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Service Robot for Household Waste Compacting

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Abstract

Nowadays, we have several robots in the market to optimize a variety of household tasks, such as vacuum cleaners, lawn mowers, pool cleaners, etc. In relation to the urban waste management, the applicable processing ways and final disposal are compaction, shredding, incineration and landfill. The application of compacting process is interesting because reduces the initial volume of waste, favoring the transportation and subsequent final disposal. Usually, this task is only performed after the waste collecting from a residence. However, this process could be started from home, by means of a service robot capable of performing the waste compacting, from an autonomous way, which motivated this research. Therefore, the objective of this work is to present the design of this robot. Initially, it was determined the type of waste to be compressed and its disposal in the dump. Then, the systems were studied: hydraulic, driving, electronic and control. In the hydraulic system were specified hydraulic actuators, valves, pump and motor. In the driving system was determined the type of wheel and the most suitable configuration for the robot, as well as the motor and transmission system. In the electronic and control system were chosen the robot sensors, the controller board (Arduino), the control logic and programming. The parts that make up the compacting robot can be easily found in the market, with estimated final cost not too high, which enables its manufacturing. The project benefits are: the waste arrive semi-processed in the treatment plant; a single collecting waste truck can cover a larger area, since it could carry a greater amount of waste per journey; greater availability of street cleaners to work in other parts of the city; and easier to treat in landfills.

Keywords: Domotics, Household waste, Mechatronic design, Robotics, Urban automation.

Introduction

One of the main problems found in cities, especially in the big cities, is waste, result of a society that consumes more each day. This process derives from the accumulation of waste that does not always have an adequate place and treatment. This tends to increase, as the population grows and generates an increase in consumption [1]. As an example, we have the city of São Paulo, where in average each person produces between 800g and 1kg of garbage daily, or from 4 to 6 liters of waste, each day 15,000 tons of waste is generated, which corresponds to 3,750 trucks loaded per day [2]. The waste, besides being an environmental problem in Brazil, can also be considered an economical problem, involving high expenses for its removal. A simple act of throwing a piece of paper in the street entails the hiring of thousands of street sweepers, the production of millions of kilos of garbage and risks to the human health.

There are many forms of treatment, processing and final disposition applicable to urban waste. In most cases, those forms are associated. The most common ones are: Compaction, Shredding, Incineration, Landfill. The Compaction process consists of a processing that reduces the initial volume of waste from 1/3 to 1/5, favoring its later transport and final disposition [3]. The great advantage of this process is that it can be made while still in the residence, before the waste is transported to a treatment station and, afterwards, to the landfill. With the compacting waste, occupying least space, the filling time of the landfills is increased, prolonging their useful storage time.

The compaction can be derived from different types of systems: mechanical, pneumatic or hydraulic system. These systems transmit the movement to the compaction mechanism. This can be done in different ways: horizontally or vertically. Figure 1

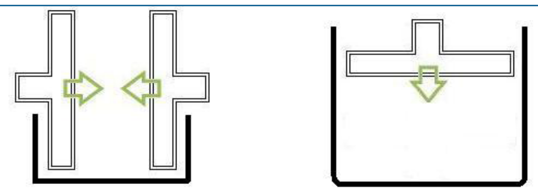

Figure 1: Compacting system types

shows two of the most used forms of compaction.

For the proposed project, we chose to use the vertical compaction in the descending way, because it has as an advantage the gain in available space to put the garbage, since all of the electrical and mechanical system is situated in the superior part of the equipment. Moreover, we chose to use a hydraulic system, since it exhibits a better balance of efforts and can reach, in most cases, higher pressures.

Thus, the objective of the project is to develop a waste compactor robot for residential use, which should be able to, once put into operation, recognize the trashcan in a residency, move towards it and start the compaction process of the residue found in it. Then the robot should go to other trashcans, continuing the compaction process. After finishing these tasks, the user would be able to take the garbage out of the trashcan, already in a pretreated stage.

In order to facilitate the implementation of the project, we identified three systems that make up the robot. The study of each system has a specific purpose, namely: **Compacting System**, step performed in order to verify the possible compacting mechanisms, determine the elements that compose it and measure them; **Locomotion System**, step aiming to determine the most appropriate configuration to the robot's movement, as well as to size the elements which make up such a system; **Electronic and Control System,** step where the sensors, actuators and electrical controllers required for the recognition of the trashcan and the robot's movement in the residence were determined. At the end of every stage, the **Robot Modeling and Simulation** was performed, in which the elements previously set out were

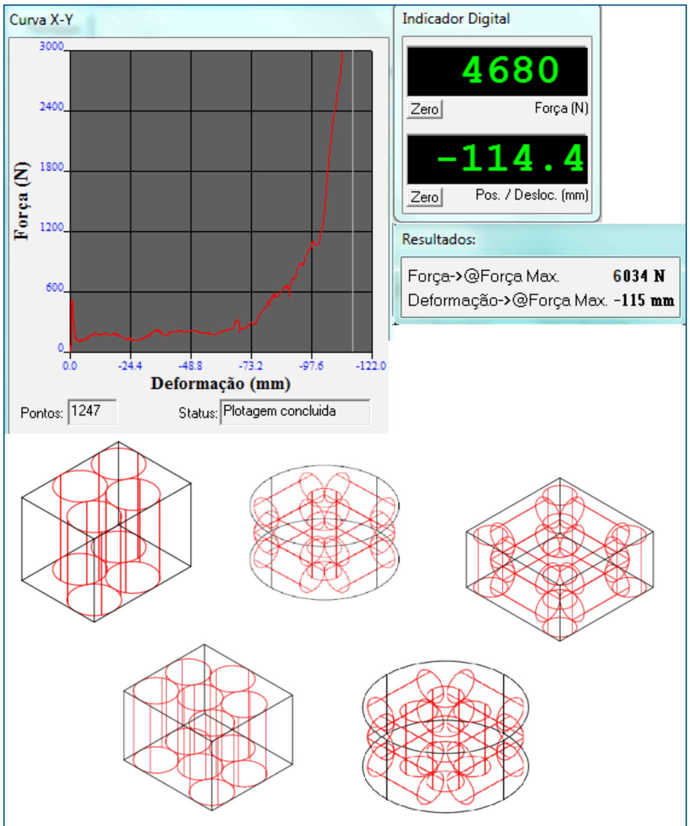

Figure 2: Force needed to compress a can and study of the trash can configuration

modeled and it was verified the resistance of some components. This presented manuscript is a revised and expanded version of the work by Almeida et al [4].

Compacting System

The vertical compaction hydraulic system comprises a hydraulic actuator, a control valve, a hydraulic pump, electric motor, hydraulic fluid and hydraulic liquid deposit. To be able to specify these elements, it is necessary first to identify the project boundary conditions.

Project Conditions

Initially it is necessary to characterize the type of waste to be compressed. In general, urban waste is a composite of organic and inorganic residues. For this project, we chose to work essentially with the waste type "soda cans", as this type of waste is one of the most difficult to be compressed and is very common in urban waste. Some studies [5,6] show that the required forceto compress a soda can is 4.6 KN (Figure 2). This force is sufficient to compress a can of approximately 0.125 m to 0.035 m high.

Once determined the force needed to compress a can, it was necessary to determine the total number of cans to be compressed, which depends on the size of the trashcan. In this case, optimization study with several trashcans of various sizes was conducted, until we reached a trashcan with 0.100 m in diameter and 0.246 m high, occupied by a maximum of 14 cans. Thus, the maximum force needed to be made by the actuator will be the product of the number of cans by the force required by each one.

$$F_{total} = 4.6 \text{ x } 14 = 64.4 \text{ KN} \quad (1)$$

Hydraulic Actuator

Hydraulic actuators transform the hydraulic work into linear mechanical energy, which is applied to a resistive object to perform work. For this project, since the actuator will need to return to its original position after compaction and since it will be installed in the robot vertically, we opted for the double-acting actuator in which the fluid pressure is applied to the mobile element in either directions, as shown in Figure 3.

Once determined the strength required for the compression, by Eq. (1), it is possible to determine the pressure required to act on the system. Taking into account the diameter of theplunger 0.1 m, the pressure is given by [7]:

$$P = \frac{0.1\,x\,4\,xF}{\pi x d^2} = \frac{0.1\,x\,4\,x\,64400}{\pi x 0.1^2} = 820 \text{ MPa} \quad (2)$$

Where: P is the fluid pressure [MPa], F is the Pressure Force on the piston [N] and d is the piston diameter [m].

Then, to determine the course that the hydraulic piston will take, it was assumed that the can compresses 75%, that is, its original length is 0.123 m and the final length will be 0.031 m. As there will be two layers of cans, the course will be 0.246 – 0.062 = 0.184

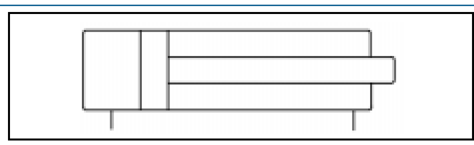

Figure 3: Double acting cylinder

m. However, a gap will be added to this value, equal to 0.016 m for calculation purposes. This gap was adopted in order to avoid any interference. In this case, the total piston stroke is 0.2 m.

In order to determine the geometry of the plunger rod, we can use the Euler criterion to calculate the axial force imposed on it. According to the Euler method [8], the plunger rod can be expressed by Eq. (3). In the equation, dh is the rod diameter, S is the safety coefficient, E is the Material's Elastic Modulus, Fa is the Axial Force and λ is the buckling length factor. For the material's elasticity module, we used the steel module, whose value is 2.1 MPa. According to the Euler method, in order to avoid the consequences and other problems of assembling, we used a safety factor of the order of 3.5. To determine the buckling length factor, you must first analyze the type of assembly to be made. In the project, the robot has one fixed extremity and another movable, which will move to compact the waste. In this case, from Figure 4, λ = 2L.

$$\mathrm{dh} = \sqrt[4]{\frac{64.S.\lambda^2.Fa}{\pi^3.E}} = 0.024 \text{ m} \tag{3}$$

Therefore, 0.024 m is the minimum value to be considered for the diameter of the rod. It was decided to adopt the value of 0.04 m for this diameter for calculation purposes.

The advance and return speed of the hydraulic cylinder can be determined from the relation in Eq. (4):

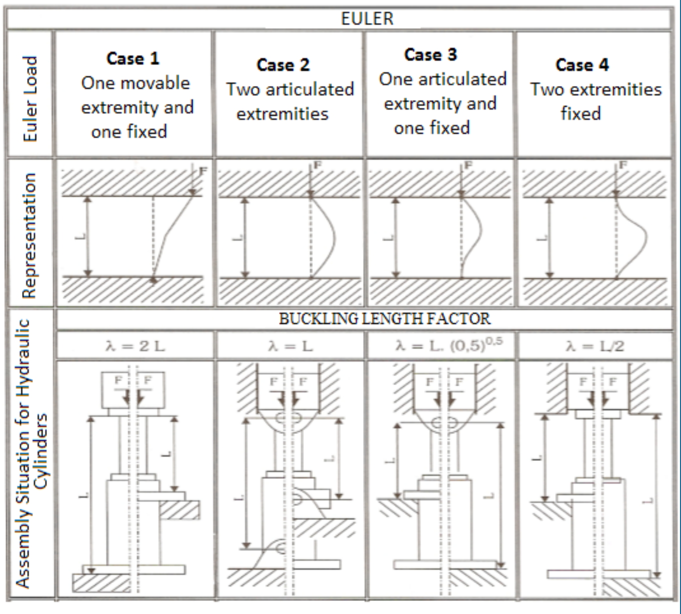

Figure 4: Free buckling length depending on the type of assembly [9]

$$\mathrm{Va/r} = \frac{\mathrm{D}}{\Delta \mathrm{ta\ ou\ } \Delta \mathrm{tr}} = 0{,}04 = 0.04 \text{ m/s} \tag{4}$$

Where: D is the displacement of the piston (0.2 m), Δta is the time variation in the advance (taken as 5 s) and Δtr is the time variation in the reverse (taken as 5 s).

The forward flow rate is the flow rate required for the cylinder to, when slackening, reach the speed (Va).

$$Ap = \frac{\pi Dp^2}{4} = 7.85 \text{ x } 10^{-3} \text{ m}^2,\ Qa = Va.Ap = 3.14 \text{ x } 10^{-4} \text{ m}^3/\text{s} \tag{5}$$

Where: Va is the advance speed, Dp is the diameter of the piston and Ap is the piston area.

The return flow rate is the flow rate required for the cylinder to, as it returns; reach the speed (Vr).

$$\mathrm{Ac} = \frac{\pi.(\mathrm{Dp}^2-\mathrm{dh}^2)}{4} = \frac{\pi.(0{,}1^2-0{,}4^2)}{4} = 6{,}60. = 6.60 \text{ x } 10^{-3} \text{ m}^2,$$

$$Qr = Vr.Ac = 2.64 \text{ x } 10^{-4} \text{ m}^3/\text{s} \tag{6}$$

Where: Vr is the return speed, Dp is the diameter of the piston and dh is the diameter of the rod.

Directional Control Valve

A control valve allows you to control the flow of a pipe usually through an obstruction in its path. The valves may have numerous pathways that are the oil inlets in the valve and exhibit directions, representing the number of positions the valve can take that will determine the direction that the fluid will take.

The double-acting actuator chosen in the project will require a 4-way valve, which provides flow control on each cylinder entry. The valve will operate in three positions. Two positions are able to control only the advance and return of the cylinder, and a third position to be able to control the cylinder in a support position. Therefore, the selected valve is of the type 4 ways x 3 positions (Figure 5).

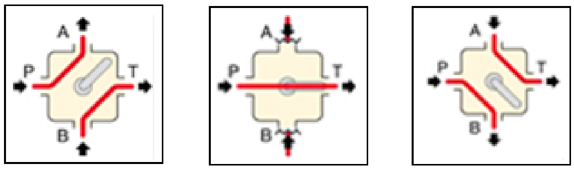

Figure 5: Control valve with 4 ways x 3 positions

Hydraulic Fluid and Reservoir

For the hydraulic system, the SAE 68 mineral oil was chosen as the hydraulic fluid. Its density is 877 kg/m³ and the dynamic viscosity is 0.596 Kg/(ms). Following the recommendation of some authors [10] for operations with pump, the reservoir volume should be between 1 to 3 times the flow of the fluid pumped given in l/min. Thus, it was decided to use 2 times that value. Therefore, it is recommended that the reservoir has 37.68 l. For better accommodation within the robot, such reservoir may have an irregular shape that has a better fit in the geometry of the robot. Furthermore, the use of a filter element is recommended to prevent particles from entering the system.

Hydraulic Pump

Pumps are hydraulic machines that receive potential energy (driving force of an engine or turbine), and transform part of this power into kinetic energy (movement) and pressure energy (power), giving these two energies to the pumped fluid, in order to recirculate it or transport it from one point to another. The pumps can be classified as centrifugal or volumetric. The rotary volumetric pumps of gear type (Figure 6) are the most popular for the displacement and pressurization of oil-based hydraulic circuits, due to lower cost, higher power per weight, among other advantages. This type of pump was selected for the system.

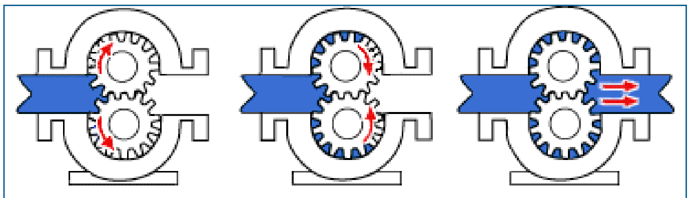

Figure 6: Rotary volumetric pump of gear type [11]

An important factor to be determined for hydraulic systems is the pump power. Initially it was determined the losses in the hydraulic pipeline and it was calculated the estimated value of 364 MPa for pressure drop. Therefore, the pump power can be calculated by the Eq. (7):

$$Pot_{pump} = \frac{Q.\Delta P}{\eta t} = \frac{3.14x10^{-4}.364x10^{3}}{0.80} = 143\text{ W} \quad (7)$$

Where: ΔP is the pressure drop [Pa]; ηt is the total efficiency [0.80]; Q is the pump flow [m^3/s] and Pot_{pump} is the absorbed power [W].

Electric Motor

An electric motor is a machine designed to transform electrical energy into mechanical energy. It is the most used of all types of engines, because it combines the advantages of electrical energy - low cost, ease of transport, cleanliness and command simplicity - with its simple construction, reduced cost, great versatility to adapt to all kinds of load and better performance. These engines are found in various settings, varying mainly the type (of continuous or alternating current) power, voltage, speed and appropriate controls. For the sizing of the required power of an engine, it is necessary to check the performance provided by the engine manufacturer. The performance varies with the engine load. Assuming 80% efficiency for the engine, the poweris given by Eq. (8):

$$Pot_{motor} = \frac{Pot_{pump}}{\eta m} = \frac{143}{0.80} = 178.75\text{ W} \quad (8)$$

Where: Pot_{motor} is the power required at the pump, Pot_{pump} is the absorbed power in the pump, and m is the engine efficiency.

Locomotion System

A mobile robot needs mechanisms that allow its mobility throughout the environment. However, there are several possible ways to move; therefore, this selection is an important aspect of the mobile robot project. In order to define the type of robot locomotion, it is necessary to analyze the kinematic and dynamic characteristics desired and its main points [12]. In the stability, analyze the number and the geometry of contact points, the center of gravity, the static or dynamic stability and the inclination of the terrain; in the type of contact, check the contact point or size and the shape of the path, the angle of contact and the friction; for the type of environment, structure and texture. Initially the element that would allow the robot to move in the environment was determined. Then the engine required to trigger such a system was determined.

Wheels

The wheel is the most popular locomotion mechanism in mobile robotics. The balance is generally not a problem for robots which use wheels, because they are designed to allow the wheels to be in contact with the ground at the same time. Wheels are simple and adjust themselves on flat ground, such as in a residence, considered in the project.

To achieve static stability at least two wheels are required, but in such circumstances, exorbitant diameters are required. To avoid the problem, at least three wheels are used, with the center of gravity located in the triangle formed by the wheels. Improved stability can be obtained by adding more wheels, although the hyperstatic nature of this geometry requires some form of flexible suspension on uneven ground, which does not fit in this project.

Considering the functions of the robot, the movement in the residence, a flat and simple ground, and waste compaction, the best option is the model with four wheels, ensuring greater stability, especially at the time of compaction. Therefore, two driving standard type wheels and two moved wheels will be used.

Electric Engine Determination

In order to determinate the electric motor and the reduction (if necessary), first we need to determine the torque for the robot's locomotion. By determining the torque, it is possible to analyze, through specific graphics of engines, the project's components. At first, it is necessary to find the resulting weight of the structure to determine the load applied to each wheel. Considering the acceleration of gravity (g) 9.81 m/s^2 and the estimated mass (m) 38 kg, the weight is:

$$P = m \times g = 38 \times 9.81 = 372.78\text{ N} \quad (9)$$

In this case, it is necessary to determine the rolling resistance since it is considered that the rolls will run without slipping. Thus, the force is given by Eq. (10), where N is the normal force and c is rolling resistance coefficient. It was considered the value of 0.0012 for the rolling resistance coefficient.

$$Fr = cN = 0.0012\ x\ 372.78 = 0.447\text{ N} \quad (10)$$

Considering two driving wheels, the value of the total frictional force (Fr) should be divided between them, that is, 0.224 N, and the wheel diameter (d) equal to 0.1 m, it follows that the torque is:

$$T = F \times d/2 = 0.224 \times 0.05 = 0.011\text{ Nm} \quad (11)$$

Each engine features a chart that lists some parameters, such as torque (T), rpm (N), current (I) and efficiency (η), and should be analyzed before your choice. Therefore, knowing the torque required to move, we might determine other parameters, such as rotation and current, important variables to set the reduction and driver in which the engine is plugged in. It is recommended to use an engine that reaches a torque above the calculated, in order to ensure that the robot can actually move.

Electronic and Controlled System

The choice of the electronic components of the robot is conditioned by the way it will behave in the environment and how it will react to the external stimulus. Hereafter the robot operating logic will be displayed, as well as the electronic components that were selected for use in this project, such as the sensors Arduino, shield and driver.

Operating Logic

To carry out the trash compaction, the robot should be able to identify the trashcan, fit in it, activate the hydraulic actuator, return the actuator, disengage from the trashcan and move towards another trashcan. In order to prevent the robot to rise during the compression process, it was placed a rod at the base of the robot structure that fixed up properly in the trash basis. Figure 7 illustrates the coupling detail between the base of the robot structure and the basis of the trash.

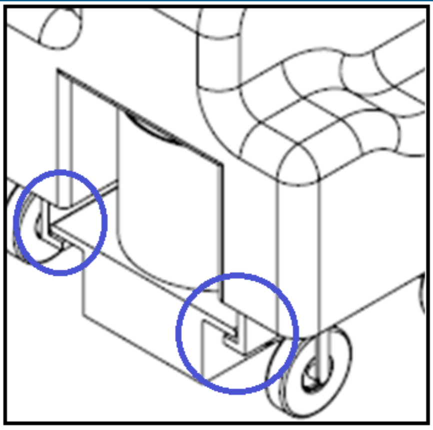

Figure 7: Coupling detail

Since the electronic interface of the project and its programming are not the main target of this project, we chose a simpler and executable programming logic. In this case, the type of movement of the robot through the residence will be in the form "line follower". The robot will move on a line previously marked on the ground, that will link the trashcans, and this movement will occur due to the sensors arranged in the base of the robot that will trigger the engine if any of them enters or leaves the demarcated line. Figure 8 shows the operating logic of the compactor robot.

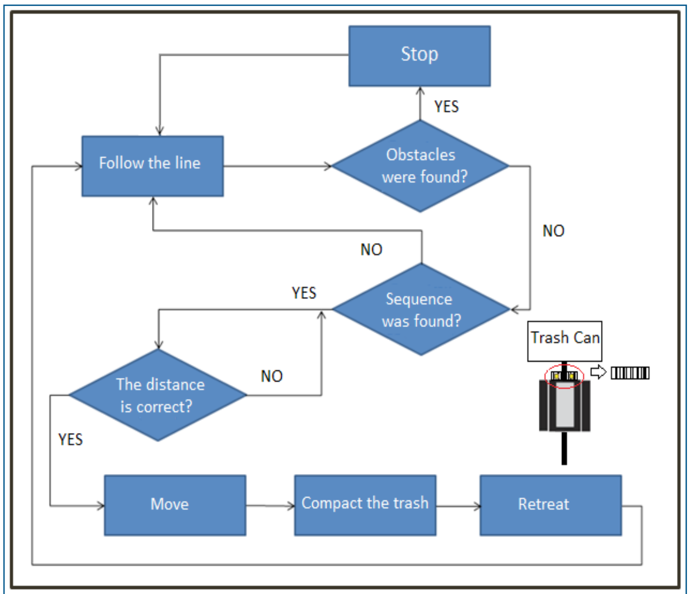

Figure 8: Flowchart of the robot's operations

Sensors

There is a wide variety of sensors that are used in mobile robots [13]. Some sensors are used to measure simple variables, such as the internal temperature of the electrical circuit or the engine rotation speed. Other sensors, more sophisticated, can be used to acquire environmental information. A robot, while moving, can find unpredictable environmental characteristics and their detection is a critical factor to be considered in the project.

For the compactor robot, two types of sensors will be needed to perform the operations. To identify the sequence delimited on the ground, light sensors will be used, whose operation is based on the emission of a light beam, which is received by a photosensitive element. One can also use line sensors. To determine precisely the distance to the trashcan, ultrasound sensors will be used, which are based on the emission of high-frequency sound waves and on the measurement of the time that the produced echo takes to return to the receiver. To measure the distance, infrared type sensors can also be used, which have a similar operation to that of the ultrasound, but, instead of a sound wave, a light beam is emitted, which is more accurate.

Arduino, Shield and Driver

Arduino is an electronic platform for prototyping, consisting of a microcontroller board, a typical programming language with an environment of development and support to the input and output of data and signals [14]. It is very flexible and does not require deep knowledge about electronics. In addition, software, libraries and hardware are open-source, meaning that they can be reproduced and used without the need of copyright payment.

The Arduino UNO will be used for the project, due to its simplicity and flexibility. It is recommended to use a Shield (plate that attaches to the original plate, adding other features) coupled to the Arduino, in order to facilitate the use of the components. The hardware Arduino UNO consists of power supply, CPU core, analogue and digital inputs and outputs, special pins and firmware.

The Driver will be connected to the engines that will allow the movement of the robot. For this, we must determine the amperage required to activate the engine, which was previously analyzed from the graph provided by the engine manufacturer. Figure 9 shows the connection between Arduino, Driver and Motors.

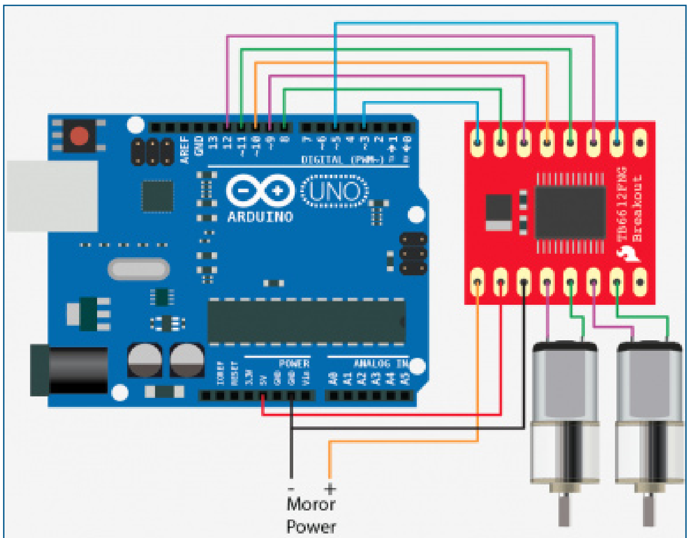

Figure 9: Schematic assembly of electronic and control system

Computational Programming

The programming was developed based on the robot's motion logic. The software was written in the most simplified form for easy understanding of the program. This can be improved to make smoother motion of the robot or to change the motion logic. Figure 10 presents a small part of the programming for use in the Arduino.

```
// Loop principal para executar as funcoes do rôbo
void loop ()
{
    Me.run (FORWARD);
    Me.setSpeed(255);
    Md.run (FORWARD);
    Md.setSpeed(255);
    cor = digitalRead(S1);
    cor = digitalRead(S2);
    cor = digitalRead(S3);
  if (corS1==HIGH) {
   viraresquerda ();}
  if (corS2==HIGH) {
   virardireita()}
  if (corS3==HIGH){
   compactar ()}
}
// FIM
```

Figure 10: Small part of the computational programming

Robot Modeling and Simulation

The modeling of the components present in the trash compactor robot was carried out. The division of the components was done according to the robot system. For the compaction system, the hydraulic piston, the hydraulic pump, the electric engine and the 4 ways x 3 positions valve were modeled. For the locomotion system, the driving wheels, the moved wheels and the electric engine were modeled, and for the electronic and control system, the battery and the Arduino were modeled. Finishing the modeling of the robot, we built the outer structure for final assembly, seeking a suitable design (Figure 11).

Since there will be an effort on the robot casting rod that engages the trash and also an effort on the trash basis, it is necessary to carry out a simulation of finite element and check the behavior of the material.Finite Element Analysis (FEA) is a numerical method used in several examples of structure analysis. Some references on FEA simulations are presented [15-17].

For analysis, it was decided to consider the material of the base of the robot structure and the base of trash an SAE 1040 steel quenched and tempered at 205°C, whose modulus of elasticity is 207 GPa, Poisson's ratio is approximately 0.3 and the flow resistance limit is 593 MPa. The software used was the *Catia V5®* to perform finite element simulations. It calculated the mechanical stress in the material through the Von Mises Criteria.

In the base of the robot analysis was used an unstructured tetrahedral mesh, with 2mm of tetrahedron size, generating a total of 532552 elements and 134802 nodes. The boundary conditions are:clamped on top, with sliding surfaces on the sides and frontal plane. The results are shown in Figure 12.

In the base of trash analysis was used the same mesh type and size, generating a total of 390950 elements and 88568 nodes.The boundary conditions are: base of trash clamped by the bottom, with sliding lower side, and flaps with rotational restriction.The results are shown in Figure 13.

From simulation, it is possible to verify that the higher tension applied in the base of the robot structure was 159 MPa, while in the base of trash was 461 MPa. Thus, as the endurance limit the flow of material used is 593 MPa, it can be concluded that the material will present a very small elastic deformation, which is annulled when the stress is terminated. Therefore, the selection of the material was appropriated for the elements that will resist the applied load.

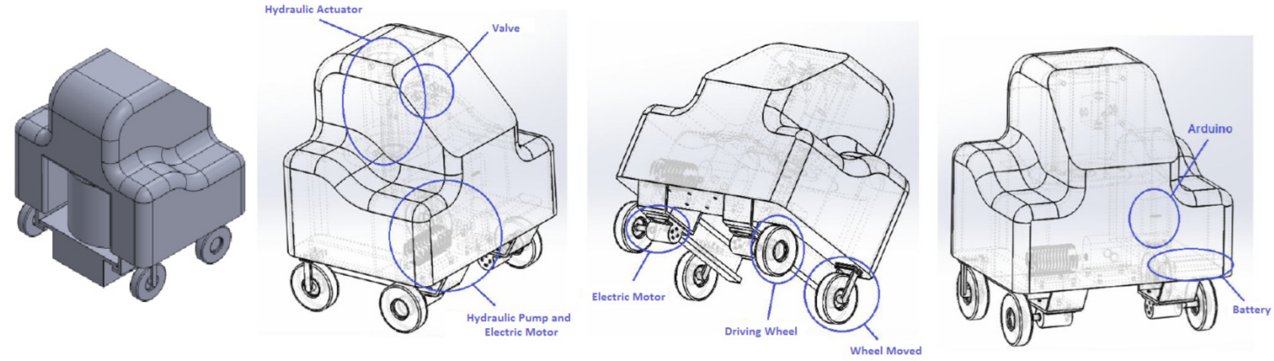

Figure 11: Modeling of the robot's systems

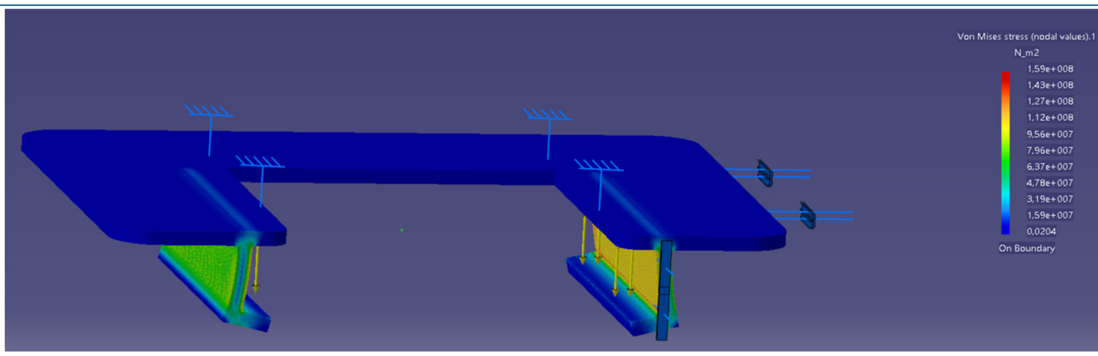

Figure 12: Simulation results of the base of the robot

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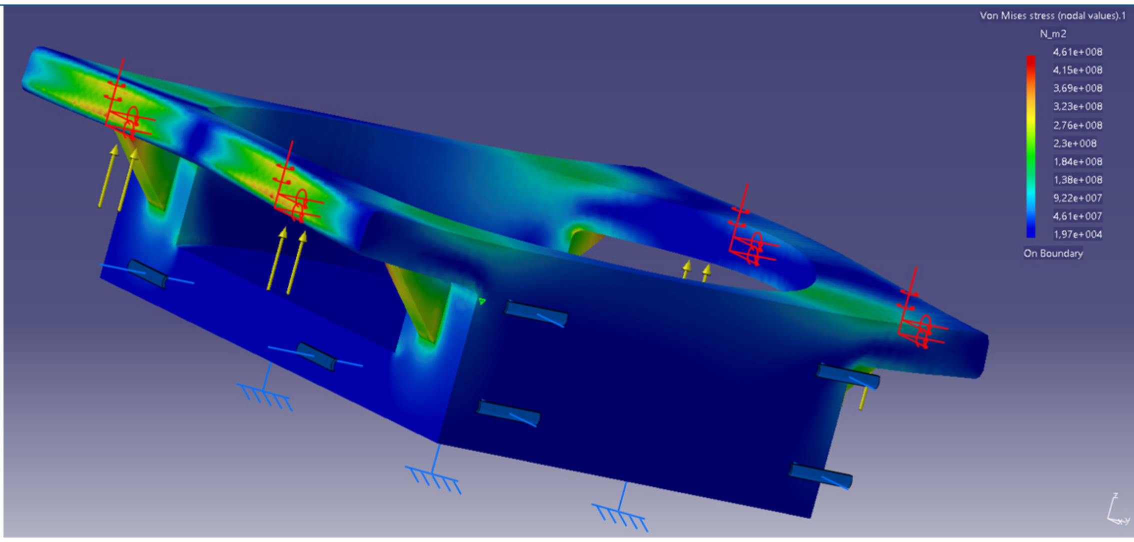

Figure 13: Simulation results of the base of trash

Conclusion

With the present work, it was possible to define the required components to compose an autonomous service robot for household waste compacting. For each system it was determined the mechanical elements. For the Compacting system, the hydraulic actuator, valve, hydraulic pump and electric motor were selected. For the Locomotion System, the driving wheels, moved wheels and the electric motor were selected, and, for the Electronic and Control System, the electronic board, the operating logic, the sensors and the electronic devices were defined. One of the great advantages of this study is the fact that the elements that make up the compactor robot can be easily found in the market, with reasonable estimated final cost, which enables its manufacturing. As benefits for the use of this robot we have: the waste arrives semi-processed in the treatment plant; a single collecting waste truck can cover a larger area, since it could carry a greater amount of waste per journey; greater availability of street cleaners to work in other parts of the city; and easier to treat in landfills.

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