A STUDY FOR CLEANER POOL ROBOT DESIGN

Lafaete Creomar Lima Junior
Federal University of Rio de Janeiro, Escola Politécnica, Mechanical Engineering Department, Rio de Janeiro - RJ, Brazil
E-mail: lclj@poli.ufrj.br

Armando Carlos de Pina Filho
Federal University of Rio de Janeiro, Escola Politécnica, Urban Engineering Program, Rio de Janeiro - RJ, Brazil
E-mail: armando@poli.ufrj.br

Aloísio Carlos de Pina
Federal University of Rio de Janeiro, COPPE, Civil Engineering Program, Rio de Janeiro - RJ, Brazil
E-mail: aloisiopina@lamcso.coppe.ufrj.br

Abstract. The development of new technologies in urban automation has increasingly intensified in recent decades. Among the research initiatives in the area, there is the study and design of service robots for use in urban areas. It is believed that a robotic society may arise in future, where various types of robots assume security functions, environmental monitoring, construction, education, entertainment, personal assistance, among other tasks. Currently, there are several types of robots sold, with applications in household tasks, mainly aimed at cleaning, such as: vacuum cleaners robots, floor scrubbers, window cleaners, pool cleaners, etc. Despite the diversity of robots, this type of technology depends on specific features and high values, and consequently, the price of these mechanisms is also high, restricting the use of such robots to people with high purchasing power. Therefore, the primary idea of the project linked to this work is to study ways of making robots for urban services, with a cost-effective, taking in mind the Brazilian reality, trying to develop mechanisms that can cheapen production, and thus such technology can be enjoyed by a greater number of people. Based on this assumption, the goal of the work presented here is to develop a robot that operates autonomously and submerged for cleaning pools. This research involves the implementation of various activities, such as studying the locomotion system and floating of the robot, the specification of sensors and actuators, the definition of aspects related to pumping and filtering water, etc. In all activities, the use of CAD can aid in visualization and analysis of the robot by means of a model and systems constructed computationally. This model can be used for testing and simulations, assisting decision-making project, and avoiding the loss of resources in manufacturing disabled prototypes. All work presented here is part of a larger project that aims to develop new technologies in urban automation.

Keywords: Robotics, Urban Automation, Machine Design.

1. INTRODUCTION

In this work, the main objective is the design of an autonomous cleaner pool robot. Basically, the use of available technology to make some housework or just to provide a friendly interface to control the home systems, configure Domotics (Home Automation), which represent a research area of Urban Automation. Some interesting works about Domotics can be seen in Alves & Mota (2003), Bolzani (2004), and Meyer (2004).

Even today, domestic cleaning robots are seen as exotic appliances or luxury toys. Cleaner pool robots do not have this kind of problem, establishing itself in the market over the years. The challenge to clean pools (mostly rectangular) is much smaller in comparison to the challenges associated with autonomous lawn mower robots, for example.

The basic mechanism of a cleaner pool robot consists of rotating brushes and two motors, one for the drive unit and rotating brushes, the other for suction, which not only allows filtering of water, but also the robot climb the walls of the pool to the surface.

In relation to navigation, it is customary to use rectangular or zigzag movements, with the aid of the walls (to crash into a wall, or detects a possible collision, the robot reverses direction of motion). There is a sensor to detect obstacles, and the robots have to external supply unit and the presence of a wiring to the surface.

The cost of this type of robot is high, with values ranging from U.S. $ 800.00 to U.S. $ 850.00. Figure 1 shows some examples of cleaner pool robots on the market today. The robots presented here have a cleaning average performance of 330 m²/h.

In the next sections, we will present a review of the characteristics of pool cleaning machines, as well as the modeling of a robot, necessary to design of a prototype. The pool floor cleaning will demand brushes, and the pool wall cleaning will need a floater. We will also need a pump and a filter. The autonomy will require some sensors and some control devices.

For theoretical basement to understanding the development of this work, we recommend: Fox & McDonald (1981), Nehmzow (2003), Siegwart & Nourbakhsh (2004), Norton (2004), Siciliano & Khatib (2008), and White (2011).

(a)   (b)   (c)

Figure 1. Some examples of cleaner pool robots: (a) TigerShark Pool Cleaner, by Aquavac
(http://www.aquavacpoolcleaners.org); (b) Aquabot, by Aqua Products (http://www.aquabot.com);
and (c) Dolphin Diagnostic, by Maytronics (http://www.maytronics.com).

2. FLOATING SYSTEM

Considering the cleaning of pool walls, we can think in two ways of perform this task: by using a sucker or a floating system. A sucker, or an array of them, depends of the wall material, and we do not want to restrain this. Then, the floating feature is the more reliable way to allow the cleaning of pool walls, because it depends only of specific mass of water instead of the pool characteristics.

The floating system (Fig. 2) consists of an empty tube, which can be filled of water for submerge. A piston controls the input and the output of water: to get the water inside the system, a steel cable pulls the sealing disc, reducing the chamber pressure. Since the opening is in contact with the pool water, the chamber is filled. When the cable is released, a spring pulls the sealing, increasing the pressure, discharging the water to the environment.
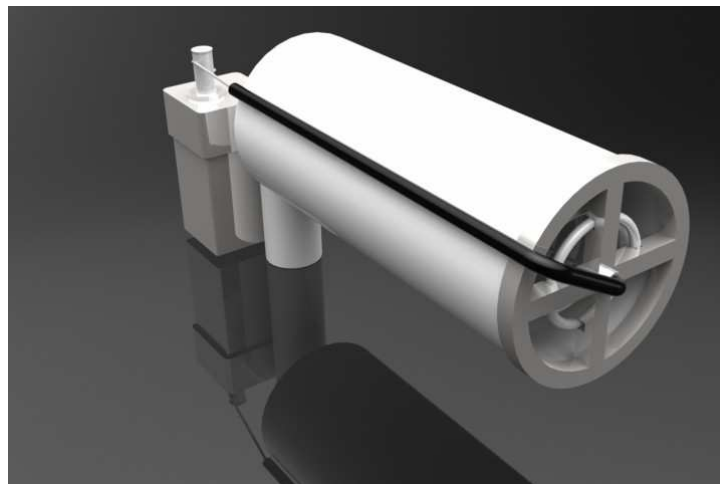

Figure 2. Floating system (Source: created by the Authors).

Actually, the input of water increases the equipment specific mass, turning this bigger than water specific mass, then, the equipment submerges. When the floater expels the water, the specific mass of the equipment is smaller than the water specific mass, and it floats. Our calculation will assume a Newtonian fluid and the load loss is negligible. Let be ρ_w the water specific mass, ρ_e the specific mass of the equipment when floater is empty, and ρ_f when it is full of water. V is the volume of displaced water, g is the gravity acceleration, T is the thrust, W is the weight, M is the mass of the equipment without the water of the floater, and m is the floater water mass. We can see in Fig. 3 the flow and the free body diagram, and the forces acting in the equipment.
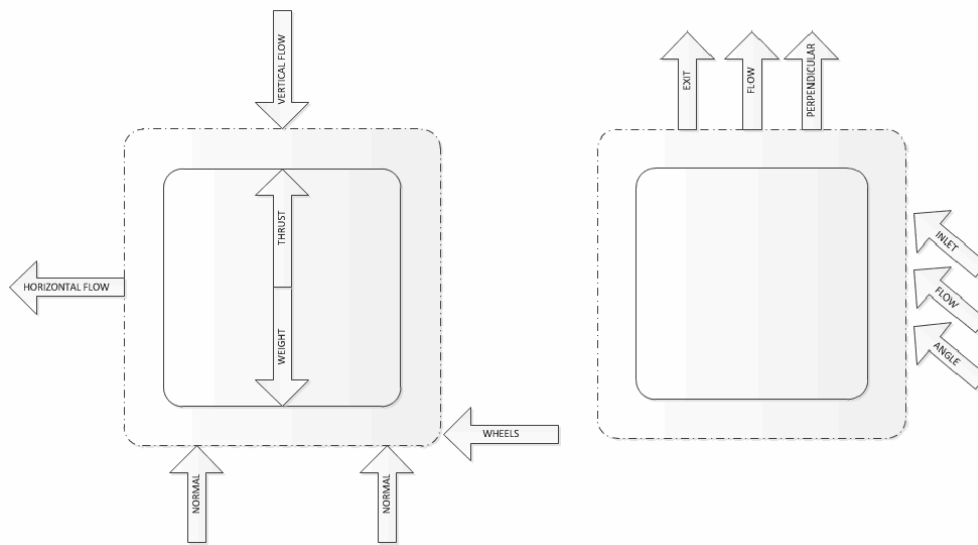
Figure 3. Control Volume and Free Body Diagram (Source: created by the Authors).

So, based in Archimedes' principle (Fox & McDonald, 1981), when the equipment is leaving the floor, the normal force tends to zero, the wheels make no force and there are no flow forces:

$$T - W < 0 \tag{1}$$

But:

$$W = \rho_f V g \tag{2}$$

$$T = \rho_w V g \tag{3}$$

$$\rho_w - \rho_f < 0 \tag{4}$$

$$\rho_w < \frac{M + m}{V} \tag{5}$$

Analogously, when floating:

$$\rho_w > \frac{M}{V} \tag{6}$$

Thus:

$$m > \rho_w V - M \tag{7}$$

This is the minimum mass of water necessary to submerge the equipment, and we have to keep in mind that the specific mass of the empty equipment should be smaller than the water specific mass, allowing flotation.

The wall cleaning will be performed when the robot is rising. However, since a precise control is very difficult to achieve, the cleaning process has to be done in a relatively short time. Then, it is necessary that the difference of specific mass be small. This will ensure the low acceleration and increase the time available to the operation.

At this point, another trouble appears: we have to ensure the contact between the brushes and the wall. In despite of this, we will have a pump and some pipe, so, we must simply to orientate them in the correct direction.

For this, we will need to create a control volume showed in Fig. 3, around the equipment. Then, we will have a model of continuous flow, caused by the pump. We know that intake mass should leave the equipment, because there is no water storage in this flow. Thus, according to Fox & McDonald (1981) the mass conservation:

$$\frac{dm}{dt} = \frac{\partial}{\partial t} \int_{\forall} \rho_w \, d\vec{\forall} + \int_S \rho_w \vec{V} \Box d\vec{A} \tag{8}$$

Becomes:

$$0 = -\rho_w V_i A_i + \rho_w V_o A_o \tag{9}$$

$$V_i A_i = V_o A_o \tag{10}$$

Analyzing the momentum conservation:

$$F = \frac{d\vec{P}}{dt} = \frac{\partial}{\partial t} \int_{\forall} \rho_w \vec{V} \Box d\vec{\forall} + \int_S \vec{V} \rho_w \vec{V} \Box d\vec{A} \tag{11}$$

$$F = [V_i(\cos(\theta)\hat{\imath} + \sin(\theta)\hat{\jmath})][\rho_w V_i(\cos(\theta)\hat{\imath} + \sin(\theta)\hat{\jmath})\Box A_i(-\cos(\theta)\hat{\imath} - \sin(\theta)\hat{\jmath})] + V_o\hat{\imath}\rho_w(V_o\hat{\imath}\Box A_o\hat{\imath}) \tag{12}$$

$$F = \rho_w[(V_o^2 A_o - V_i^2 A_i \cos(\theta))\hat{\imath} - V_i^2 A_i \sin(\theta)\hat{\jmath}] \tag{13}$$

Using the mass conservation:

$$F = \frac{\rho_w V_o^2 A_o}{A_i}[(A_i - A_o \cos(\theta))\hat{\imath} - A_o \sin(\theta)\hat{\jmath}] \tag{14}$$

This relation allows us to calculate the force in the wall direction during the flotation. In addition, it shows us the parameters that we could change to maximize this reaction. θ is measured based on the intake surface normal, and as we can notice, $\theta = 0°$ provides no force, because the flow enters and leaves the equipment without any changes in its direction, while $\theta = 180°$ provides the maximum force in the wall direction. Although this seems to be the best setup, we must remember a restraint: the intake area of this system must be under water all the time, but it will be hard to ensure this when $90° < \theta < 180°$. So we will get better results using $0° < \theta < 90°$, because this way the water intake will be ensured. Then, the best choice is $\theta = 90°$, because this will get the largest results:

$$F = \frac{\rho_w V_o^2 A_o}{A_i}[A_i\hat{\imath} - A_o\hat{\jmath}] \tag{15}$$

By analyzing this result, the area influence became more evident. We know the product area versus velocity gives us the volume of water per unit of time, which will be determined by the pump capacity, so if we take a careful look into the component $\hat{\imath}$, which press our robot against the wall, and substitute the area versus volume by the pump capacity C, we will have:

$$F = \rho_w V_o C\hat{\imath} \tag{16}$$

That is, with the same pump, and the same value of C, we improve the force by improving the velocity, in other words, by the mass conservation: we improve the force, reducing the exit area. At the first estimation, we will use a 45° angle, because we still need the suction of the suspended particles due to the equipment functioning.

3. LOCOMOTION SYSTEM

Now we will choose the locomotion settings. Basically, we must choose the type and the number of wheels or rolls.

Theoretically, only two wheels are needed to maintain the robot work position. However, clearly, this demands a very precise gravity center and forces control. As we can see in Fig. 4, if there are only vertical forces acting on the robot, the gravity center must be inside the dashed box, which is directly related with the wheel width. Rolls are large enough to keep the robot in working, but our environment makes it impossible the use of rolls in this case.
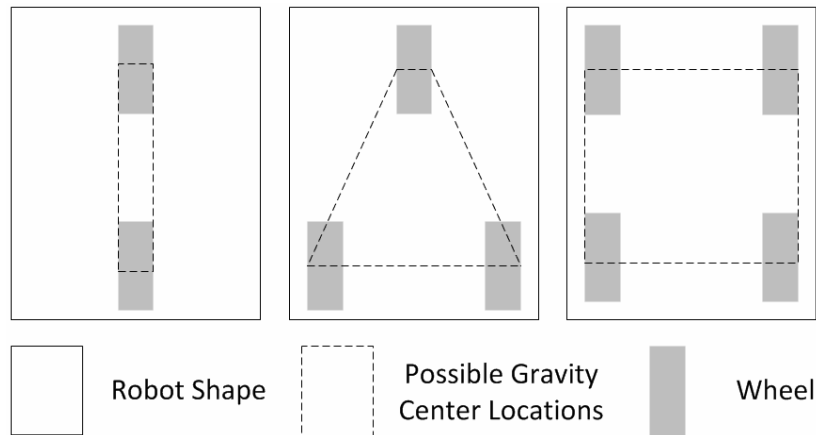

Figure 4. Possibilities of wheels location (Source: created by the Authors).

Since the free space under the robot is a requirement, we will not use rolls, because they obstruct a large area.

Then, the solution is adding another wheel. Then, our gravity center has to be inside the triangle determined between the wheels. Again, this disposition has some problems: it does not allow us to take very good advantage of the robot base space.

Then, we decide to use four wheels, because this option gives us a bigger useful area, with the wheels placed on the equipment border, demanding a smaller gravity center control, in the large dashed area. Besides, it resists to more adverse conditions when gravity center is placed near the dashed square center.

As we know, there are many types of wheels (Siegwart & Nourbakhsh, 2004), but the environment requires the simpler one, since the wheel will be in direct contact with water, and therefore it does not need lubrication. Besides, much complex wheels may deadlock the robot just due to a little particle.

Although there are some types of wheels that make possible an omni-directional movement, this is not necessary, because the environment has generally simple shapes. Then, two-directional simple wheels are enough.

In order to allow the movement, we will have another question to answer: will we transmit torque to wheels or will we use a water flow to provide propulsion? Even if the second option was adopted, we still would need wheels, and more than this, we would need a bigger pump. The biggest problem is that the equipment will not run if the pool has a too shallow area. Thus, we will opt for an engine and torque transmitted to wheel model, which allows the equipment movement even if it is not in the water.

Since the floor force will be transmitted by friction, this implies that we have to analyze the normal and the friction forces.

The first approach is the dry friction, although the word dry does not seem adequate. It is a simple model, in which the friction coefficient has to be adapted to the environment. Our start point to this analysis is to suppose only roll movement, that is, there is no relative movement between the contact point of the wheel and the floor. Therefore, we have a friction force proportional to the normal force. However, how do we know the real normal force?

First, we must remember that in aquatic environment we need to consider the weight and the thrust. Besides, there is the pump force, which contributes to the normal forces and to the motion forces. Thus, by using the previous results we have:

$$N = W - T + \frac{\rho_w V_o{}^2 A_o}{A_i}[A_i - A_o \cos(\theta)]$$

(17)

$$N = M + m - \rho_w V g + \frac{\rho_w V_o{}^2 A_o}{A_i}[A_i - A_o \cos(\theta)]$$

(18)

And the dry friction theory says:

$$F = \mu N \qquad (19)$$

However, we have to add the flow force in this direction in order to know the total force, so:

$$F = \mu N + \frac{\rho_w V_o^2 A_o^2}{A_i} \sin(\theta) \qquad (20)$$

Then:

$$F = \mu \left[M + m - \rho_w V g + \frac{\rho_w V_o^2 A_o}{A_i} [A_i - A_o \cos(\theta)] \right] + \frac{\rho_w V_o^2 A_o^2}{A_i} \sin(\theta) \qquad (21)$$

This is the maximum force that the robot can use to transmit by friction and the force transmitted by the flow, in other words, this is the force available for the robot motion.

At this point, there is an interesting question to approach: how do we transmit torque from engine to wheels? Although this does not seem to be a problem, we must remember that each wheel will go through a different distance when the equipment changes its direction. Therefore, there are two common ways to do this.

The first one is just use two engines, where each engine can operate in a different rotation, allowing the curve movement. This choice has two problems for our project. The first problem is the fact that buying and placing two engines is harder than one. The other trouble is how to control the difference of rotation between them.

Therefore, we will adopt another solution, which requires only one engine. This solution is the differential gear, which allows different rotations on wheels (see Fig. 5). This consists in an input gear or shaft, a crown, which receives the torque from the gear and delivers to the wheels through the other parts, when the equipment is running in a straight line. However, when it is turning, the planetary and satellite gears move, and let the external wheel rotate faster than the internal wheel.
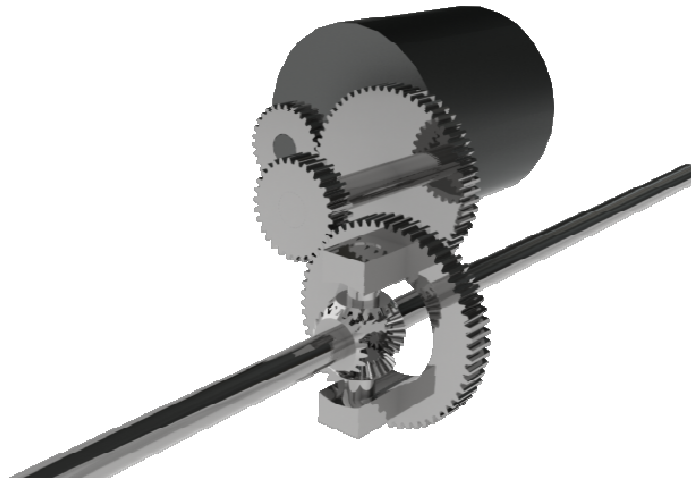

Figure 5. Power-train, with differential gear (Source: created by the Authors).

Then, to calculate the necessary torque to the differential available by the engine or a gearbox, we have:

$$T_d = \frac{r_p}{r_c} r \mu \left[M + m - \rho_w V g + \frac{\rho_w V_o^2 A_o}{A_i} [A_i - A_o \cos(\theta)] \right] \qquad (22)$$

This relation allows us to specify the engine and, if necessary, the gearbox.
For the directional wheels, we will use just a servo connected to wheel forks, providing simplicity and reliability.

4. CLEANER SYSTEMS

In order to properly clean the pool floor and walls, we will need something to remove the dirt, most commonly brushes. There are many types of brushes available, like rolls of bristles. This one, besides cleaning by its rotation, also implies a force, interfering in the motion forces. That is, this type of brush can interfere with the motion devices by adding friction, and also adding new resulting forces in the system.

Then, we immediately think on the rotating brushes. With this type of brushes, due to its rotation axis normal to the floor, implies a friction force, but the forces caused by the rotation cancel out themselves. In other words, this type of brush does not interfere aggressively with the motion of robot as the first one.

In order to cover a larger range by pass of the robot, we will use two brushes (Fig. 6), preferentially rotating in opposite directions. They will be preferentially placed in front of the filter elements. This disposal allows the suspended particles to enter the filter system and be retained on the filtering element.
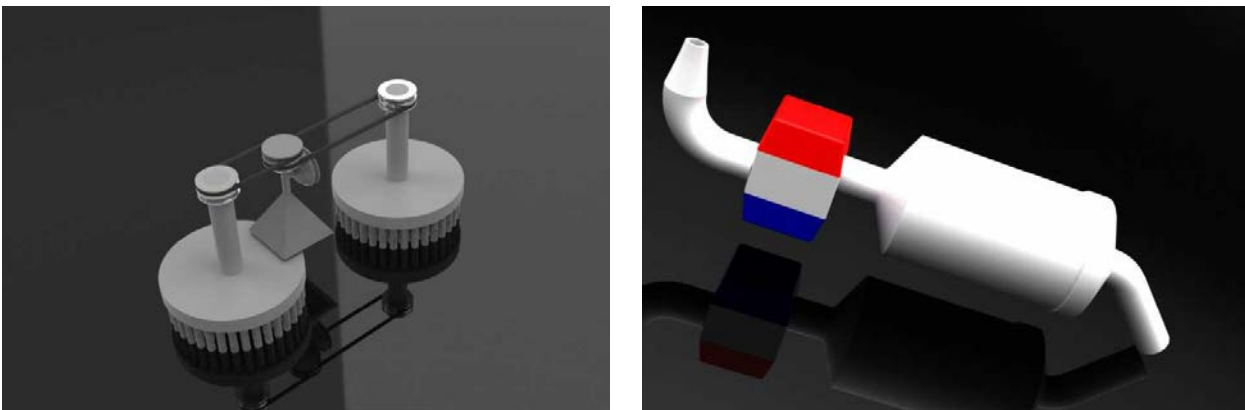

Figure 6. Brushes, pump and filter (Source: created by the Authors).

The filter, due its characteristics, retains dirt, which can restrain the passage. To avoid this, we could adopt more than one filter, each one would retain a part of the particles and this arrangement would work for more time.

However, a smarter solution is to adopt a cup filter (Fig. 6). Besides of retaining particles, this type of filter has lateral surfaces to keep filtering even when the basis is full of dirt. Therefore, this type of filter makes the project simpler and functional. With it, the robot will run a complete cleaning cycle until it needs a filter cleaning.

For this reason, the filter compartment must be easily accessed. This implies that the pump and the pipes would be installed inside the robot, but the filter lid, with the intake curve, must be removable by the robot outside. Thus, a quick coupling lid would be a good choice, although a gasket is necessary. This arrangement prevents a damage caused by a costumer mistake when he reassembling the filter lid after cleaning, because the joint is placed outside the seal compartment.

In order to force the water into the filter, and to allow the floating control as described before, we will adopt a pump. There are many pump types, and although this makes our selection more complex, it also gives us a opportunity to more adequate choice of a pump.

Considering the floating requirements, our equipment must have few mass changes, keeping the specific mass as stable as possible. Therefore, the pumps that have a variable amount of water as a working characteristic, implying in a variable total mass, do not achieve our requirements.

Obviously, the more adequate ones are the centrifuge pumps, whose water mass is constant, and due to their circular movement, they apply a constant force into the equipment structure too. A very common pump for underwater application is the bilge pump (Fig. 6), largely used in ROV's (Remotely Operated Vehicles) as a thrust source. This is our choice, mainly because of its low cost and simple installation.

The pipes could be commercial ones, assembled in the needed shapes. However, this option causes a very large load loss. Thus, the best option is to manufacture a unique element, with the requested shapes.

5. SENSORS AND CONTROL

As an autonomous robot, our equipment has to be able to decide the next action. Basically, a specific sensor identifies every point where the robot must stop doing something to do another action. Siciliano & Khatib (2008) made a table with the available sensors and their main characteristics.

Many robots opt for mapping the environment, by using a group of sensors. This type of robot can achieve the best efficiency. Nevertheless, it requires a very accurate sensing, and although it seems not to be a problem, it must remember the environment.

The wheel sensing is a problem in the way that it is an underwater environment: the lower friction, added to a lower normal force due to the presence of thrust, which reduces even more the friction force, induces the slipping instead of pure rolling. Since the main way to control distances is to monitor the wheel and relate its rotation to the translation movement of the equipment, when this relation is not valid anymore, we loss accuracy assuming this hypothesis, and then, mapping makes no sense.

However, there is another problem: when floating, the robot is subjected to flow forces, which can move laterally the equipment. In spite of the flow seems to be small, the pool filtration system can be active and then, there are significant flow forces, and even a fountain can interfere on the positioning of the equipment.

As a possible solution, we can suggest the use of external points of reference, which can communicate to the robot sensors. However, this solution makes the project more expensive and requires much user interference: if the user places it inadequately, the robot loses its efficiency, or even does not clean some pool areas.

Then, for low cost and simple equipment, we decided to monitor just the obstacles.

When our robot comes across a wall, for instance, it needs to recognize it and decide what to do. Thus, we need a sensor as switch that tells the robot that there is an obstacle in front of it. Knowing this, the equipment will stop, and discharge water from the floater. This will make it float.

When the robot arrives in the water surface, a special switch warns the machine. Then, it will receive water in the floater and submerge. This switch can consist of a lever with a very low specific mass material agglomeration in the extremity. Thus, it will always have a bigger thrust than weight when inside the water, but when it is exposed to the air, the opposite occurs and the weight moves the lever down, signalizing that the surface is there.

When the equipment is going down, the brushes can be turned off. Then, when the equipment arrives in the floor, it will need a rear sensor to warn this. Therefore, with this sensor information, the robot needs to run backwards and make a curve, for instance, 150° arc of circle. Then, the cycle is repeated.

However, the equipment can go through the wall by its lateral side. Since this is not its preferential direction, two lateral sensors must warn this, one in each side. With this information, the equipment should make a curve and go ahead.

The robot should follow this algorithm for a limited time. This limit can be a pre-define value of a group of values that the user can choose according to the pool dirtiness.

It could be selected near the energy font. Since we need some electric cables, we can place an adjustable timer, which permits the flux of current only for a limited time. As pre-defined times, we can offer, for instance, one hour as a fast cleaning, one hour and a half as a normal cleaning and two hours as a heavy cleaning.

6. SIZING AND SELECTION OF PARTS

Now, we already have the basis of our project, so we have to build the systems and parts of our robot.

Our starting point is the filter and pump system. We chose 1,000 gallons per hour bilge pump, which has relatively low price compared with others, and this flow can give to the robot the needed force. It costs between U.S. $ 32.00 and U.S. $ 48.00.

Our intake angle will be set as 90°, the input pipe has a 1 1/8" diameter and the output pipe has a reduction, ending in a ½" diameter. With this data, we can calculate the forces.

The normal force that will press the equipment against the wall will be 7.5N and the force aligned to the movement will be 1.2N.

In this line, we also have the filtration element. Since it is a prototype, we can use a commercial one, so, there is 3,600 liters per hour element, used in stationary pool filters. This is approximately the flow capacity given by the pump, and then it is adequate to our needs.

Now, we will choose the power-train. Before any selection, we have to figure out the pool sizes where the equipment will run. Thinking of a home pool, a 10m x 10m pool ground as a largest value seems to be acceptable, therefore it results in a 100m² of area. Since our equipment has a width of 300mm, it will have to run approximately 333m. Thus, in order to run this area in one hour as we discussed before, it will need to run approximately 0.1m/s.

However, we must count the wall cleaning time, and remember, since our equipment does not map the environment, it must pass more than one time in the same place to cover the whole pool. Then, for this situation, a higher speed seems to be more adequate, like 0.5m/s.

The nylon friction coefficients in wet surfaces are between 0.04 and 0.3. Admitting that weight and thrust cancel out each other, by using a 30mm wheel radius and a crown radius 4 times greater than the pinion radius, from Eq. 22, the torque in the differential gear is between 2.6N.mm and 19.62N.mm for the maximum possible torque transmitted due to friction to the pool floor. If we suppose that, in the floor conditions, the total weight is about 1Kg heavier than the thrust, those torques are 2.9N.mm and 21.87N.mm. Thus, the engine must be able to supply more than this quantity in its normal operation condition.

Since there is no precisely controlled movement, we, firstly, use a simple DC engine. The choice of the engine tension could be considered a practical issue, but the other parts are 12v, so we will select the engine based on this.

Then, we will use a 12v DC motor. After a quick search on supplier's catalogs, we could find a 2500rpm and 15.68N.mm motor, which with two four time reductions can supply the requirements and some extra power, needed to move the brushes. This type of motor can be bought for U.S. $ 3.00 to U.S. $ 5.00, if in large quantities.

For the direction system, a micro servo is enough, which releases 147N.mm, used only to rotate the front wheels axis. This micro servo can be found for U.S. $ 5.00 to U.S. $ 10.00.

In order to dimension the size the floating system, we need a guess of the weight. Based on the 3D model, we have approximately 8Kg, and our pump system has 2Kg of water when working, so our total mass is approximately 10Kg. The volume is about 11E6mm³, this means that the displaced water weights approximately 11Kg.

In other words, our equipment must have at least one liter of water to make the ground cleaning and less than one liter on the floater to make the wall cleaning.

If using a 100mm diameter and 128mm of useful course, we can admit this amount of water. Therefore, admitting a pre-charge of 50mm, and computing the water pressure at the maximum deep of 5 meters, we need a 7.70KN/m spring.

In order to be compatible with the maximum course, we need a 1N.m stepper motor, which costs between U.S. $ 50.00 and U.S. $ 55.00, reduced with a 4:1 relation, coupled at a 10mm diameter pulley.

Figure 7 presents an external view of cleaner pool robot modeled from sizing and selection of parts.

Figure 7. External view of robot model (Source: created by the Authors).

From the study of the systems that constitute the robot, as well as specifying the elements of each system, and using the computational model created, it is possible to perform tests and simulations that in the case of positives results may be used to manufacture of a prototype, in the future.

7. CONCLUSION

We tried to make the equipment as simple as possible, but some complexity cannot be avoided. As an engineering design, many of the systems are reflex of the designer's previous experience, which sometimes does not represent the best solution. Anyway, this work intended to show a project sequence to develop a cleaner pool robot, with best cost-effective than those found in the market, indicated to Brazilian reality.

We still need more refined electrical project and the control definitions must be improved. Other point that can be addressed is trying to avoid the motor wheels, moving the equipment only with the fluids force. This would make the equipment unable to run on dry surfaces, but it can remove the differential gear system.

The next step of the project is performing tests and simulations, and build a prototype. This one is the most demanding phase of the project, first due to the costs (everything is expensive when not bought in quantity), but also because some processes which would provide us a better result in terms of functionality, does not make sense to use. For instance, for the careen, the use of injected ABS is more adequate to the robot proposal, but the costs are prohibitive, then we have to opt for the molded ABS.

8. ACKNOWLEDGEMENTS

9. REFERENCES

Alves, J.A. and Mota, J., 2003. *Casas Inteligentes*. Centro Atlântico, Portugal, 144 p.
Aquabot. Available in: <http://www.aquabot.com>. Accessed in: June 2013.
Bolzani, C.A.M., 2004. *Residências Inteligentes*. Editora Livraria da Física, 332 p.
Dolphin Diagnostic. Available in: <http://www.maytronics.com>. Accessed in: June 2013.
Fox, R.W. and McDonald, A.T., 1981. *Introdução a Mecânica dos Fluidos.* Rio de Janeiro: Guanabara Dois.
Meyer, G., 2004. *Smart Home Hacks: Tips and Tools for Automating your House*. O'Reilly Media, Inc., 328 p.
Nehmzow, U., 2003. *Mobile Robotics: A Practical Introduction*. Springer-Verlag, New York, 304 p.
Norton, R.L., 2004. *Projeto de máquinas: Uma abordagem integrada*. Porto Alegre: Bookman.
Siciliano, B. and Khatib, O., 2008. *Springer Handbook of Robotics.* Berlin: Springer-Verlag Berlin Heidelberg.
Siegwart, R. and Nourbakhsh, I.R., 2004. *Introduction to Autonomous Mobile Robots*. London: The MIT Press.
TigerShark Pool Cleaner. Available in: <http://www.aquavacpoolcleaners.org>. Accessed in: June 2013.
White, F.M., 2011. *Fluid Mechanics*. 7th ed., McGraw-Hill Higher Education, 896 p.

10. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.