# Prototyping Small Robots for Junior Competitions: MicroFactory Case study

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**Abstract:**
In this paper it is discussed the proposal of a small robot prototype to be applied in the MicroFactory competition, a downsized version of the Robot@Factory competition. The MicroFactory is intended to help junior competitors to make the transition from the Junior Leagues to the senior competition Robot@Factory. The Robot@Factory competition takes place in an emulated factory plant, where Automatic Guided Vehicles (AGVs) must cooperate to perform tasks. To accomplish their goals the AGVs must deal with localization, navigation, scheduling and cooperation problems, that must be solved autonomously.

*Keywords:*
Mobile robot competitions, AGVs, Prototyping

## 1. INTRODUCTION

Robotic competitions are an excellent way to foster research and to attract students to technological areas (1). The robotic competitions present standard problems that can be used as a benchmark, in order to evaluate and to compare the performance of different approaches. Although there are many robotic competitions (2) (3) (4) (5), there is the need to create new ones, in order to solve new challenges. The factory environment is a prime candidate to use robots in a variety of tasks. A competition where mobile robots are tackling transportation problems in the shop floor is a challenge that can foster new advances in service robots and manufacturing (6)(7)(8). The Robot@Factory is an official competition of the Robotics Portuguese Open, presenting problems that occur when using mobile robots to perform transportation tasks. The robots must be able to navigate, cooperate and to self-localize in an emulated factory plant, to transport and handle materials in an efficient way. The introduction of a downsized version of the Robot@Factory is intended to help junior competitors to make the transition from the Junior Leagues to the senior competition Robot@Factory. The downsized version of the Robot@Factory competition, the MicroFactory, reduces significantly costs for competitors and also for the organization, when compared with the standard competition. A picture of the 2006 edition of Robotics Portuguese open can be seen in Figure 1.

The paper is organized as follows: After a brief introduction the Robot@Factory competition is described, then a proposal of its downsized version is described, where it are discussed its benefits, when compared with the standard competition. Then it is detailed a proposal of a Micro-Factory robot prototype and finally some conclusions and future work are pointed out.

Fig. 1. Robotics Portuguese Open

## 2. ROBOT@FACTORY COMPETITION

In this section it is presented the Robot@Factory competition description and the rules that teams must follow in order to qualify for participation. This competition is an official competition of Robotica, the Main Robotics Portuguese Competition, since 2011. The official competition arena is shown in Figure 2.


Fig. 2. Competition arena.

### 2.1 Robot dimensions

Each robot must fit within a cuboid of 45 x 40 x 35 cm. The robot must be completely autonomous and cannot establish any kind of communication with external systems that are not explicitly provided by the organization.

### 2.2 Competition arena

The competition arena, shown in Figure 2, emulates a factory shop floor where there are warehouses and machinery. The dimensions of this area is 3.5 x 2.5 m. There are eight machines available and two warehouses. One of them is used as a raw material storage and the other one is used as a destination.

### 2.3 Machinery and warehouses description

Each machine provides an area where the pieces should be placed in order to be processed by the machine. The robot must pick and place the part materials from the machine. While the part is placed in the machine it is processed and should not be removed. An RGB LED indicates that the machine is able to accept parts (light green), the machine is processing a part (yellow light), the part in this machine is already processed (white light) or that the machine is broken (blink red light).

### 2.4 The part materials

The materials to be transported by the robots should respect standard dimensions, width and length corresponding to an Europallete 80 x 120 mm (1:10 scale), the height should have a value between 30 mm and 50 mm. Each piece has an LED showing an RGB color that identifies the type of material. When a part arrives to a machine, it can be processed and its color is changed in order to illustrate a different type of part.

### 2.5 Solving problems in the competition

Team responsible can access the robot up to four times, if one of the robots is not expected to be able to recover. While robot comes out from the arena the time scheduling continues unchangeable.

### 2.6 Competition starting

The robots must be placed in the closed park one hour before the start of each competition. Teams should not to have access to the robot until about 10 minutes before the start of their competition. There, the referees indicate the teams that should prepare the robot to start their competition.

### 2.7 Competition rounds

Since this is a competition that can accept participants with different background, it must be differentiated in three rounds. Event organization can provide, for some rounds, an external localization system for robots. This system will identify the robots using a pattern that must be placed on top of each robot and can provide the position and orientation of the robot.

*First round* The main purpose of the first round is to collect the pieces of the raw material warehouse and transport them to the end warehouse. The robot should transport the most parts it can from the warehouses.

*Second round* The main purpose of the second round is to process some parts of the raw material. The raw material should be transported from the initial warehouse to the machinery, in order to be processed. When the processing task is ended, the parts should be transported to the final warehouse.

*Third round* The main purpose of the third round is to sequentially distribute the parts through several machinery. Some parts collected from the raw material warehouse should be placed sequentially in more than one machine to process. Only after the completion of this operation the parts should be transported to the final warehouse. There will be three types of parts in operation. During this round some tracks may be partially or totally blocked. In this round teams are authorized to use two robot at the same time, the used robots must cooperate to perform its tasks.

## 3. MICROFACTORY COMPETITION

The introduction of a downsized version of the standard Robot@Factory competition is intended to help junior competitors to make the transition from the Junior Leagues to the senior competition Robot@Factory. The downsized version of the Robot@Factory competition, the MicroFactory, reduces significantly costs for the competitors and also for the organization, when compared with the standard competition. The main differences from the Robot@Factory competition, when compared to its downsize proposal, are essentially the following items:

- The dimensions reduce (both in the Arena as well as in robot).
- In order to reduce complexity, for the organizers and competitors, the machines and part materials do not have leds to provide the robots information about their status.
- Passive elements are used to indicate the status of the part materials, as described in subsection 3.2.

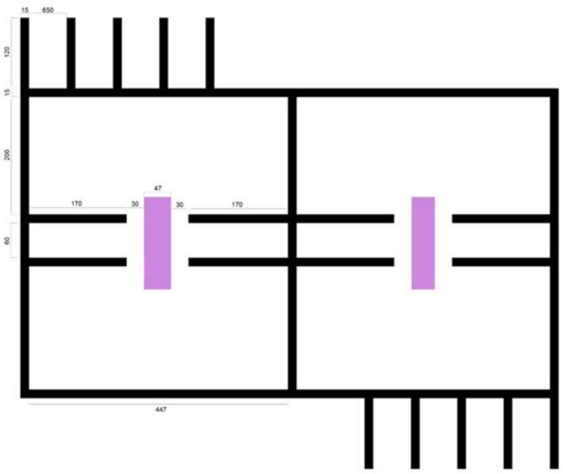


Fig. 3. Downsized robot arena with dimensions in mm

### 3.1 Competition Arena

The arena dimensions are shown in Figure 3, the lines on the floor can be used by the robot to navigate in the arena.

### 3.2 The part material

The part materials and the machines do not have information provided by leds, being the state of the part material identified by the number of marbles in the part material. Examples of part materials are shown in Figures 5 and 6, where two alternatives are shown, being possible the use of 3D print technology as well as the use of Lego$^{TM}$.

### 3.3 Machinery and warehouses description

The two, previously presented, prototyping alternatives (Lego$^{TM}$ and 3D print) are also possible to be used in the development of machines, raw material and final destination warehouses. An example of the Lego$^{TM}$ usage in a Machine prototyping is shown in Figure 6. The competition machine will be prototyped using 3D print technology, being provided with a system that drops marbles into the material parts when their status has to be changed.

## 4. MICROFACTORY ROBOT PROTOTYPE

In the MicroFactory competition each team is free to prototype their own robot, as long as its fits within a cuboid of 20 x 20 x 20 cm, as alternative they can use an official robot provided by the organization. The official robot prototype was developed using an open source hardware and software arquitecture, being all its details provided to the teams by the organization. The prototyped mobile robot consists in small prototype, being presented in Figure 7, that uses inexpensive hardware, such as servo motors, an Arduino Uno platform, an infra-red detector array and For the sensor and actuator interface it was used an Arduino Servo and Sensor Shield. The robot was prototyped using 3D print technology, as an example the robot chassis 3D printer models is presented in Figure 8.

In the next subsections the prototype sensors and actuators are described.

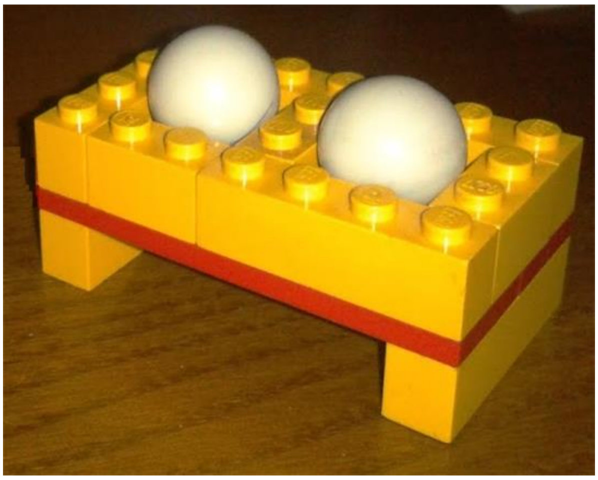

Fig. 4. Lego$^{TM}$ part material

Fig. 5. 3D printed part material

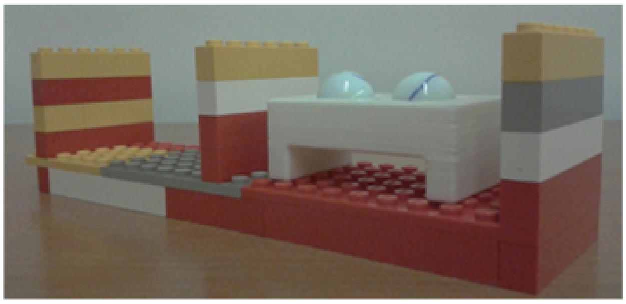

Fig. 6. Machine

### 4.1 Sensors

*Zumo reflectance sensor* The robot is equipped with the Zumo (9) reflectance sensor, providing an easy way to add line sensing or edge detection. It features six separate reflectance sensors, each consisting of an IR emitter coupled with a phototransistor that responds based on how much emitter light is reflected back to it. The purpose of using the referred sensor is to sense and follow a line. A Zumo reflectance sensor array is shown in Figure 9. More information about this sensor can be found in (9).

*Encoders* The used incremental encoders are an inexpensive piece of hardware that would not increase considerably

 

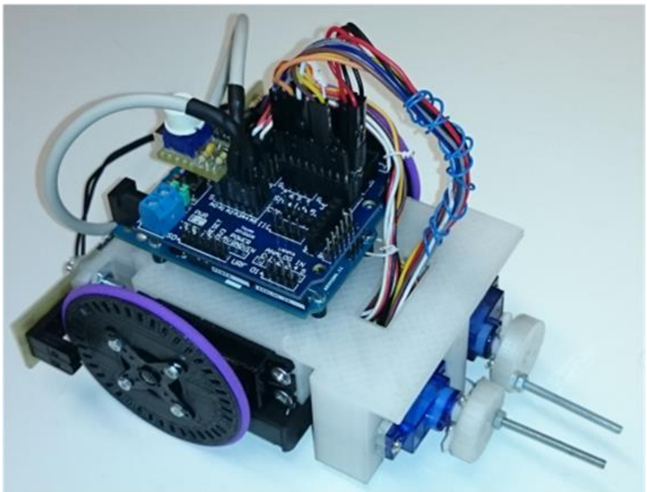

Fig. 7. Robot prototype.

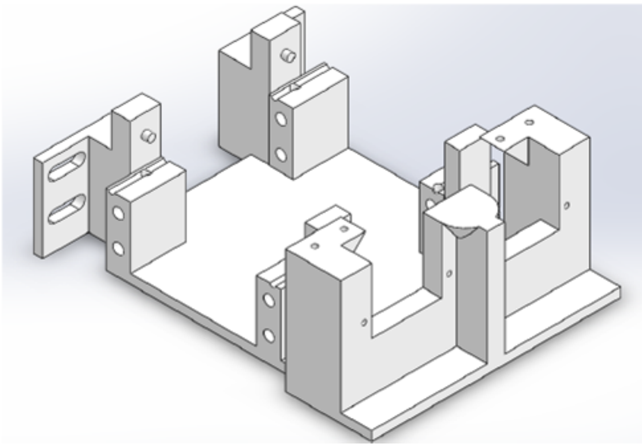

Fig. 8. Robot prototype 3D Chassis printer model.

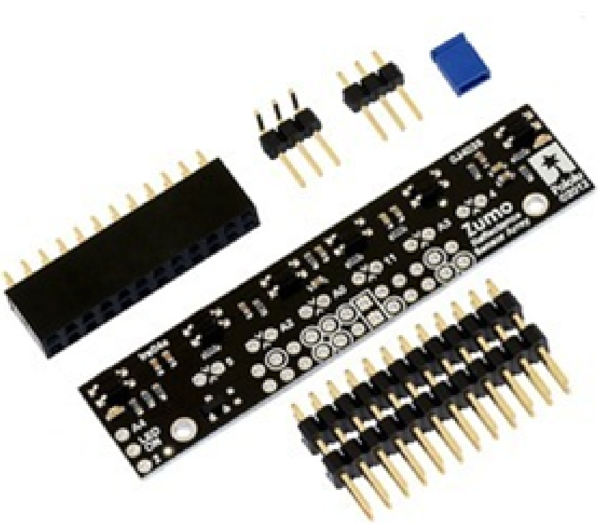


Fig. 9. Zumo reflectance sensor (9).

the cost of the robot prototype. It is based on IR emitters coupled with phototransistors, applied to obtain two signals in quadrature. The robot with encoders is shown in Figure 10.

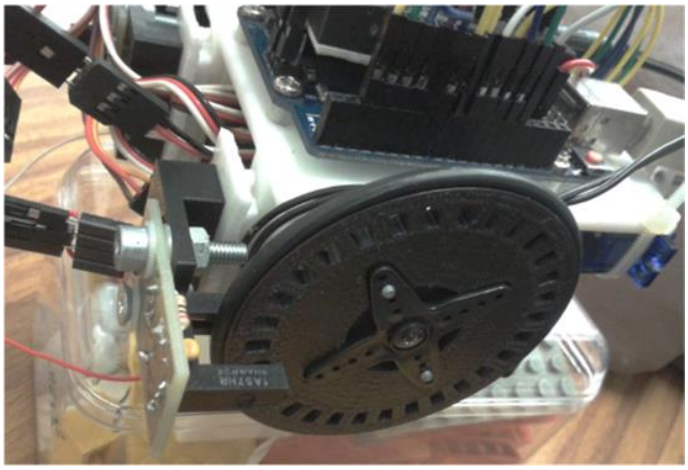

Fig. 10. Robot with encoders.

The use of incremental encoders it is only necessary to obtain the actuator model, prototypes with and without encoders are available. A compact wheel for the robot without encoders is shown in Figure 11 and a wheel prepared for the robot with encoders is shown in Figure 12.

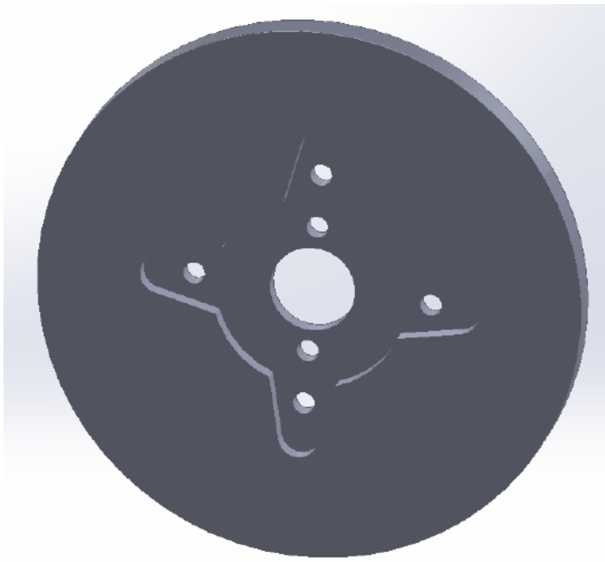

Fig. 11. Robot compact wheel.

### *4.2 Actuators*

The proposed robot actuators are servos, both for the fork as well as for the its locomotion. A servo motor is a complete assembly made of a small high RPM motor, gear reduction, H-Bridge and position control circuitry. If the servo is not modified it is used to produce a rotational position based on a Pulse Width Modulated (PWM) signal.

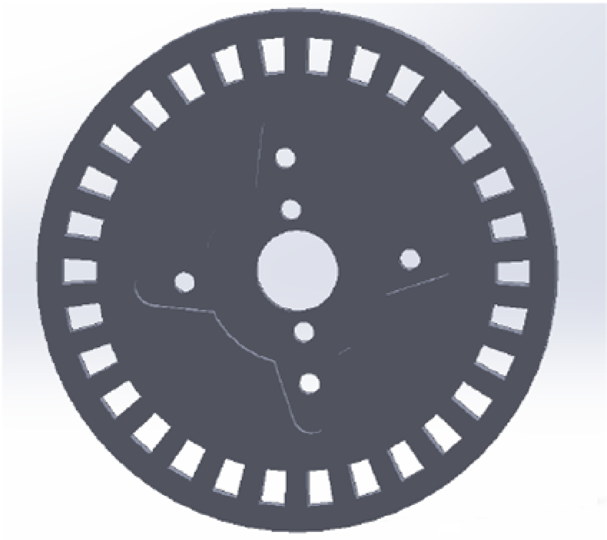

Fig. 12. Robot wheel prepared for encoders use.

*Locomotion actuator* The robot locomotion actuator is the Futaba S3003 Servo. The Futaba S3003 servo motor has three inputs: PWM (white), power (red), and ground (black). Based on the PWM signal the servo will turn its shaft to a position within a range of approximately 200°. When a PWM command is given to the circuitry an error signal is produced. This error signal turns the motor in the appropriate direction. The motor gearing turns a position potentiometer, which gives a feedback signal to the position control circuitry. When the correct position is indicated by the potentiometer, the error signal becomes small enough, so the motor stops turning. For the proposed robot, continuous rotation is necessary, so the locomotions servo motors must be modified. This modification consists in disconnecting the position potentiometer from the gear train, setting the potentiometer for a known PWM signal and removing the angle stops from the motor shaft. Some offset developed by software is necessary to get the two motors to turn at the same speed. More detailed information of the Futaba S3003 servo motor and its modification can be found in (10). In order to obtain the actuator model it was necessary to know for each control signal the output velocity of each modified servo-motor, incremental encoders were used for that purpose, the actuator was powered with 6 Volt.

The control signal is the same as for a standard servo, only this time the length of the on time pulse will affect the speed and directions. For a certain pulse width the servo will stop. Values above or below will make the servo rotate faster in either direction. The signal ($d$), depicted in Figure 13, is the difference for the stopping pulse width. This value must be divided by 40000, in order to obtain the time in seconds. As there is a gearbox with an high ratio, the dynamic response is very fast. The most important aspect of the model is the non linearity introduced by the modified controller. This non linearity can be seen in Figure 13 where the steady state speed for a certain pulse width has a small dead zone and a non linear behavior as it approaches the maximum speed. In order to model these non linearities, equation 1, saturated for values inferior to zero, was estimated. Using the experimental speed measures the best fit was found by optimizing the values of $a_2..a_0$, $b_2..b_0$. The total error, being the sum of the absolute differences, was used as the target function (11). The estimated parameters can be seen in Table 1.

$$\omega(d) = \frac{a_2.d^2 + a_1.d + a_0}{b_2.d^2 + b_1.d + b_0} \tag{1}$$

| Parameters | Value |
|---|---|
| $a_0$ | -34.760E-6 |
| $a_1$ | -69.581E-3 |
| $a_2$ | 488.777E-3 |
| $b_0$ | -29.663E-6 |
| $b_1$ | 2.278E-3 |
| $b_2$ | -1.964 |

Table 1. Estimated parameters.

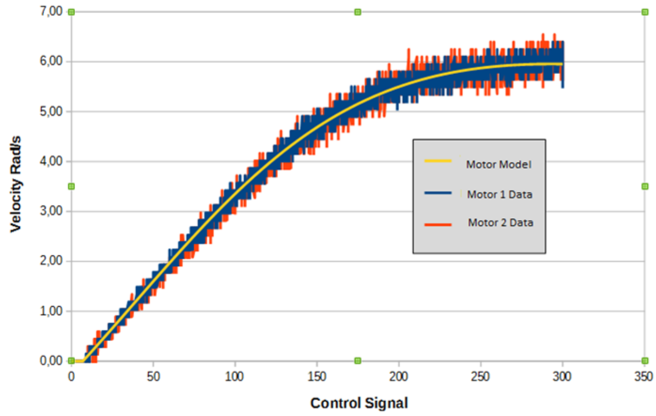


Fig. 13. Futaba S3003 Model.

In order to invert equation 1, equation 2 can be obtained. The solution for equation 2, corresponds to equation 3, resulting in a function with its domain from 0 to 5.955 Rad/s, that has as input a velocity and as output the servo control signal.

$$(\omega b_2 - a_2)d^2 + (\omega b_1 - a_1)d + \omega b_0 - a_0 = 0 \tag{2}$$

$$d = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{3}$$

where:

- $a = \omega b_2 - a_2$
- $b = \omega b_1 - a_1$
- $c = \omega b_0 - a_0$

For an input inside the referred function's domain, equation 3 returns two values, the chosen value must be equal or greater than 7 and less or equal than 293. Values from 0 to 6 are inside the dead zone and values superior to 293 correspond to the saturation zone.

*Fork actuator* For the Fork it was used the T-Pro Mini Servo SG-90 9G without any modification, being shown in Figure 14 (12).

Fig. 14. T-Pro Mini Servo SG-90 9G.

## 5. CONCLUSIONS AND FUTURE WORK

The introduction of a downsized version of the Robot-@Factory is intended to help junior competitors to make the transition from the Junior Leagues to the senior competition Robot@Factory. The Robot@Factory competition takes place in an emulated factory plant, where Automatic Guided Vehicles (AGVs) must cooperate to perform tasks. To accomplish their goals the AGVs must deal with localization, navigation, scheduling and cooperation problems, that must be solved autonomously.

The downsized version of the Robot@Factory competition, the MicroFactory, reduces significantly costs for competitors and also for the organization, when compared with the standard competition. The introduction of passive elements in the Robot competition arena reduces complexity in competition setup implementation. The fact that the teams that do not implement hardware have access to a robot prototype provided by the organization is very important to promote the competition to a wider audience.

The robot locomotion actuator is the Futaba S3003 Servo. For the proposed robot, continuous rotation is necessary, so the locomotion servo motors must be modified. This modification consists in disconnecting the position potentiometer from the gear train, setting the potentiometer for a known PWM signal and removing the angle stops from the motor shaft. Some offset developed by software is necessary to get the two motors to turn at the same speed.

The presented sensor and actuator prototype description and accurate models provides the participating teams valuable knowledge, that can be very helpful in order to develop higher performance robot control software.

As future work the authors intend to provide the official competition robot prototype with a sensor that gives the robot information concerning the part status, identifying the number marbles in each part and also to evaluate the effectiveness of the introduction of the new robot competition.


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