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 successful 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 successfully 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 ourselves 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 alter-
  natives to the usual floor mounting of 
  robots, or, not to simply imitate a man 
  with a robot because there may be the bet-
  ter ways, 
- to start with the simple applications (co-
  rorary of Murph y’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 ro-
bot application in shipyard is dependent on 
the efforts made to apply the above consid-
erations. Anything less than maximum dedi-
cation 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 in-
teracting factor. It is a network of factors 
whose causes and effects are not easily 
identified. Nearly all of us have been tro-
ught up to believe 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 rig-
orous test of deductive thinking. But expe-
rience suggests that deductive thinking is 
simply not natural, so we have to be train-
ed, 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 pro-
cesses, we need to think in a complex way. 
In fact, we probably do not need a more com-
plicated 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 complexi-
ties.

The Analytic Hierarchy Process (AHP) deri-
ved by Seaty [8,9] is such a problem sol-
ving framework. It is a systematic procu-
dure for representing the elements of any 
problem. It organizes the basic rationali-
ty by breaking down a problem into its sma-
ller 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 com-
prehensive framework to cope with the in-
tuitive, 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 requi-
re 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 indu-
trial robotisation by the authors of this 
paper [11,12] and the more details of this 
subject reader could find in these refer-
ences.

PRIORITY SETTING OF SURFACE 
PROTECTION WORKING PLACES 
AND OPERATIONS IN SHIPYARD

The operations of surface protection in 
shipyards are very important, hard, dan-
gerous and fatiguing 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 protecti-
on to chose for the first application of 
industrial robot. The first step is the 
decomposition of the problem as a hie-
archy.

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 evalua-
ted in terms of the criteria of the second 
level (Fig. 1.).

Factors of criteria are: sociological fac-


tor, motivation (PSY); technological factor (TCO); technical factor (TCI); worker safety factor (SAF); productivity factor (PRO); economical factor (ECO).

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

Fig. 1. Decomposition of the problem into a hierarchy

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

<table>
<thead>
<tr>
<th>Rang</th>
<th>Sign</th>
<th>Microlocation</th>
<th>GPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D1</td>
<td>Plating over sea level</td>
<td>0,1625</td>
</tr>
<tr>
<td>2</td>
<td>C2</td>
<td>Plating under sea level</td>
<td>0,1416</td>
</tr>
<tr>
<td>3</td>
<td>C1</td>
<td>Plating over sea level</td>
<td>0,1122</td>
</tr>
<tr>
<td>4</td>
<td>D2</td>
<td>Deck</td>
<td>0,1085</td>
</tr>
<tr>
<td>5</td>
<td>B2</td>
<td>Chimneys</td>
<td>0,0914</td>
</tr>
<tr>
<td>6</td>
<td>C7</td>
<td>Super structure</td>
<td>0,0831</td>
</tr>
<tr>
<td>7</td>
<td>D3</td>
<td>Store places</td>
<td>0,0777</td>
</tr>
<tr>
<td>8</td>
<td>C3</td>
<td>Engine room</td>
<td>0,0488</td>
</tr>
<tr>
<td>9</td>
<td>D6</td>
<td>Engine room</td>
<td>0,0358</td>
</tr>
<tr>
<td>10</td>
<td>D4</td>
<td>Tanks</td>
<td>0,0327</td>
</tr>
<tr>
<td>11</td>
<td>C4</td>
<td>Pump rooms</td>
<td>0,0308</td>
</tr>
<tr>
<td>12</td>
<td>B1</td>
<td>Duble hull blocks</td>
<td>0,0215</td>
</tr>
<tr>
<td>13</td>
<td>D5</td>
<td>Peak Tanks, wing tanks</td>
<td>0,0156</td>
</tr>
<tr>
<td>14</td>
<td>C5</td>
<td>Duble hull blocks, peak and wing tanks</td>
<td>0,0153</td>
</tr>
<tr>
<td>15</td>
<td>C6</td>
<td>Duble hull blocks for fuel and water</td>
<td>0,0097</td>
</tr>
</tbody>
</table>

GPI - Global Priority Index

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 systematically 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  Range list of global priorities of observed locations for welding operations

<table>
<thead>
<tr>
<th>rank</th>
<th>location</th>
<th>area</th>
<th>global priority vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>P</td>
<td>BT</td>
<td>0.3100</td>
</tr>
<tr>
<td>2.</td>
<td>N</td>
<td>BT</td>
<td>0.1719</td>
</tr>
<tr>
<td>3.</td>
<td>MP</td>
<td>BT</td>
<td>0.1491</td>
</tr>
<tr>
<td>4.</td>
<td>LP</td>
<td>BT</td>
<td>0.1388</td>
</tr>
<tr>
<td>5.</td>
<td>S</td>
<td>BT</td>
<td>0.0738</td>
</tr>
<tr>
<td>6.</td>
<td>PM</td>
<td>O</td>
<td>0.0512</td>
</tr>
<tr>
<td>7.</td>
<td>CP</td>
<td>O</td>
<td>0.0448</td>
</tr>
<tr>
<td>8.</td>
<td>K</td>
<td>O</td>
<td>0.0229</td>
</tr>
<tr>
<td>9.</td>
<td>AD</td>
<td>O</td>
<td>0.0204</td>
</tr>
<tr>
<td>10.</td>
<td>IT</td>
<td>O</td>
<td>0.0170</td>
</tr>
</tbody>
</table>

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

Applying the method of the Analytic Hierarchy Process the range-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 priorities of microlocations for these two types of ships.

After detailed analysis we decided to choose 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),

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 (self-moving manipulator - SM; manipulator on vehicle - MV; manipulator on rails - MR).

THE RIGHT CHOICE OF MANIPULATOR'S STRUCTURE AND CONFIGURATION

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

<table>
<thead>
<tr>
<th></th>
<th>PI</th>
<th>MP</th>
<th>CF</th>
<th>WV</th>
<th>EC</th>
<th>PRIORITY VECTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>1</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>9</td>
<td>0,504</td>
</tr>
<tr>
<td>MP</td>
<td>1/7</td>
<td>1</td>
<td>1/4</td>
<td>1/5</td>
<td>2</td>
<td>0,055</td>
</tr>
<tr>
<td>CF</td>
<td>1/4</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>0,271</td>
</tr>
<tr>
<td>WV</td>
<td>1/2</td>
<td>5</td>
<td>1/4</td>
<td>1</td>
<td>4</td>
<td>0,135</td>
</tr>
<tr>
<td>EC</td>
<td>1/4</td>
<td>1/2</td>
<td>1/7</td>
<td>1/4</td>
<td>1</td>
<td>0,035</td>
</tr>
</tbody>
</table>

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 microlocations. 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 lengths 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 assignment 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:

- length 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 exploitation 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: lightweight, versatility, reliability, ease of operation, serviceability and safety.

Manipulator of such a robot has to be of telescopic type, with four main degree of freedom: translation Z, rotations θ, φ and Ψ and with rotation δ of welding gun gripper (Fig. 9.). Working area is approximately 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 throughout the entire project and the results seem to be objective and real.

REFERENCES

[1] Aono; Robots for Shipyards, common research study of MITI (Ministry of International Trade and Industry), JIRA (Japan Industrial Robot Association) and MOTO (Ministry of transport), Japan, 1984.

Resumen. Los trabajos de protección superficial y soldaje en la industria naval, entre otras cosas, se caracterizan por la gran intervención 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 multivariados. Están determinados los indicadores manométricos 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. Self-moving caterpillar manipulator (SCM) for microlocations C1, D1, D3 and C2 for surface protection operations

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

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

Fig. 7. Two-hand fixed manipulator (FHM) for microlocation D4 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