QFD DESIGN METHOLOGY AND CONSTRUCTION OF A TYPE ROVER MOBILE ROBOTIC PLATFORM

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ABSTRACT

This document describes the process that took place for the realization of a platform Mobile Robotics Rover type. Details how the methodology Quality Function Development (QFD) for choosing a suitable Rover prototype was used and that meets the specifications of the customers surveyed, then information about the design process used by aid of CAD type is provided, and completion by the construction process. The results obtained are collected and achievements that it has fulfilled the platform. The purpose of the prototype is to meet the specifications required by customers and design specifications raised for exploration both structured and unstructured surfaces.

Keywords: CNC, QFD, rover robot.

INTRODUCTION

In the continuous pursuit of development of science, the research to explore unchartered places by humans has emerged, technological developments capable of transporting it to places never before imagined. One of these technological developments became what is today known as specific as robots and mobile robots for exploration, these may be land, water, air type. i.e. the twin robots Spirit (see Figure-1) [1] and Opportunity, developed by the "Jet Propulsion Laboratory" of NASA in California during 2002 and 2003 were two robots class "Rover" sent to Mars in late 2003, each of the robots explored opposite sides of Mars and managed to carry out research of different natures [5], with this man knew and clarified many doubts that he had about this place which it has never been explored before.

Figure-1. Robot spirit.

Not only this robot were used for exploration in places of difficult access, they are also sent to places where the risk to human personnel is quite high, as geological disasters and public order or in harsh environments. There are many kinds of geological disasters including tsunamis, earthquakes, volcanoes, exhaust gas (natural), floods, droughts, landslides, thunderstorms, avalanches, etc; in such situations robots are sent before humans primarily with the aim of not losing human lives and because they have fewer needs than humans and can access and better withstand different harsh conditions. In the military, they are also found like the Rover type robots, these are used for observation, exploration, inspection, and rescue; it should be noted that any form and independently in that field exploration robots are used, it must have the capacity to mobilize in any terrain.

It is observed the wide diversity of rovers for different purposes is very large, that is why the focus of this work is in the implementation of a design methodology QFD for the design and construction of a robot RCL type Rover.

STATE OF ART

As seen in recent years, robots have been used to explore inaccessible places or places that pose risks to humans; the most common situations in which rovers are used is in buildings that present deterioration in its structure by natural disasters. Another situation where these types of robots are implemented is for scanning technology. Is when they want to enter military building that is under the power of groups outside the law, in this situation the robot plays the role of negotiator.

One of the companies that design exploration robots is iRobot [3]. In the inventory there are land exploration robots and underwater exploration. IRobot robots are used by the military as operational support, including the iRobot Negotiator are 200 [4] (see Figure-2).

Figure-2. IRobot.

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The platform is designed to support SWAT teams, this robot has the ability to see, hear and assess dangerous situations at a safe distance. The Negotiator 200 transmits video in real-time, two-way audio, has a bomb detector, detection monitor for hazardous materials and is in the ability to solve high-risk situations, hostage taking, search and rescue.

NASA also has been implementing exploration robots for scientific purposes in the field of exploration of new worlds, the vast majority of robots are designed by NASA Rover type robots. These consist of wheels or tracks capable of traveling through territories of different nature, usually used to investigate hostile territories where it would be dangerous, too expensive or even impossible to carry a human being.

The Sojourner Rover is a small robotic six-wheeled vehicle built by Jet Propulsion Laboratory of NASA, designed to be sent to Mars in the Pathfinder [8] [9], with ability to transmit images and perform experiments on Martian soil.

During the passing of the years there have been developments of large number of robots with different mechanisms to adapt to different surfaces, some of them are listed below [8]:

Sojourner

Made by JPL-USA, synchronized longitudinal direction with passive suspension and center differential, see Figure-3. In 1997, the Pathfinder Sojourner Rover mission (see Figure-3) touched the surface of Mars using the robotic arm Surveyor. [9]

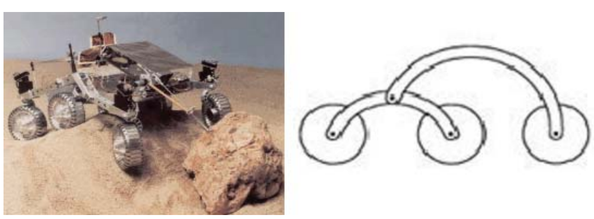

Figure-3. Sojourner.

Shrimp

Made by EPFL-suisse, synchronized and differential longitudinal direction with passive suspension. [8] (See Figure-4)

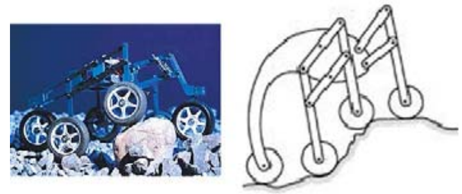

Figure4. Shrimp.

Octopus

The locomotion mechanism has 15 degrees of freedom. Both the charger and the two bodies are joined on each side in a passive differential configuration. It has touch sensors on the wheels capable of detecting more information about obstacles and, consequently, the robot can adapt their behavior to the ground (see Figure-5).

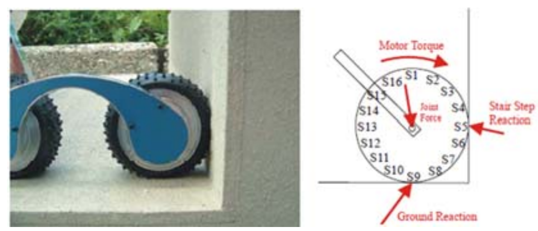

Figure-5. Sojourner.

DESIGN CRITERIA

When we talk about how to move robot locomotion the study is vital, basically considerations on the characteristics of locomotion mechanisms that must be made for the implementation of a robot are:

- Walkability
- Maneuverability.
- Terrenobrabilidad.

These features are important [8] and according to their purpose they have to adapt to any of the classifications of locomotion on different robots. There have been developments in various types of locomotion concepts and the best known are shown in Fig. 6. Each of these types of locomotion concept has its advantages and disadvantages which are shown in Table-1 [8].

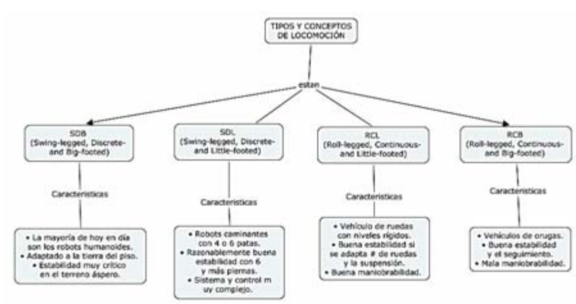

Figure-6. Sojourner.

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Table-1. Comparison.

Competencia Concepto	TransitaBilidad	Maniobrabilidad	Terrenobra bilidad	Complejidad del sistema	Complejidad del sistema
SBD	Buena	Buena	Baja	Alta	Muy Alta
SDL	Muy Buena	Buena	Buena	Muy Alta	Alta
RCL	Buena	Buena	Muy Buena	Baja	Baja
RCB	Buena	Baja	Buena	Baja	Baja

For the considerations on the characteristics of the mechanisms of locomotion and comparing each with different types of locomotion as is shown in Table-1, it is seen that systems more efficient and less complex to implement locomotion are RCL. That is why this type of locomotion for the development of this work was chosen. In these types of robots (RCL) there are different types of concepts that the robot climb an obstacle are:

- Friction. Figure-7.
- Relocating center of gravity. Figure-8
- The adaptation of a passive or active suspension mechanism. Figure-9.

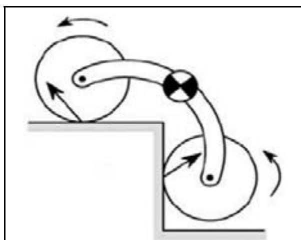

Figure-7. Friction.

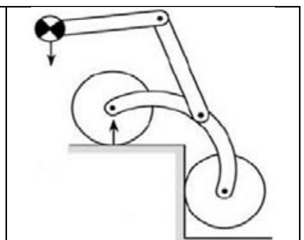

Figure-8. Relocating CG.

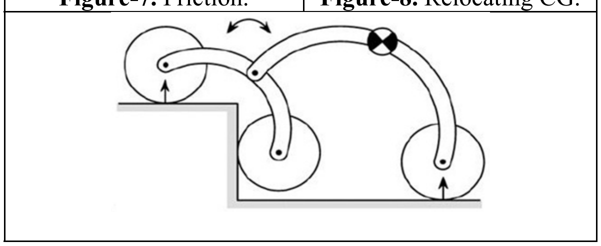

Figure-9. Adaptation.

Concepts of RCL

It can be considered different concepts of locomotion RCL, 3 of them and are called as a concept C, D and E, each varying their suspension design. [7].

***RCL* Concept C**

The basic design consists of a torsion mechanism synchronized. The chassis is connected to the cabin payload by two bars through the central joints on both sides see Figure-10, the joints have a degree of freedom, the synchronization mechanism connects both sides of the chassis such that the tilt angle about the pivot points is equal in amplitude but opposite in direction. The relative movement of the various components is about a transverse axis defined by the two pivot points. [7]

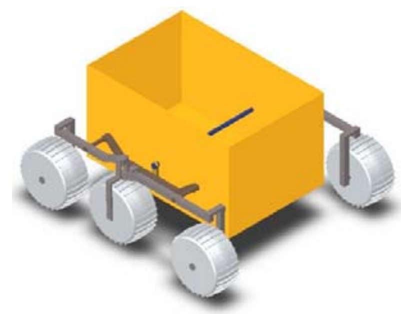

Figure-10. Concept C model.

RCL* Concept *D

The locomotion system concept D is a wheeled chassis with formula 6 x 6 x 4 ie six wheels, the six driven and four guidelines. The wheels are attached to the cargo through the fork shaped brackets and leverage multi-suspension system. The suspension ensures constant contact of all the wheels with the ground-and full utilization of the tensile force generated by each wheel in motion see Figure-11. [7]

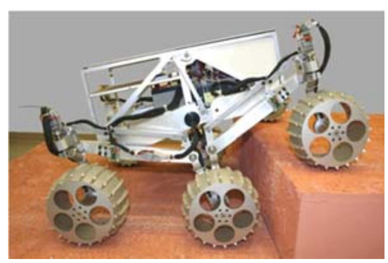

Figure-11. Concept D model.

RCL* Concept *E

The E concept is a wheeled chassis with 6 x 6 x 4 + 4W ie six wheels, driven by six wheels four corners are four steering wheels for mobility in difficult terrain. The design consists of three modules, independent, each with two wheels that is;

- Left Module (front and middle wheel)
- Module Right (front and middle wheel)
- Rear module (two rear wheels, one on each side)

The design is much simpler compared to the concepts C and D, provides vertical movement of all wheels. It requires no average linkage see Figure-12 similar to the concepts C and D, which simplify the system

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of locomotion, and design for assembly of the prototype. The weight of locomotion system concept E is much lower than the concepts of C and D. [7]

Figure-12. Concept E model.

SELECTION CRITERIA

Choice of locomotion system

For the choosing of the mechanisms, different simulations were performed in order to analyze and check the functioning of the various mechanisms. With this idea and versatility and good performance offered by Rover robots adaptation of a suspension mechanism with passive or active joints, simulated robots were developed with this type of condition, these were the: SHRIMP, CRAB, nexu, HELIOS and finally the Spirit Mars Exploration Rover (MER) of NASA. Simulations of the same conditions were carried in a low virtual world with obstacles 10 cm high and a slope of 15 degrees with the horizontal, also engines that were used were fixed in a torque equal to 3,059 kgf-cm for all the wheels in each prototype. The simulations are shown in Figure-13, Figure-14, Figure-15, Figure-16 and Figure-17.

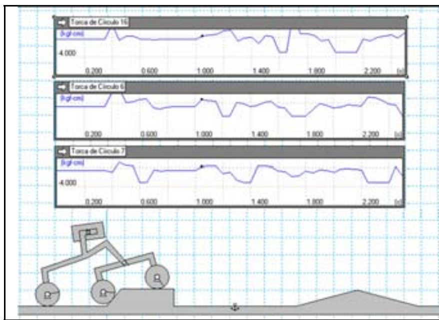

Figure-13. MER (Spirit).

Figure-14. NEXU.

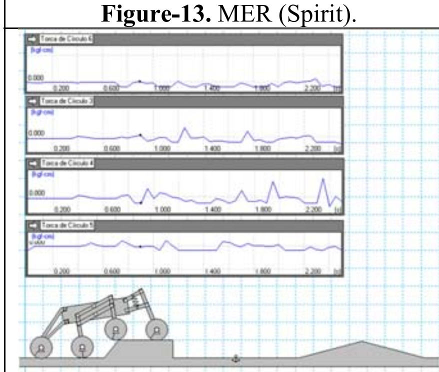

Figure-15. SHRIMP.

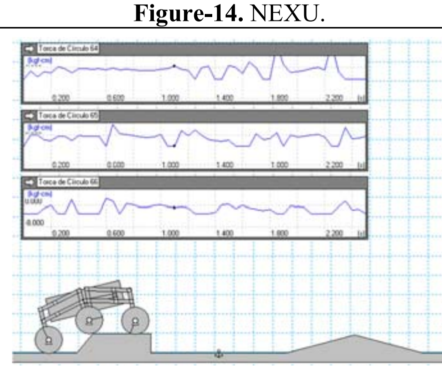

Figure-16. CRAB.

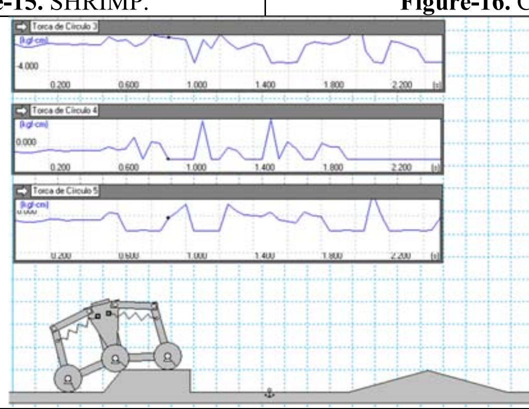

Figure-17. HELIOS.

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From these simulations it was observed that the mechanisms that perform outstanding performance were: The SHRIMP, CRAB, and the Mars Exploration Rover Spirit of NASA (MER), this was determined by analyzing the graphs of each of the torques on the engines. They analisis of the platforms does not vary greatly in its torque and neither the value of torque increases as that bypass obstacles through the ground.

In addition to the functioning of mechanisms to different types of obstacles in the simulation program, a study done about these Rover was based on the new metric [10], this was introduced with the aim of characterizing suspension systems in terms of compliance kinematic constraints while moving on uneven terrain. For this purpose, the wheel speeds depending on the state of the Rover were calculated using a kinematic model. Slippage is used as another value as it occurs if the kinematic constraints are violated. This study of different settings such as changing the center of mass and the wheelbase is reached the Rover type CRAB and RCL-E obtain good results with both indicators, while the performance presented MER was significantly lower [10].

To make a final decision in search of the mechanism used, a design methodology based decision-making through the QFD, for this survey were developed to potential users or potential buyers applied, this step will be explained below.

Survey

To select a suitable prototype that meets the project requirements and meets both the specifications of potential users, a survey of 10 questions for potential market, which is comprised of people specialized in mobile robotics applied.

QFD method

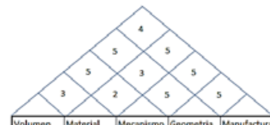
The information obtained from the survey was used to determine user requirements and incorporating the requirements that were determined at the beginning of the project, client specifications were established and using the method of the QFD (Quality Function Deployment) will become design specifications for proper selection of the prototype. The method of QFD is a set of matrices, displays the various needs identified by the same customers, for a given product or service, compared with the situation and finally transforms them into technical design specifications properly prioritized.

This method was applied to be clear about what you want according to user requirements and focus the desired characteristics translate into the product to develop. This was done taking into account:

- Knowledge of the state of competition.
- The costs involved improvements. [2]

The QFD obtained shows that one of the most important design aspects of the prototype is the size of the robot, other aspects to consider is the weight, maneuverability, portability, and cost of the robot. The aspects which will not have emphases are: speed and extra accessories you can have in the robot (see Table-2 QFD).

Table-2. QFD.



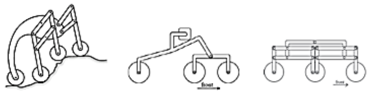
	Volumen	Material	Mecanismo	Geometria	Manufactura	Importancia del Cliente	Relacion de mejora	Relacion de mejora	Peso Relativo
Estabilidad	3	1	5	5	3	3.4	3.06	10.404	0.09546916
Tamaño	5	3	5	5	4	4.4	3.168	13.9392	0.12790885
Peso	5	5	5	5	1	4.2	3.024	12.7008	0.11654505
Velocidad	4	4	4	3	1	3.2	2.176	6.9632	0.0638957
Estetica	5	3	5	5	4	4.4	2.376	10.4544	0.09593164
Maniobrabilidad	4	3	5	5	3	4	3.28	13.12	0.12039171
Portabilidad	4	3	5	5	3	4	3.04	12.16	0.11158256
Seguridad	5	4	4	4	2	3.8	3.04	11.552	0.10600344
Costo	5	5	5	5	5	5	2.5	12.5	0.11470247
Accesorios	5	2	3	5	3	3.6	1.44	5.184	0.04756941
abs Importancia	4.5131917	3.39388645	4.73496205	4.76620517	2.9863605	20.39460586		108.9776	1
Real Importancia	0.2212934	0.16641098	0.23216737	0.2336993	0.146428939				

As a result of the QFD was obtained that aspects such as volume, mechanisms and geometry of the robot are of great importance when selecting the prototype, other aspects such as materials and manufacturing processes are not very important though these two aspects directly influence the construction costs of the robot, so a solution that is easy to implement and that it is able to meet project requirements sought.

Decision making

In the process of selecting the right prototype and that it meets the specifications of the project, a decision matrix which compares each of the characteristics of the proposed prototypes determining whether or not are appropriate for the project, giving a weight was performed on each evaluating the prototypes feature separately, the value of the weights are calculated depending on the values obtained in the QFD. The matrix was obtained during the decision-making process is seen in Table-3 Matrix decision. Alternative 2 was the most prominent of the process as it is on other solutions virtually most aspects of analysis, confirmed as the most comprehensive platform, based on technical criteria, as well as their suitability to the project specifications. In addition to alternative 2 comparison of the other has a superior size but this is an offset by other aspects of great importance such as geometry, ease of implementation and mechanism construction, manufacturing costs and aesthetics. Another important aspect to highlight alternative 2 is that the complexity of locomotion control is easily implemented as this is like the other two alternatives that can rotate around its center.

Table-3. Decision matrix.



Criterios	Peso relativo %	Alternativa 1	Alternativa 2	Alternativa 3
Estabilidad	9.54691606	6.5	9	9
Tamaño	12.7908855	12	9	11
Peso	11.6545051	10.5	9.5	7
Velocidad	6.38956997	5.7	6	5.5
Estetica	9.5931641	8	9	8.5
Maniobrabilidad	12.0391714	9.5	11	12
Portabilidad	11.1582564	5.5	7	5
Seguridad	10.6003436	5	8.5	10
Costo	11.4702471	10	9	8
Accesorios	4.75694088	2	4	3
Volumen	22.1293401	20	18	18
Material	16.6410985	13.7	15	13
Mecanismo	23.2167372	22	20	19
Geometria	23.3699302	19	21	18
Manufactura	14.6428939	13	14	12
		162.4	170	159

DETAILED DESIGN

Architecture and systems

Once the selection process of the mechanism to implement is completed, we proceeded to a 3D CAD program for dimensioning and generating parts and assemblies required for visualization of the idea.

As primarily a platform model given dimensions, placement and choice of number of actuators, and tires developed; proposing a model engine 10, four for direction at the ends 6 and 6 for the platform wheels. This model can be seen in Figure-18, showing a mechanism that meets the kinematic model proposed by the Mars Exploration Rover Spirit of NASA, and which was selected in the decision matrix. This prototype has some approximate dimensions of 62 cm x 44 cm. With the idea of robot platform, we proceeded to make a detailed and formal design, which it carried out the realization of the CAD for the different parts and systems that have the platform; including the wheel assembly shown in Figure-18 the complete prototype assembly with all parts and mechanisms is observed here placement engine, battery and other platform components shown.

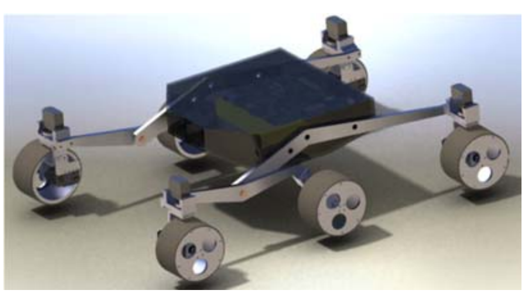
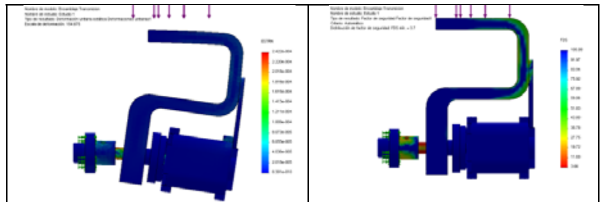


Figure-18. Detailed design prototype.

SIMULATION

During the design process, it was determined what elements of the platform, the major stresses and deformations are concentrated, ensuring that the prototype ground support requirements without damage that might impair their proper functioning. By simulating the stresses and strains that focus on each of the elements concluded that the shafts that transmit engine power to the wheels are those who come to suffer more damage if it were to overload the prototype. On the results obtained it shows that the minor axes safety factor (see Figure-19a) with a value of 3.84 and greater strain of $2.5x10^{-4}$ m (see Figure-19b).



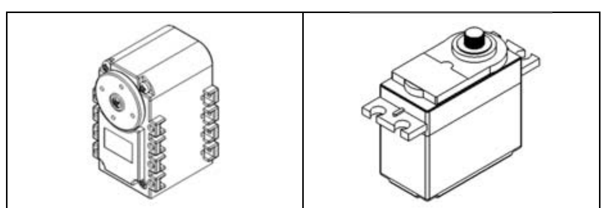
a)Security Factor | b)Unitary deformation

Figure-19. Simulation.

Actuators selected for handling this platform were chosen on the weight of the platform and the payload loaded proposed. The weight of the platform was found by the CAD program, and also the mass about with all its components is of 7600 grams, other variables are the center of mass on the platform it is suitable for a very good stability as it is below the prototype.

After learning the different platform variables such as weight and center of gravity that were investigated and several actuators for movement 6 servo motors (Figure-20a) were selected, among its main features this engine has a torque of 16.5 Kgf.cm 10V DC 900mA, these servo-motors have the ease of being able to manage the control position or velocity also by feedback, temperature and speed if necessary, this can be achieved because the control mode is serial communication that makes it possible to have full-duplex communication.

For steering movements 4 servo motors (Figure-20b) were selected as general characteristics has a torque of 4.5 Kgf.cm 6V DC 1200mA unlike the previous one you can only manage to control position but sufficient for the application.



a)Servo AX-12 motor | b)Futaba motor

Figure-20. Simulation.

CONSTRUCTION PROCESS

Defined CAD proceeded to build the prototype, at this stage several processes for the developments of these were used; these are shown in Figure-21.

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Figure-21. Process construction.

CONCLUSIONS

The selected material for creating the robotic platform were suitable, since the use of aluminum for bars, brackets and shafts for copper joints. With the simulations demonstrated that aluminum provided the platform the necessary rigidity for efforts that will undergo another advantage of the use of aluminum was the weight, this helped to the platform out light and allow a better choice for displacement.

The Selected engines were convenient considering that in testing platform exceeded obstacles approximately 12 cm high and allowing the platform to raise slope steeper than 15 ° with respect to the horizontal, approximately and as tested 30 degrees to the horizontal much the expectations were at first.

Implementation rubber acrylonitrile shore hardness approximately 70-75 platforms provide the necessary hardness to the tire is not deformed but at the same time gives adhesion necessary for the platform exceeds a lot of obstacles for different terrains.

ACKNOWLEDGEMENT

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