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PRACTICAL METHOD OF CONSTRUCTING MECHATRONICAL PRODUCTS

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Abstract: A team of students was formed at the Faculty of Mechanical Engineering in Podgorica with the task of developing its own solution for autonomous robot and presentation of the robot at one of the worlds' contests. Being that a robot is typical mechatronical device, in order to develop such product, knowledge in the field of mechanical engineering, electrical engineering and mechatronics was needed, so that was a motive for selecting students of mechanical engineering, electrical engineering and mechatronics as a team members. This team took part at the Robot Challenge competition, held in Vienna, Austria, on 29th and 30th of March, 2014, competing in the Puck Collect discipline. Construction of an autonomic mobile robot for collecting pucks of different color is developed using the methodological procedure of constructing. This article describes steps used in developing construction and shows the final design solution.
Keywords: mechatronics, autonomic mobile robot, construction, design solution

1. INTRODUCTION - PUCK COLLECT DISCIPLINE

Robot Challenge is a competition that is being organized since 2004 and up until now over 1500 different autonomous robots was presented since then. Puck Collect is one among the several disciplines organized at this competition. This particular discipline requires the robot to move around the field, collect the pucks of appropriate colour and dispose them in its own base. During the competitive round two robots compete against each other. One of the robots has the task of disposing blue pucks, while the other one should deliver red pucks for the time period of 3 minutes. Each properly disposed puck counts for one point. If the disposed puck is in inappropriate colour, team is counted for one negative point. Round winner is the robot (and the team) which collects more points. Court dimensions are 2500x2500 [mm]. Bases (one blue, and the other red) are placed diagonally. Their dimensions are 700x700 [mm]. Ten red and ten blue pucks (with diameter of 40 mm, and height of 20 mm) are randomly distributed on the court (Figure 1).

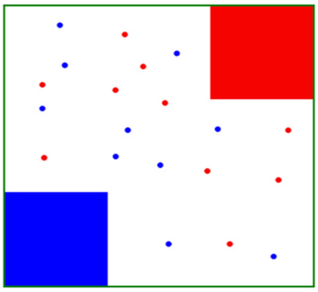


Figure 1. Court and the randomly distributed pucks

2. METHODOLOGICAL PROCEDURE OF CONSTRUCTING

Development of construction for the puck collecting mobile robot is based on methodological procedure of constructing. Constructors' experience and intuition have the dominant role in conventional methods for constructing. Regarding this, engineer was often in situation to choose the solution that seemed the most suitable at the moment, without comprehensive analysis of all the possible solutions and factors that define technical and economical validity of the product. Considering all mentioned, methodological approach tends to develop the process of construction as a general method that could be applied for the realisation of any constructors task, not only for individual cases. Methodological approach tends to include logical thinking to a greater extent in the process of constructing, while suppressing intuition, subjective decisions and "blind" following of a seemingly good idea, at the same time. This approach does not neglect constructors' talent and intuition, but improves ones creativity and directs him/her on the development of new, better and more optimal solutions, while simplifying and rationalising process, regarding time and resources consumption.

Multiple methods in the field of methodological approach in constructing occurred with the development of science of constructing. Methods differ from one another in terms of complexity and approaches on problem solution. Method called "Practical method of product construction" is being developed at the Faculty of Mechanical Engineering in Podgorica for the past fifteen years. It can be used for development of new or modification of existing products. This method focuses on finding more optimal and more creative solutions through the realisation of appropriate physical effects. Procedure implies seven logically dependant and mutually conditioned steps:

- task defining and change of properties,
- functional structure (logical model of construction),
- principles of solutions (physical model of construction),
- configuration of construction (objective model of construction),
- solution improvement (interference and fault analysis),
- selection of the most optimal solution and
- development of design details.

2.1. Task defining and change of properties

This phase implies comprehensive analysis regarding possibility of realization and market placement of the product, investors' requirements, etc. Previous, similar, solutions are observed and analyzed, good ideas are pointed out, adequate literature is collected as well as all the important information. It is necessary to define all the requirements that derive from comprehensive analysis and place them into the requirements list consisted of three categories: fixed requirements, tolerated requirements and wishes.

All of these requirements derive from the investors' requests, market analysis, customer needs, etc., depending on for whom is product being developed and quantity of units that need to be produced. Fixed requirements are those whose fulfilment is unconditional. Therefore, all the solutions that are not up to those requirements are considered unsuitable and eliminated at the beginning. Tolerated requirements are the requirements that have a breach, or interval within whom the solution could be found. It would be good if wishes could be fulfilled, but it is not obligatory. Wishes represent the main criteria for selection of optimal solution among the solutions that fulfil previous two categories of requirements. Table 1 shows the list of requirements for the puck collecting robot.

Table 1. List of requirements for the puck collecting robot

List of requirements		
Fixed	Tolerated	Wishes
Autonomous operation of robot	Robot dimensions: up to 500x500 [mm]	Minimal costs of production
		Minimal costs of materials
	Time for task realisation: up to 3 minutes	Simple design
		Good mobility
		Higher speed of robot

2.2. Functional structure (logical model of construction)

Overall function of the product should be defined in one sentence. In this particular case, that sentence is: "It is necessary to create an autonomous mobile robot which will move around the court, collect pucks in appropriate colour and dispose them to the defined location." Overall function needs to be disassembled in multiple partial and elementary functions. Partial functions contain defined and existing solutions (i.e. gears, heat exchanger, etc.), while elementary functions are based on application of appropriate physical effects. In this particular case, overall function is disassembled into the following partial and elementary functions: motion, collecting, (puck) colour identification, sorting, storing, detecting an appropriate base, and disposal (of pucks). By combining partial and elementary functions, various functional structures can be formed. Some of the possible functional structures are shown in the Figure 2.

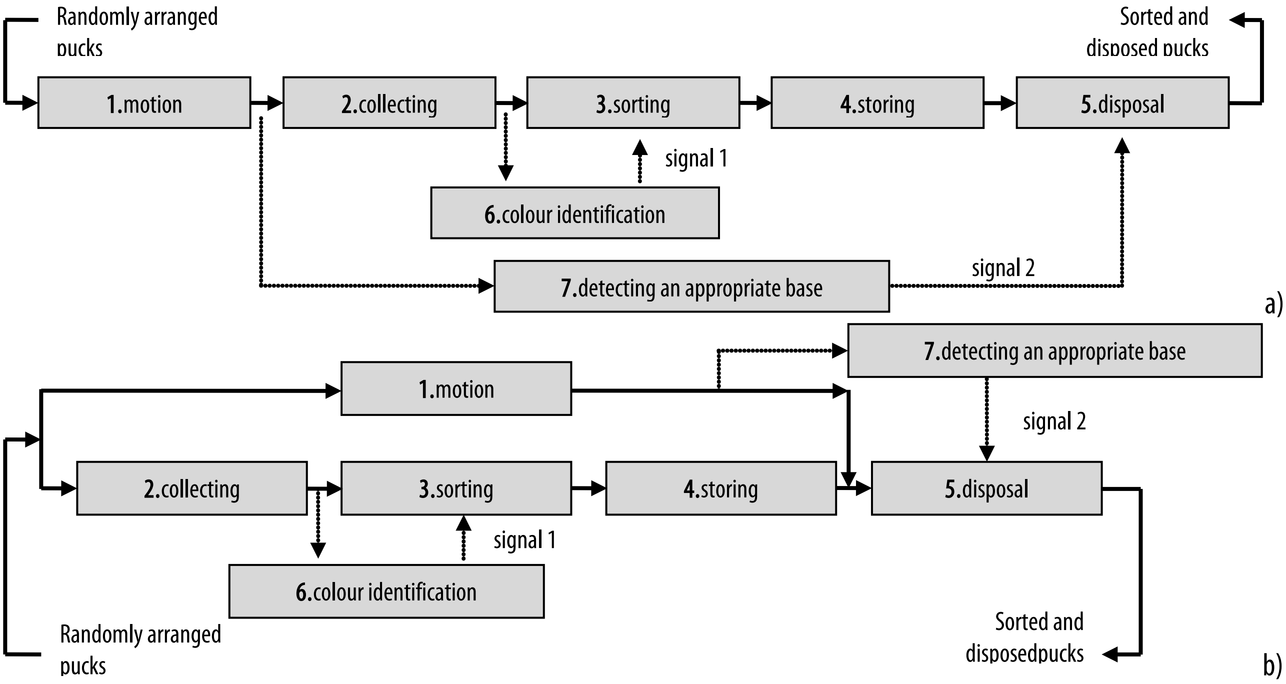


Figure 2. Functional structures for the autonomous mobile puck collecting robot

Next step is forming of a list for selection of an optimal functional structure. Each functional structure is evaluated with the "+" or the "-" sign based on the questions that derive from the list of requests:

- is the functional structure appropriate for the technical task,
- are the requirements fulfilled,
- is realisation of the project possible,
- is the development of the construction simple,
- are the material, manufacturing and maintenance costs optimal, etc?

Only the functional structures evaluated with all the "+"'s are appropriate for the next phase.

3. PRINCIPLES OF SOLUTION (physical model of construction)

It is necessary to define all the possible physical effects, which represent potential solutions of partial functions, for the previously disassembled overall functional structure. It is recommended to come up with as many solutions as possible during this phase, and write them down – even the ones that are not entirely fulfilling tasks' requirements. Each solution needs to be numbered, sketched and (if possible) described with appropriate equation. Principles of solutions for the partial function "sorting" are shown in the Table2. All the other partial and elementary functions should be treated in this manner.

Table 2. Principles of solutions for the partial function "Sorting"

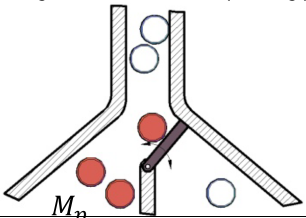
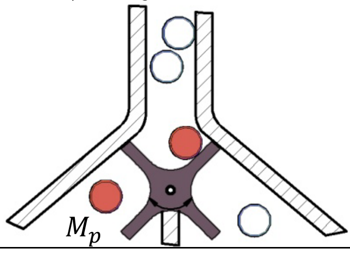
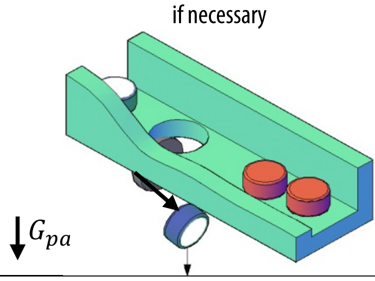
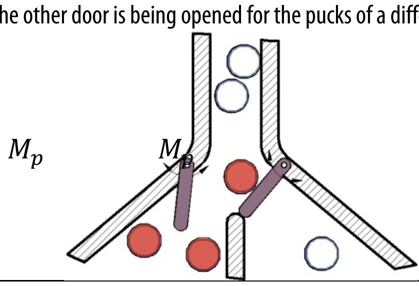
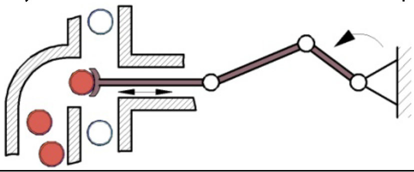
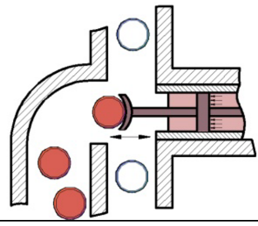
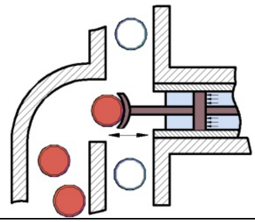
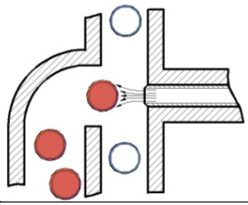
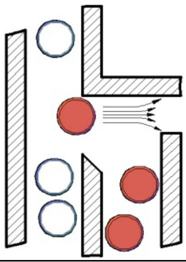
3.Partial function: **SORTING**			
Field of physics	Physical effect	Principle solution	Solution no.
Mechanics	Rotational motion of the septum $M_p \geq M_i = J \cdot \varepsilon$	Sorting is done by a single septum that would be in a right or left position depending on the colour of the upcoming puck 	3.1
Mechanics	Rotational motion of the rotating element $M_p \geq M_i + F_{tr} \cdot h$ $M_p \geq J \cdot \varepsilon + G_{pak} \cdot \mu \cdot h$	Sorting is done by rotating element with barriers (septum) 	3.2
Mechanics	Effect of free fall (free fall of the puck through the gape) $G_{pak} = m \cdot g$ $v_{pak} = \sqrt{2 \cdot g \cdot h}$ Rotational motion of gapes' door $M_p = M_i = J \cdot \varepsilon$	Sorting is done by a channel with a gape at its bottom which would open and close if necessary 	3.3
Mechanics	Rotational motion of the door $M_p = M_i = J \cdot \varepsilon$	Sorting is done by two doors. One door is being opened for the pucks of one colour, and the other door is being opened for the pucks of a different colour. 	3.4

Table 2. Principles of solutions for the partial function "Sorting" (continuing)

3.Partial function: **SORTING**			
Field of physics	Physical effect	Principle solution	Solution no.
Mechanics (mechanisms)	Impact force of the element (slider) into the puck – action force $F = m \cdot a$	Sorting is done by element which would divert the direction of pucks' motion 	3.5
Hydraulics	Impact force of the element (piston) into the puck – action force $F = m \cdot a$	Sorting is done by element which would divert the direction of pucks' motion 	3.6
Pneumatics	Impact force of the element (piston) into the puck – action force $F = m \cdot a$	Sorting is done by element which would divert the direction of pucks' motion 	3.7
Fluid mechanics	Air flow	Sorting is done by air flow which would divert the direction of pucks' motion 	3.8
Fluid mechanics	Suction force	Sorting is done by suction of elements of an appropriate colour 	3.9

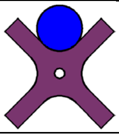
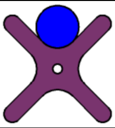
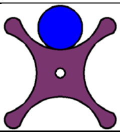
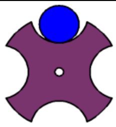
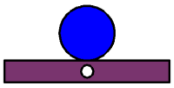
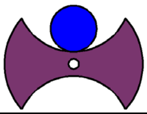
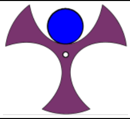
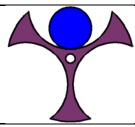
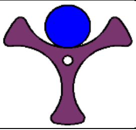
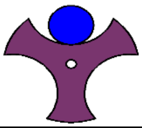
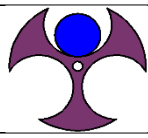
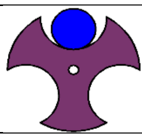
All the proposed principles of solutions are evaluated in the same manner as the functional structures in the previous phase. So called morphological box is being created out of the positively evaluated solutions. Afterwards, basing on the principle of compatibility, solutions are combined and various conceptual variants are formed in that manner. Conceptual variants need to be evaluated in reference to the criteria formed according to the list of requirements. Each criterion, based on its significance, has its own weight factor. Each criterion for conceptual variant can be evaluated with a degree from 0 to 4. That depends on a degree of fulfilment of conceptual variant in reference to a criterion based on list of requirements. Total value obtained by multiplication of weight factor and degree of fulfilment for each criterion represents the basis used for further evaluation of optimal solutions.

4. CONFIGURATION OF CONSTRUCTION

4.1. Objective model of construction

It is necessary to form a three-dimensional model of construction which will be capable of reproducing the previously defined physical effects in the previous phase, based on the optimal conceptual variant. This phase implies certain calculations and estimates that will enable quality synthesis of individual elements of construction. First step is forming of a basic dispositional sketch for the principle solution. Basing on the dispositional sketch, constructional variants are formed. They are all based on the same physical effects, but differ from one another regarding form, quantity, dimensions and position of working bodies and surfaces. List of conceptual variants for the adopted and optimal solution for partial function "Sorting" is shown in the Table3. List of conceptual variants for other partial functions is also formed in this manner.

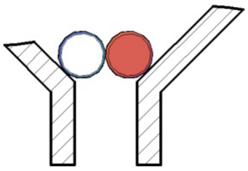
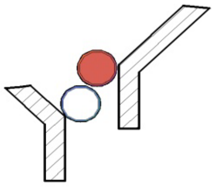
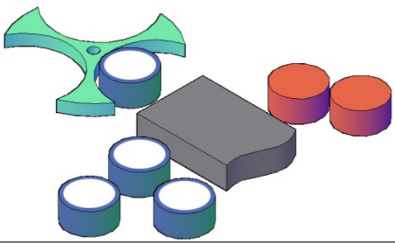
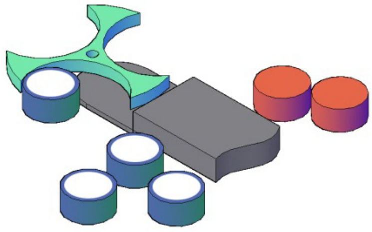
Table 3. Variation matrix for the principle solution 3.2

Basic disposition	3.2.1 			
Shape variation of the working surfaces	3.2.2 	3.2.3 	3.2.4 	
Quantity and shape variation of the working surfaces	3.2.5 	3.2.6 	3.2.7 	3.2.8 
	3.2.9 	3.2.10 	3.2.11 	3.2.12 

4.2. Solution improvement (interference and fault analysis)

Each individual variant is considered and checked separately to determine if it could perform without interferences. If any interference or fault causing the non-functionality of the construction is determined, it is necessary to propose the countermeasures for its removal or reduction of its effects. Interference and fault analysis for individual variants is shown in the Table 4.

Table 4. Interference and fault analysis for puck collecting robot

Partial solutions	INTERFERENCES AND FAULTS	COUNTERMEASURES
1.8.1 to 1.8.6	Insufficient motor power for robots' motion	Calculation of the relevant properties of the motor is needed. Number and placement of drive motors should be determined basing on the calculations
2.6.1 to 2.6.5	Possible jam of the pucks in the conic element constriction 	Right side of the conic element should be moved forward in reference to the left side (or vice versa) 
3.2.1 to 3.2.12	Possible disposition of puck in an inappropriate disposal compartment 	Set up an additional barrier between the compartments which will direct puck in the appropriate compartment for disposal 

4.3. Selection of the most optimal variant

Main goal of the evaluation of variants is a selection of a single conceptual variant for each partial function. Overall optimal variant is obtained by combining those conceptual variants. Due to numerous possible solutions, evaluation procedure is performed in two steps. First step implies the selection of the optimal variants obtained after the interference and fault analysis (in the same manner that optimal conceptual variants were evaluated and selected). Second step implies forming of the morphological box out of optimal conceptual variants, combining them in all the compatible ways and selecting the most optimal one after the process of evaluation. The result of all the previous phases of methodological approach is the first assembly technical drawing, shown in Figure 3.

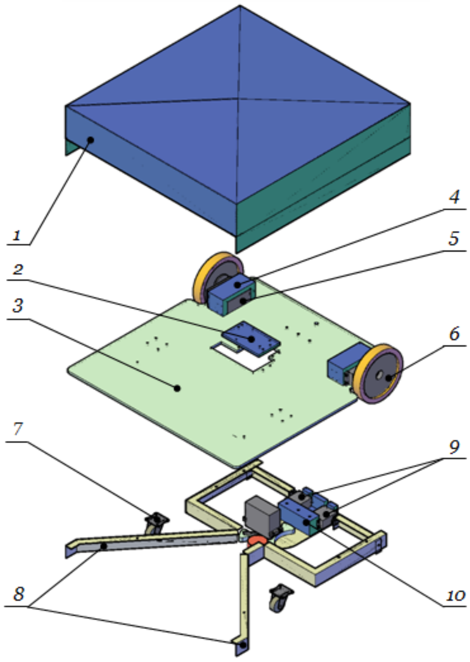


Figure 3. Final model for construction of puck collecting robot (disassembled): 1) cover, 2) electrical components support, 3) base Plexiglas plate, 4) the drive motor support, 5) drive motor, 6) driving wheel, 7) free wheel, 8) conic element, 9) storage compartments' door motors, 10) storage compartments' door motors' support

4.4. Development of design details

This phase refers to a fine design improvements. Up until this phase, the assembly technical drawing and first three-dimensional model of the construction are obtained. Basing on that information, each individual part of the construction is considered and analyzed. Final dimensions and shape of each element are defined and then the workshop drawing is being made. Final calculations and estimates are being done for defining tolerances, surface quality and similar, if needed. Result of this phase is completion of the technical documentation. Manufacturing of each element should be done at the end according to the workshop drawings.

5. CONCLUSIONS

Originally, the idea was for robot to suck pucks and sort them in the suction channel. Application of the methodological approach for the design development pointed out to a much realistic and simplier solution.

Comprehensive analysis determined the weaknesses of the construction and proposed measures for the improvement.

The result is a very simple, but effective design which can be improved in the future, also using the methodological procedure approach. Participation at the competition provided an opportunity to see other teams' solutions for this particular task, good ideas, but also the weaknesses other robots have. This could be valuable experience for further adaptation and improvement of our robot.

Team work and application of methodological approach of the design development led to a simple conceptual solution. However, robot design should be improved in the upcoming phases. Suggestions for the improvement are following:

- supporting wheels should be substituted with the so called "Bull's-eye caster" wheels, considering that supporting "standard caster" wheels affect the predicted path of the robot;
- by using the "Omni" wheels as the driving ones, mobility and agility of the robot would be greatly improved, which is very important for the successful task realization;
- one directional door which would open only on the inside of the robot should be set up at the entry area of the conical element (this door would prevent the collected pucks to leave the conical area during the backward motion of the robot);
- number of the ultrasonic sensors should be reduced due to Doppler Effect which may occur when there are many ultrasonic sensors operating on different frequencies in the limited area. Ultrasonic sensors could be replaced with the bumper sensors;
- colour detection sensor is based on the SMD technology, so for a precise reading and determination of the colour object must be very close to the sensor (about 2mm). Due to this fact, usage of the more powerful sensor should be considered;
- finally, instead of the DC motor, modified servo motor should be used for the sorting operation. Servo motor can provide valuable information regarding position and rotation speed.

Acknowledgement

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