The Priority Manipulator's Configurations in Shipyards and its Preliminary Design

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Abstract. The great participation of direct human work characterizes today's shipbuilding industry. The actual status in development of science and technology makes possible the replacement of humans with industrial robots in a great number of these working places. The strategy of industrial robots introduction in shipyards has to be adapted to existing working conditions, and introduction has to be done gradually. The paper deals with a new method for priority setting of manipulator's configurations for surface protection and welding operations in shipyards, based on the Analytic Hierarchy Process. The numerical measure of priority of working places is based on the comparative pairwise judgments of social, psychological, technological, technical, safety, productivity and economical factors on different working locations. After the priority working places and priority working operations are chosen, the priority structures of adequate robots/manipulators are suggested according to their geometric, kinematic, dynamic and control characteristics.

Keywords. Industrial robots and manipulators, shipbuilding industry, surface protection, welding, priority setting, Analytic Hierarchy Process.

INTRODUCTION

The use of industrial robots in production operations is a relatively new aspect of manufacturing engineering. The development and implementation of robots applications generally follows the same basic sequence as any other manufacturing process. However, the robot's unique combinations requires some special considerations for succesful application |10|.

The use of industrial robots in shipbuilding industry is a quite new aspect, so there is not much experience from this field and existing data are very poor and unattainable |1,2,3,5,6,7|.

Today's shipbuilding industry is characterized with great participation of direct human work on hard, dangerous and fatiguing jobs. The actual status in development of science and technology makes possible the replacement of humans with industrial robots or with other automatic machines in a great number of these working places. The operations of surface cleaning, surface protection, coating, painting and welding are surely the operations which can be succesfully done by today's industrial robots.

The strategy of industrial robot introduction in shipyards has to be adapted to existing working conditions, and introduction has to be done gradually. The experience from other fields |4,10| confirms that the first robot installed at any location is the most important, and this fact was our motto throughout entire project and investigation. Our efforts in this project was oriented in these directions:

- to become thoroughly familiar with working locations and operations,
- to include workers and foremen in project and so to get their ideas and make them feel that they are part of the action,
- to get management to back aurselves up, because total commitment by everyone is

necessary for success,

- to be honest in answering questions from the workers,
- to provide comprehensive maintenance training of sufficient staff to cover all shifts and give them the tools necessary to do their jobs,
- to use our imagination and consider alternatives to the usual floor mounting of robots, or, not to simply imitate a man with a robot because there may be the better ways,
- to start with the simple applications (corollary of Murhpy´s law says "If you have 50%-50% chance of success, there is a 75% chance of failure").

It is obvious that the success of first robot application in shipyard is dependent on the efforts made to apply the above considerations. Anything less than maximum dedication to all of the above could result in some degree of failure.

Industrial processes today seems to consist of many complex nonlinear problems which feed one another. Every industrial plant can be described as a complex system of interacting factor. It is a network of factors whose causes and effects are not easily identified. Nearly all of us have been trought up to belive that clear headed logical thinking is our only sure way to face and solve complex problems. Our feelings and our judgments must be subjected to the rigorous test of deductive thinking. But experience suggests that deductive thinking is simply not natural, so we have to be trained, and for a long time, before we can do it well.

It is generally believed that because the industrial processes are so complicated, that to solve real problems in such a processes, we need to think in a complex way. In fact, we probably do not need a more complicated way of thinking. Most of us have difficulty examining even a few ideas at a time. We need an approach to organize our problems in complex structures but which also allow us to think about them one or two at a time. In other words, we need a conceptually simple and decisionally robust approach, so that we can use it easily and that it can handle real systems compliexities.

The Analytic Hierarchy Process (AHP) derived by Seaty |8,9| is such a problem solving framework. It is a systematic procudure for representing the elements of any problem. It organizes the basic rationality by breaking down a problem into its smaller constituent parts and calls for only simple pairwise comparison judgments to develop priorities in each hierarchy.

The Analytic Hierarchy Process does not insist on explanations. It provides a comprehensive framework to cope with the intuitive, the rational and the irrational in us all at the same time. It is a method we can use to integrate our perceptions and purposes into an overall synthesis. The Analytic Hierarchy Process does not require that judgments be consistent or even transitive. The degree of consistency of the judgments is revealed at the end of the process.

The Analytic Hierarchy Process has been for the first time used on the field of industrial robotisation by the authors of this paper |11,12| and the more details of this subject reader could find in these references.

PRIORITY SETTING OF SURFACE PROTECTION WORKING PLACES AND OPERATIONS IN SHIPYARD

The operations of surface protection in shipyards are very important, hard, dangerous and fatiquing jobs. For these reasons we chose surface protection operations for the first application of industrial robot in shipyard.

The problem was to decide which working places and operations in surface protection to chose for the first application of industrial robot. The first step is the decomposition of the problem as a hierarchy.

In the first level is the overall goal: "The right first application of industrial robot on surface protection operations in shipyard". In the second level are seven factors of criteria which are to be evaluated in terms of the criteria of the second level (Fig. 1.).

Factors of criteria are: sociological factor, fluctuation (SOC); psyhological factor, motivation (PSY); technological factor (TCO);technical factor (TCI); workers safety factor (SAF); productivity factor (PRO); economical factor (ECO).

Alternative locations are: iron sheet preparation (loc.A); pre-equipping on supports (loc.B) whith two (2) microlocations; slide way (loc.C) whith six (6) microlocations; equipping shore (loc.D) with seven (7) microlocations.

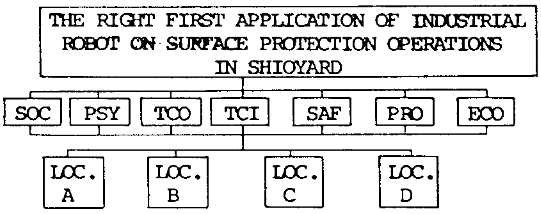

Fig. 1. Decomposition of the problem into a hierarchy

Applying the basical principles of Analytic Hierarchy Process the rang list of global priorities of observed microlocations occurs (Table 1).

TABLE 1 Rang-list of global priorities of observed microlocations for surface protection operations

Rang	Sign	Microlocation	GPI
1.	D1	Plating over sea level	0,1625
2.	C2	Plating under sea level	0,1416
3.	C1	Plating over sea level	0,1122
4.	D2	Deck	0,1085
5.	B2	Chimneys	0,0914
6.	D7	Super structure	0,0831
7.	D3	Store places	0,0777
8.	C3	Engine room	0,0488
9.	D6	Engine room	0,0358
10.	D4	Tanks	0,0327
11.	C4	Pump rooms	0,0308
12.	B1	Duble hull blocks	0,0215
13.	D5	Peak Tanks, wing tanks	0,0156
14.	C5	Duble hull blocks, peak and wing tanks	0,0153
15.	C6	Duble hull blocks for fuel and water	0,0097

GPI - Global Priority index

PRIORITY SETTING OF WELDING PLACES AND OPERATIONS IN SHIPYARD

Welding operations in shipyards are also very important, hard, dangerous and fatiquing jobs. These operations cover aproximately 28-30% of overall operations in shipbuilding industry, and about 38-40% of energy consumption in shipyards |5,7|. For these reasons mechanization or even robotization of these operation have to be one of the vital goals in terms of increasing productivity and effectivies in shipbuilding industry.

Welding operations in Shipbuilding "Split" are divided in two main areas:

1. welding operations for ship hull construction (BT),
2. all other welding operations (O).

This global division is made after detailed inspection of all the places and locations in shipbuilding industry "Split" where welding operations take place.

In these main areas we distinguish ten (5+5) main locations, and these locations are as follows:

1. Area BT (ship hull construction):
   - LP - panel line,
   - MP - small assembly line,
   - P - assembly line,
   - N - ship on pedestal,
   - S - special products line.
2. Area O (all other locations):
   - K - crane wheels,
   - AD - autocrane parts,
   - PM - motor and pump supports,
   - PC - pipes an tubes,
   - IT - heat exchangers.

All these locations are carefully inspected and welding operations and methods are systematicaly investigated. The aim of this project is to decide which working locations and operations to chose for the first application of industrial robot for welding. The first step is decomposition of this complex problem as a hierarchy. In the first level of the hierarchy is the overall goal: "The right first application of industrial robot on welding operations in shipyard". In the second level are seven factors of criteria, and in the last, third level are all locations divided in two areas (Fig. 2.).

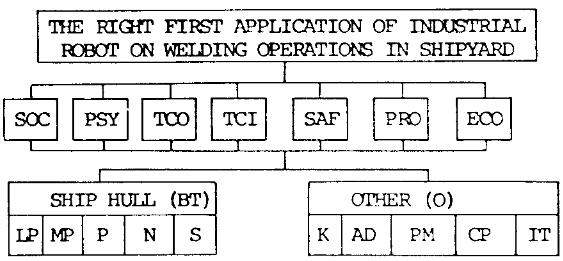

Fig. 2. Decomposition of new complex problem as a three-level hierarchy

In the same way as in the Chapter 2. the rang list of global priorities of all the locations for welding operations occurs (Table 2).

TABLE 2 Rang list of global priorities of observed locations for welding operations

rang	location	area	global priority vector
1.	P	BT	0,3100
2.	N	BT	0,1719
3.	MP	BT	0,1491
4.	LP	BT	0,1388
5.	S	BT	0,0738
6.	PM	O	0,0512
7.	CP	O	0,0448
8.	K	O	0,0229
9.	AD	O	0,0204
10.	IT	O	0,0170

PRIORITY SETTING OF MANIPULATOR STRUCTURES AND CONFIGURATIONS ON PRIORITY MICROLOCATIONS FOR SURFACE PROTECTION OPERATIONS

Applying the method of the Analytic Hierarchy Process the rang-list of priorities of observed microlocations for the right first application of industrial robot on surface protection jobs in Shipyard Industry "Split" was derived. After introducing the results of these general investigations on two types of ships (crude oil tank ships and general cargo ships) in terms of appropriate working surfaces and productivity costs, we get appropriate vectors of global priorites of microlocations for these two types of ships.

After detailed analysis we decided to chose the priority structure and configuration of manipulator at following microlocations and/or group of microlocations:

1. Microlocations C1 (plating over sea level on location C), D1 (plating over sea level on location D) and D3 (store places),
2. Microlocation C2 (plating under sea level),
3. Microlocation D4 (store tanks),
4. Microlocation B1 (double hull blocks).

The priority manipulator´s structure and configuration choice is a new complex problem and we decompose it on a new three level hierarchy. In the first level is the overall goal: "The right choice of manipulator´s structure and configuration on particular microlocation". In the second level are five new factors of criteria and in the third level there are manipulators-alternatives (Fig. 3.). New factors of criteria are: possibility of installing (PI); manipulator´s price (MP); control features (CF); working velocity (WV); energy consumption (EC).

Manipulators-alternatives are various structures and configurations of manipulators for particular microlocations (selfmoving manipulator - SM; manipulator on vehicle - MV; manipulator on rails - MR).

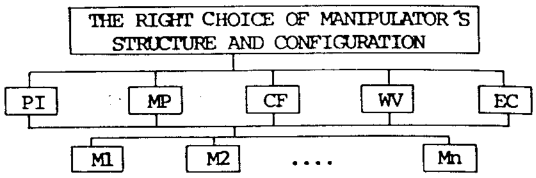

Fig. 3. Decomposition of the problem into a hierarchy

The pairwise comparison matrix of new factors of criteria is on Table 3.

TABLE 3 Pairwise comparison matrix of factors of criteria

	PI	MP	CF	WV	EC	PRIORITY VECTOR
PI	1	7	3	5	9	0,504
MP	1/7	1	1/4	1/5	2	0,055
CF	1/3	4	1	4	7	0,271
WV	1/5	5	1/4	1	4	0,135
EC	1/9	1/2	1/7	1/4	1	0,035

Using Analytic Hierarchy Process (pairwise comparisons and judgments, local priorities, principle of composition) we derived global vectors of priorities of manipulators-alternatives on particular microlocations and/or group of micrlocations. Basic design ideas of priority manipulators are on Fig. 4, 5, 6 and 7.

PRIORITY SETTING OF MANIPULATORS STRUCTURES AND CONFIGURATIONS ON PRIORITY LOCATION (ASSEMBLY LINE, P) FOR WELDING OPERATIONS

From Table 2 it is obvious that locations from area BT are on the top of priorities, and that location P (assembly line) is absolutely on the first place with "weighting factor" of 0,31. The conclusion is that location P (assembly line) from area BT (ship hull construction) is the right location for the first application of industrial robot on welding operations in shipyard "Split".

After applying the Analytic Hierarchy Process (decomposition of the problem as a three level hierarchy with new factors of criteria - weldment geometry, weldment approachability, safety and weldments lenghts and with new alternatives - flat stiffened sections, regular space sections, curved stiffened sections and irregular space sections) the rang-list of the priorities of ship hull sections occur and the flat stiffened sections are on the top of these rang-list.

After detailed analysis on the priority location P (assembly line) the next decision occurs: The robotisation of welding operations on this location has to be realized by two different types of robots/manipulators:

1. Great portal robot for welding of butt and fillet weldments on floor, vertical and horizontal positions,
2. universal portable lightweight robot for fillet overhead weldments, but also for all other types and positions of welding.

The basic assiqnment of great portal robot is welding of butt and fillet weldments on floor, vertical and horizontal weldments on location P (assembly line).

Manipulator of such a robot has two main parts, constructively separated but functionally connected in one entireness. These parts are portal carrier for two-dimensional X-Y positioning of manipulator arm(s) and flexible arm(s) with appropriate welding equipment (Fig. 8.). The dimensions of the portal carrier are defined with dimensions of standard sections, and typical sections in Shipbuilding industry "Split" have basic dimensions as follows:

lenght 10-14 m, extremely 16 m
width 6-12 m, extremely 16 m
height 0,85-2,5 m

The manipulator arm has to be very flexible, with 5,6 or even 7 degrees of freedom, of robust construction, with all necessary welding MIG/MAG equipment, actuators, sensors, etc.

The very different dimensions and shapes of ship hull sections and appropriate weldments make special requirements for programming and control of portal robot. The complete exploatation of portal robot possibilities could be achieved with off-line programming.

The primary task of universal portable robot is welding of fillet overhead weldments in space sections but also all other types and positions of welding.

Basic characteristics of such a robot are: lighweight, versatility reliability, ease of operation, serviceability and safety.

Manipulator of such a robot has to be of telescopic type, with four main degres of freedom: translation Z, rotations θ, $\emptyset$ and Ψ and with rotation δ of welding gun gripper (Fig. 9.). Working area is aproximately presented on Fig. 10.

CONCLUDING REMARKS

The conception of industrial robot introduction in shipyards has been developed. The AHP approach has been used as a complex problem-solving framework. The surface protection and welding operations have been analyzed. The numerical measures of priority of observed locations and operations have been derived. The priority structures and configurations of adequate manipulators for priority location have been determined and their basic preliminary designs have been suggested. The workers, foremen and authors have been working together througout the entire project and the results seem to be objective and real.

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Resumen. Los trabajos de protección superficial y soldaje en la industria naval, entre otras cosas, se caracterizan por la gran intervención del trabajo manual del hombre. El actual grado de desarrollo de la ciencia y la tecnología permiten la sustitución del hombre por robots industriales y manipuladores, en serie de puestos de trabajo y en distintas operaciones en relación con dichos trabajos.

En la presente exposición se describe un nuevo método para la elección de manipuladores de configuración prioritaria en distintos puestos de trabajo, dentro de los procesos de protección superficial y soldaje, basado en estudios analíticos multinivelares. Están determinados los indicadores numéricos prioritarios de diversas configuraciones de manipuladores, en distintas localizaciones navales.

Se presenta la solución teórica de manipuladores prioritarios, tanto para protección superficial como para soldaje.

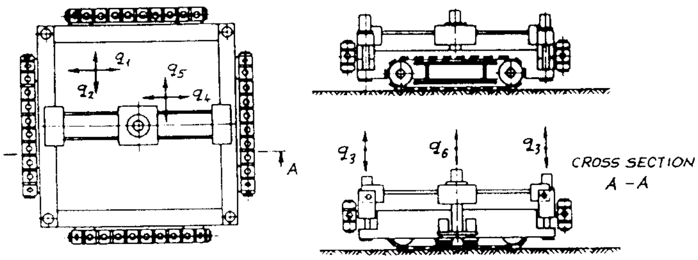

Fig. 4. Selfmoving caterpillar manipulator (SCM) for microlocations C1, D1, D3 and C2 for surface protection operations

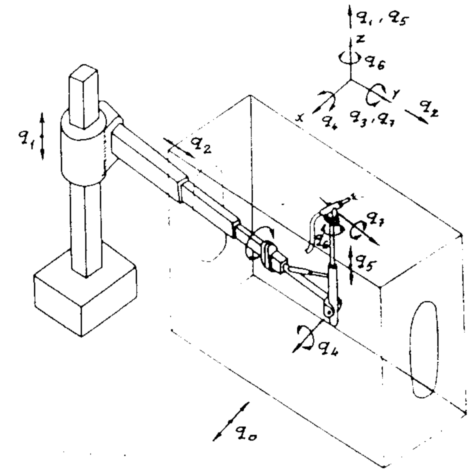

Fig. 5. One-hand fixed manipulator (F1M) for microlocation B1 for surface protection operations

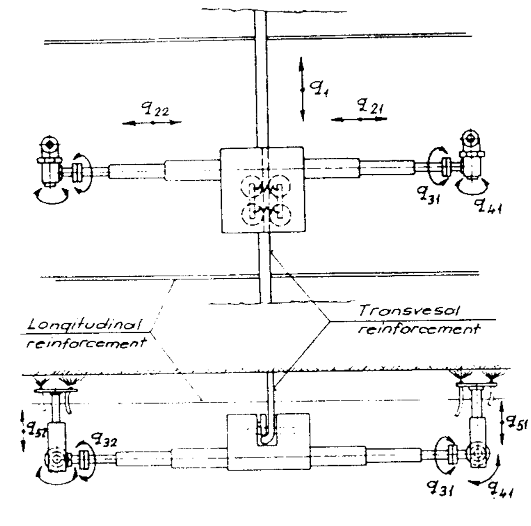

Fig. 7. Two-hand fixed manipulator (F2M) for microlocation D4 for surface protection operations

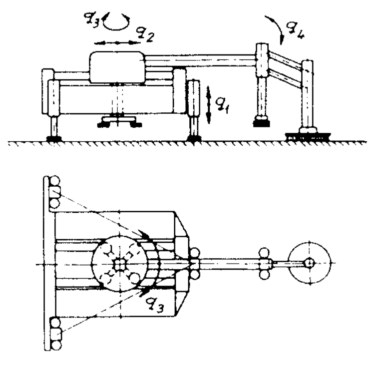

Fig. 6. Selfmoving legged manipulator (SLM) for microlocations C1, D1, D3 and C2 for surface protection operations

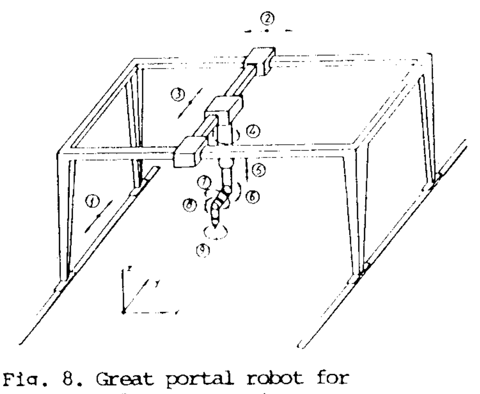

Fig. 8. Great portal robot for welding operations

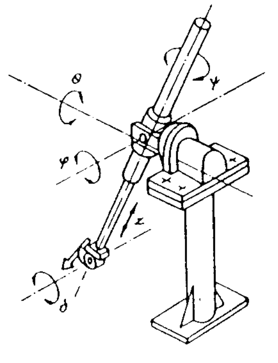

Fig. 9. Universal portable robot for welding operations

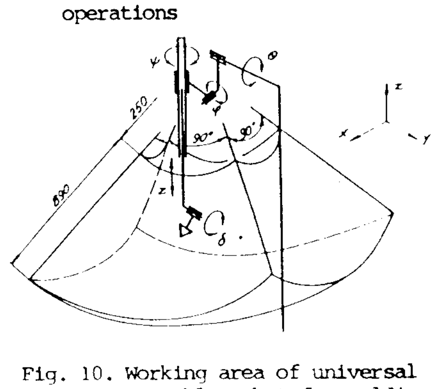

Fig. 10. Working area of universal portable robot for welding operations