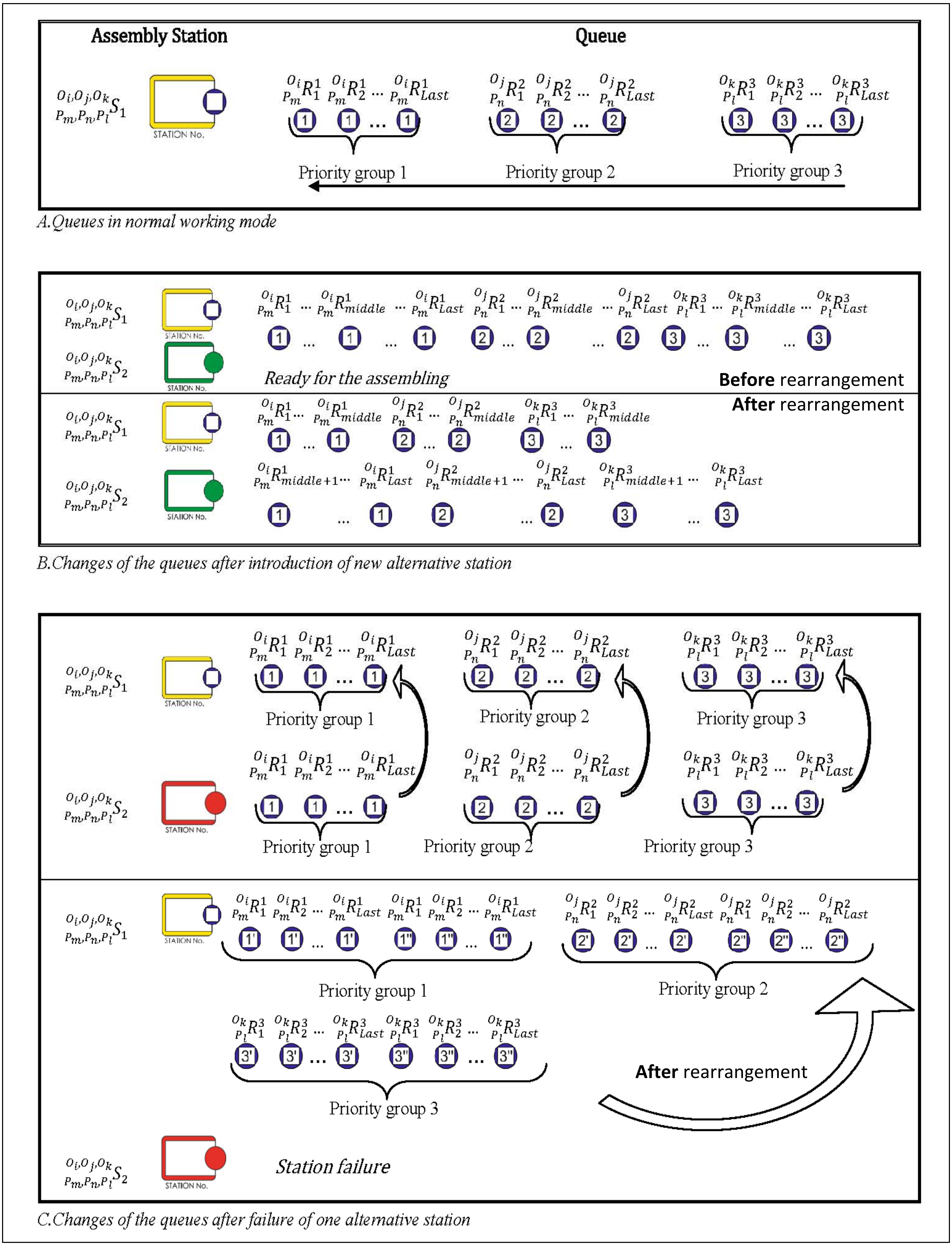


Figure 3. Queues states and rearrangements

in the assembling of n-th product, with the third priority numbered from one till the last.

$$
\begin{aligned}
{}^{O_i,O_j,O_k}_{P_m,P_n,P_l}S_1 :\ & \blacksquare\, {}^{O_i}_{P_m}R^1_1\ \blacksquare\, {}^{O_i}_{P_m}R^1_2 \ldots \blacksquare\, {}^{O_i}_{P_m}R^1_{last} \\
& \blacksquare\, {}^{O_j}_{P_n}R^2_1\ \blacksquare\, {}^{O_j}_{P_n}R^2_2 \ldots \blacksquare\, {}^{O_j}_{P_n}R^2_{last} \\
& \blacksquare\, {}^{O_k}_{P_l}R^3_1\ \blacksquare\, {}^{O_k}_{P_l}R^3_2 \ldots \blacksquare\, {}^{O_k}_{P_l}R^3_{last} \\
{}^{O_i,O_j,O_k}_{P_m,P_n,P_l}S_2 :\ & \blacksquare\, {}^{O_i}_{P_m}R^1_1\ \blacksquare\, {}^{O_i}_{P_m}R^1_2 \ldots \blacksquare\, {}^{O_i}_{P_m}R^1_{last} \\
& \blacksquare\, {}^{O_j}_{P_n}R^2_1\ \blacksquare\, {}^{O_j}_{P_n}R^2_2 \ldots \blacksquare\, {}^{O_j}_{P_n}R^2_{last} \\
& \blacksquare\, {}^{O_k}_{P_l}R^3_1\ \blacksquare\, {}^{O_k}_{P_l}R^3_2 \ldots \blacksquare\, {}^{O_k}_{P_l}R^3_{last}
\end{aligned}
\tag{5}
$$

The result of rearrangement of the queues is:

$$
\begin{aligned}
{}^{O_i,O_j,O_k}_{P_m,P_n,P_l}S_1 :\ & (\blacksquare\, {}^{O_i}_{P_m}R^1_1\ \blacksquare\, {}^{O_i}_{P_m}R^1_2 \ldots \blacksquare\, {}^{O_i}_{P_m}R^1_{last}) \\
& (\blacksquare\, {}^{O_i}_{P_m}R^1_1\ \blacksquare\, {}^{O_i}_{P_m}R^1_2 \ldots \blacksquare\, {}^{O_i}_{P_m}R^1_{last}) \\
& (\blacksquare\, {}^{O_j}_{P_n}R^2_1\ \blacksquare\, {}^{O_j}_{P_n}R^2_2 \ldots \blacksquare\, {}^{O_j}_{P_n}R^2_{last}) \\
& (\blacksquare\, {}^{O_j}_{P_n}R^2_1\ \blacksquare\, {}^{O_j}_{P_n}R^2_2 \ldots \blacksquare\, {}^{O_j}_{P_n}R^2_{last}) \\
& (\blacksquare\, {}^{O_k}_{P_l}R^3_1\ \blacksquare\, {}^{O_k}_{P_l}R^3_2 \ldots \blacksquare\, {}^{O_k}_{P_l}R^3_{last}) \\
& (\blacksquare\, {}^{O_k}_{P_l}R^3_1\ \blacksquare\, {}^{O_k}_{P_l}R^3_2 \ldots \blacksquare\, {}^{O_k}_{P_l}R^3_{last}) \\
{}^{O_i,O_j,O_k}_{P_m,P_n,P_l}S_2 :\ & \text{Out of function}
\end{aligned}
\tag{6}
$$

The rearrangement of queues in the case of failure of one alternative station is shown in (6) and at Fig. 3.C.

4. PLANNING

The main aim of planning BAS work is to achieve the highest possible productivity of BAS during the assembly of one unlimited sequence of orders. Maximal productivity means maximal number of assembled product during one particular period of time, taking into consideration the external priority of BAS orders, system's bottle-necks, limitations in the number of production facilities, and the limited capacity of each essential production unit. It is only possible to achieve the above-mentioned aim through the carrying out of all activities which are placed on the critical path in as short a time as possible. The work of assembly stations, mobile robots and operators has to be simultaneous and synchronized, based on the chosen BAS working scenario.

The interface between factory planning system and BAS is a pool of BAS orders as shown at Fig. 4. Each BAS order has an external priority as a measure of order urgency. Normal urgency is priority 2; urgent order is priority 1; and low priority order is 3. Locked orders have priority 0.

Scheduling optimization module has to find out the most suitable BAS order from the pool of BAS orders taking in to the consideration: target scenario, criterion of planning, actual state of BAS, free and reserved resources of system during the time planed.

The result of optimization is (sub)-optimal order. This order will be built in virtual scenario of BAS in the case of simulation or in working scenario of BAS in the case scheduling planning. The results obtained from scheduling planning give data which build the queues. The queues determine the order and sequence of pieces, in which different products will be assembled.

5. COMMUNICATION

Each single assembly module or assembly station has two-communication channels one vertical to BAS central computer and other horizontal to the mobile robots. Main tasks of central computer of BAS are to plan the global production of BAS, synchronize the part supply and setups, bring the demands from factory level, and organize the BAS as an integral part of factory. The horizontal communication between assembly station and mobile robot with the assembly pallet which carry one particular product from one to other assembly station in the search for the assembly station which can complete the next assembly operation is kernel part of self-organization of systems.

The assembly pallets are transported through the assembly system by lineless mobile robots. After each assembly operation the assembly station makes the quality check to find out, if the assembly operation has completed successfully if yes assembly station gives this information to the mobile robot.

This information has key role in the search for the station that can carry out the next assembly operation on the product of this type.

The horizontal communication between the control system of one assembly unit and the mobile robot includes following information: pallets type, palettes status, product type, assembly stage of product - which is next assembly operation on that product which has to be done, quality status of product - was the last assembly operation completed successfully. If the last assembly operation was not successful the quality status of product will be negative, and all assembly units will tell that they are not responsible for next operation. For such cases is in the system organized special repairing station. At this place the robots/pallets are waiting on the shop operators which will try to correct the part. If he cannot correct the mistake, he will move the product from the pallet and reset the pallet and send it to the system as new pallet free to take the first part of next product. After the product successfully completed all assembly operations and tests he will be removed from the pallet and packed for transport. The robot/pallet will be reset and send as the free robot/pallet back to the system.

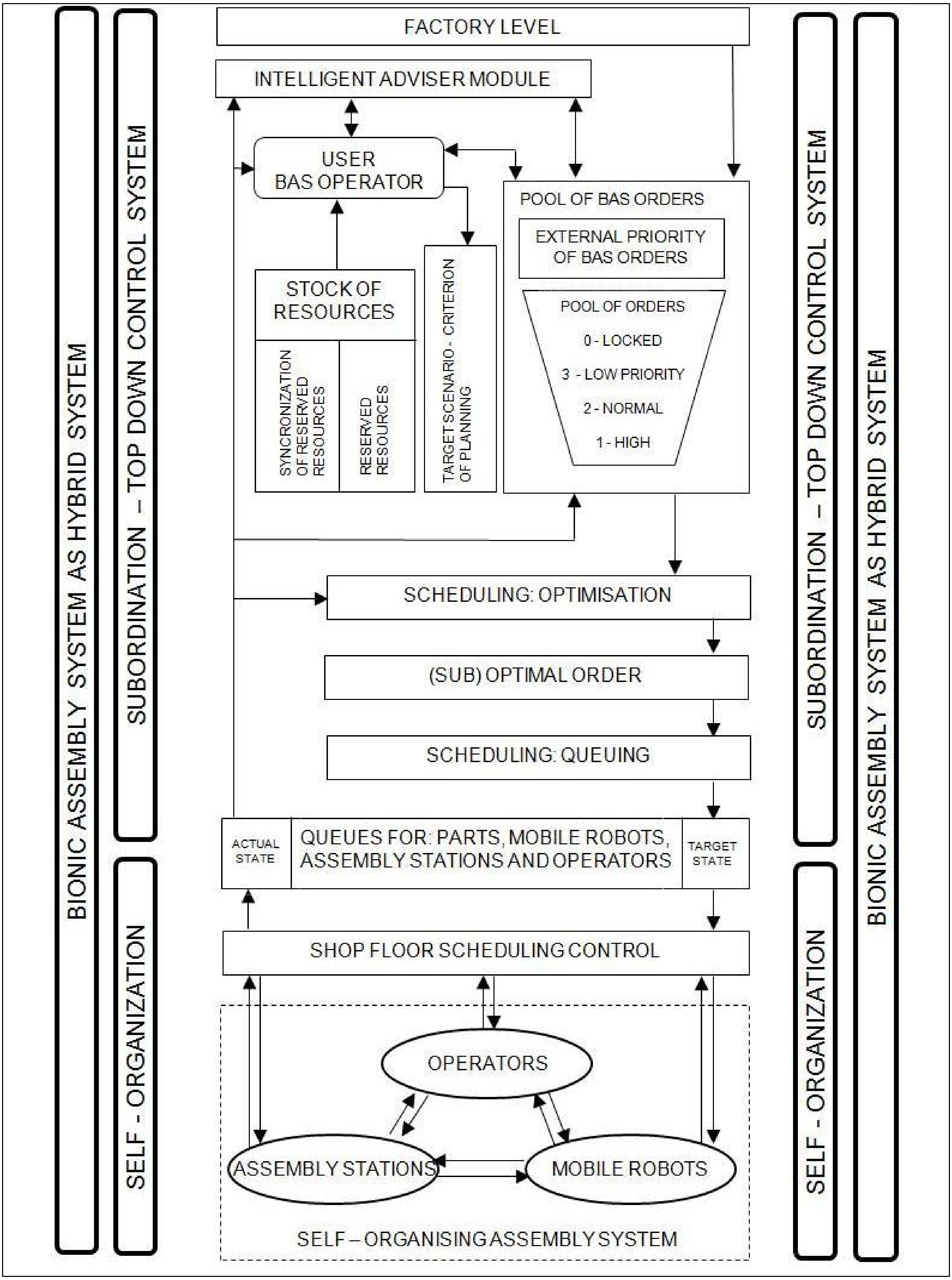


Figure 4. Hybrid Control Structure of Bionic Assembly System

6. SCHEDULING STRATEGIES

Scheduling strategies are designed to fulfill the key aim: Just-in-Time delivery of products according to the specification of customer order. The scheduling strategies are task oriented to fulfill the order for one particular customer in good time. That means one customer has ordered different quantities of different types of products, and all his products have to be assembled, packaged and prepared for the delivery and transportation at predefined day and time (yyyy-mm-dd hh:mm).

The first step in the production planning at the factory level is to combine orders from different customers to find out the best way to fulfill wishes of all customers. The result of this planning is called system order. It tells what and how many (product types and their runs) and how urgent (priority) has to be assembled during the next period of time. All unlocked orders in the pool of the orders are making the system order (Fig.4.) Assembling a run of one product type here is called as assembly order. The logic and hierarchy of working cycles during the completing of one system order are presented at Fig.6.

1. *Step:* The group of assembly orders with the highest priority is selected from the system order.
2. *Step:* From these group the first product type is selected
3. *Step:* The first piece in the run of that product type will be assembled.
4. *Step:* Mobile robot is getting order to assemble that piece. It takes suitable assembly pallet and goes from the assembly station for the assembling of the first part till the assembly station for the assembling of the last part of that piece and finally to the unloading and packaging station. During the assembling procedure mobile robot can have alternative ways. This is happening when one assembly operation can be completed by the different assembly stations or workers. During the selection of the most suitable station for the next assembly operation robot follows the criteria of “the shortest completing time” of the next assembly operation. The time for the completing of the next operation is the sum of the waiting time and operation time. During the assembling procedure of one piece of product mobile robot is coming to the different situations as shown at Fig.7. What to do in the particular situations can be determined with following “if-then” rules, shown in Fig.5. This assembly process is happening in the shop-floor and follows basic principles of self-organization. Participants in self-organizing process are mobile robots, assembly stations and shop-floor operators. This part is shown at the bottom of the Fig.4.
5. *Step:* The procedures 3, 4 are repeating until the very last piece of the run is assembled.
6. *Step:* The procedure is repeating for the next product type in the priority group.
7. *Step:* When the last product type in the priority group is assembled the whole procedure from step 2 till 6 is repeating for the next priority group.
8. *Step:* End of system order: when the last piece in the run of the last product type in the lowest priority group is finished, the system order is completed.
9. *Step:* It is a time to prepare the next system order for the time coming. Generation of system orders can be made also more continuously.

A_rule

if {the next step of assembly is packing}
then {the new assembly order, a robot has to go to the loading/unloading station}

B_rule

if {the quality state of product is negative}
then {the robot has to go the repair station. wait to the shop floor operator. the shop floor operator will try to repair the product. if this is not possible, he will remove it from the system, and will prepare the pallet and the mobile robot for assembling of the next (new) product. the results of repair operation: the state of assembly and the quality state}

C_rule

if {a assembly station becomes active or passive}
then {the rearrangement of the queues of alternative assembly stations}

D_rule

if {the quality state of product is positive and the next operation is assembly operation}
then {find out which assembly station(s) can perform the next assembly operation; if there are more than one, find out which is better, taking into consideration existing queues and priorities}

E_rule

if {the mobile robot is present and the assembly station is busy or there are waiting robot(s) with equal or higher priority or there are robot(s) of equal priority which are waiting for longer time}
then {the mobile robot has to wait in the queue of the assembly station for the next operation}

F_rule

if { the assembly station is free and there are no robot(s) with higher priority in the queue}
then {docking, execute assembly operation, check the quality of results of the assembly operation, write the new state of assembly and the quality state of product, undocking}

Figure 5. Mobile robots’ acting rules

```
Start
{
    For (i=1;i=iSYSTEM ORDER;i=i+1)
    {
    Completition of System Order in BAS according to the priorities starts with the highest priority (j=1) and finishes with the
    lowest priority (j=3)
            For (j=1;j=3;j=j+1)
            {
                    For (k=1;k=last;k=k+1)
                    {
                            For (l=1;l=lRUN;l=l+1)
                            {
                                    For (m=1;m=mLAST;m=m+1)
                                    {
                                            Find out and go to the most sutable assembly station and make
                                            Next assembly operation: ijklm_ASSSEMBLY_OPERATION ( )
                                    }
                                    l-th example of k-th product type is finished
                            }
                            Run of k-th product type is finished
                    }
                    Runs of all product types with j-th priority are finished
            }
            i-th system order for all priorities is finished
    }
    All system orders are finished
}
End
```

Figure 6. Logic of working cycles during the completing of BAS system orders

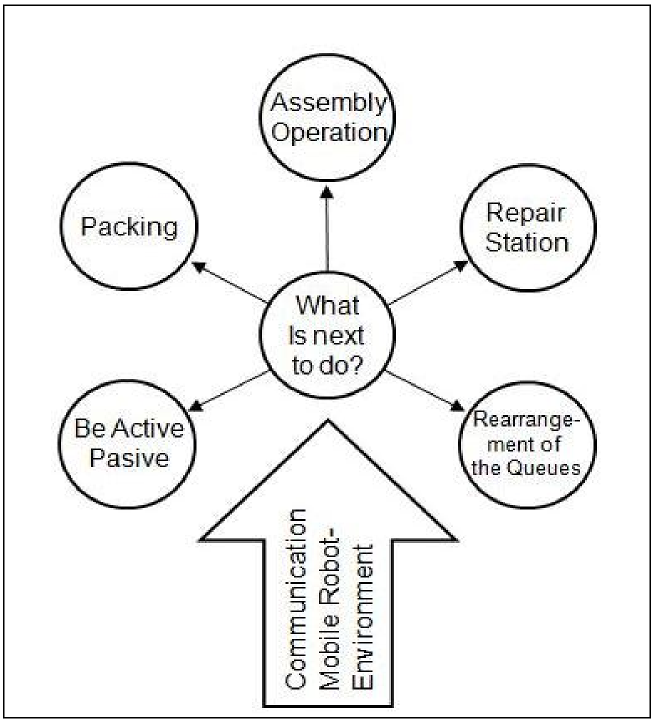


Figure 7. Five Basic Tasks for Mobile Robots

7. BAS BASIC CHARACTERISTICS

Bionic Assembly Systems are able to cover different needs in the exploitation in one better way than classical types of assembly systems, such as flexible assembly systems. The main characteristics of BAS are:

(1) The variable structure of system, the number of stations can vary from min 1 of each type to unlimited;
(2) This system is possible to organize as workers friendly system, which has the possibility to be high, automated from one side and has ability to integrate of workers from other side;
(3) Product mix and size of run can vary in extremely wide range;
(4) Self-organizing behavior of system make it robust against external and internal disturbances;
(5) Variable dynamic layout of system can be used for optimization of working scenario and system parameters;
(6) The BAS can very quickly respond on the demands of master scheduling system.

8. CONCLUSION

The proposed concept of Biologic Assembly System (BAS) is logical result of the further development of flexible assembly systems. The BAS has stronger characteristics of self-organizing, robustness, and adaptation. The main problem is the conflict between hierarchy and heterarchy. The concept is suitable for application by most complex flexible assembly systems. The concept accepts the variations in the structure of assembly system. Introducing of additional assembly stations without change scheduling strategies and scenarios can increase the capacity of system. This system is possible to organize as workers friendly system, which has the possibility to be high, automated from one side and has ability to integrate workers from other side. This characteristics of system open basically new trend in the development of automation, and that is the (re)integration of workers in high automated industrial environment. This development can be highly interested for the solving of present situation in development countries which have high rate of unemployed skilled people which cannot be integrated in classical automated systems. Variable layout of system can be used for optimization of working scenario and system parameters. The future research will be focused on dynamic system reconfiguration, layout reconfiguration, system starting procedures and solution of conflict situations between centralized and self-organizing parts of the control system. The system is suitable for integration in present computer integrated production structure at factory level.

9. ACKNOWLEDGEMENTS

This paper is supported by the Erasmus Mundus Action 2 Programme of the European Union.

10. REFERENCES

[1] Katalinic, B. Concept of Design and Scheduling of Self-Organising Complex Flexible Assembly System, *Proceedings of the 3rd International Workshop on Emergent Synthesis* - IWES 01, (Editors: P. Butala & K. Ueda), ISBN 961-4238-49-3, pp 89-96, March 12-13, 2001, Bled, Slovenia, 2001

[2] Katalinic, B. Design and Scheduling of Next Generation Self-organising Complex Flexible Assembly System Called Biologic Assembly Systems, *Proceedings of 2nd Asian Symposium on Automation and Robotics ASIAR'01* -Symposium at a Glance, Asian Institute of Technology, Bangkok, Thailand, 16th – 19th May, 2001

[3] *** http://www.merriam-webster.com/ dictionary/organization, *Accessed on:* 2012-02-27

[4] *** http://thesaurus.com/browse/ organization *Accessed on:* 2012-02-27

[5] *** http://www.businessdictionary.com/ definition/self-organization. html , *Accessed on:* 2012-02-29

[6] Katalinic, B., Visekruna, V. and Kordic, V. Bionic Assembly Systems: Design and Scheduling of Next Generation of Self-organizing Complex Flexible Assembly System in CIM environment, *Proceedings of The 35th CIRP International Seminar on Manufacturing Systems*, 12-15 May 2002, Seoul, Korea, 2002

[7] Kukushkin, I., Katalinic, B., Cesarec, P, and Kettler, R: Reconfiguration in Self-Organizing Systems*, Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium, ISBN 978-3-901509-83-4, ISSN 1726-9679, pp 0641-0642*, Editor Branko Katalinic, Published by DAAAM International, Vienna, Austria, 2011

[8] Pyanichnikov, V., Katalinic, B. and Platonov, A. Application of the autonomous mobile robots «AMUR» for the modeling of the self-organizing systems, (in Russian), UDK 681.518.3, Intellectual and Adaptive Robots, Vol. 6, No 1-2, 2011, pp 8-18

[9] Kito, T. and Ueda, K *Introducing Bounded Rationality into Self-Organization-Based Semiconductor Manufacturing,* 2008, Part 2, 65-73, DOI: 10.1007/978-3-540-76862-3_5, Dynamics in Logistics, Springer, 2008

[10] Katalinic, B., Cesarec, P., Stopper, M and Kettler, R. Self – organizing systems in nature and technology*, Proceedings of the 7th International DAAAM Baltic Conference, pp 346-351, ISBN 978-9985-59-982-2,* "Industrial Engineering, 22-24 April 2010, Tallinn, Estonia, 2010

[11] Katalinic, B. Collective Behaviors of an Interconnected Bionic Assembly System – Working Scenarios & Strategies, *Chapter 58 in DAAAM Internationals Scientific Book 2007*, B. Katalinic (Ed.), DAAAM International, ISBN 3-901509-60-7, ISSN 1726-9687, Vienna, Austria, 2007

[12] Berger, F.; Laengauer, C.; Hornung, J.; Hamilton, P.; Dolezal, C.; Zeitlinger, R. & Cesarec, P. Bionic Assembly System: Queuing, Technology Matrix And Life File, *Annals of DAAAM for 2009 & Proceedings of the 20th International DAAAM Symposium, 2009*, 20, 0021-0022, 2009

[13] Pyanichnikov, V., Platonov, A. and Katalinic, B. Supervisory Group Control of Mobile Technological Robots, *Report at the 1st Russian-German Seminar on Space Robotics*, Stuttgart, 2012-02-20, Karlsruhe Institute of Technology and German Airspace Academy, Stuttgart, 2012

[14] Ueda, K., Hatono, I., Fujii, N. and Vaario, J. Line-Less Production System Using Self-Organization: A Case Study for BMS. *Annals of the CIRP*, 2001; 50/1: 319-322.

[15] Ueda, K., Kito, T. and Fujii, N. Modelling Biological Manufacturing Systems with Bounded-Rational Agents. *Annals of the CIRP*, 2006; 55/1: 469-472.

[16] Ueda, K., Markus, A., Monostori, L., Kals, H.J.J. and Arai, T. Emergent Synthesis Methodologies for Manufacturing. *Annals of the CIRP*, 2001; 50/2: 335-365.

[17] Ueda, K., Vaario, J., and Ohkura, K. Modelling of Biological

[18] Manufacturing Systems for Dynamic Reconfiguration. *Annals of the CIRP*, 1997; 46/1: 343-346.

[19] Ueda, K., Vaario, J., Takeshita, T., and Hatono, I. An Emergent Synthetic Approach to Supply Networks. *Annals of the CIRP*, 1999; 48/1: 377-380.

[20] XIA Pingjun YAO Yingxue LIU Jiangsheng LI Jianguang, Generating Optimized Assembly Sequence by Virtual Reality and Bionic Algorithm, 2007-04, *Chinese Journal of Mechanical Engineering*

[21] Monostori, L., Vancza, J. and Kumara, S. Agent-Based Systems for Manufacturing, 55-2-2006, *CIRP Annals - Manufacturing Technology*

Bioničan montažni sistem: režimi rada, kontrola i planiranje rasporeda

Katalinic B., Pryanichnikov V. E., Ueda K., P. Cesarec, Kukushkin I. and Roman Kettler

Primljen (4. jun 2012.); Recenziran (18. septembar 2012.); Prihvaćen (23. septembar 2012.)

Apstrakt

Inovacije na polju montažnih sistema idu u mnogim pravcima. Jedan od njih je stvaranje nove generacije automatskih montažnih sistema zasnovanih na prirodnim fenomenima. Bioničan montažni sistem (BAS) je novi koncept naprednog montažnog sistema koji kombinuje dve osnovne kontrolne strukture i principa: centralizovan kontrolni sistem koji se zasniva na hijerarhiji i samoorganizujući *kontrolni sistem koji se zasniva na heterarhiji. Ovaj rad opisuje hibridnu kontrolnu strukturu, radne scenarije, planiranje rasporeda, konfiguracije i logiku radnih ciklusa tokom montaže jednog neograničenog niza montažnih naredbi. Ovi sistemi imaju neke dodatne mogućnosti za minimalizaciju vremena montaže uz korišćenje rekonfiguracije sistema i plana. Različite mogućnosti rekonfiguracije BAS sistema prikazane su u radu.*

Ključne reči: *montaža, bioničan montažni sistem, hibridna kontrolna struktura, plan, rekonfiguracija, raspored, samoorganizacija*