BB 8

Course Report

Robôs Móveis Autônomos
SSC - 0714

Universidade De São Paulo
ICMC

Jahir Medina
USP ID: 10659682

June 24, 2018

Contents

List of Figures

---

1 Introduction

BB - 8 is an spherical robot from the movie saga Star Wars, its main attractive resides in its movement manner, rolling.

Although his displacement by rolling , it always keep its head at the top (relative from floor) , cuteness besides, this movement style helps to keep balance , speed and *momentum* [1].

In the movie is possible see it doing some "acrobatic" movements inside the millennial falcon [3]. This kind of "skills" are only possible because his *non-holonomic* general behavior

Figure 1: BB-8 , Real Footage [4]

(as a mechanical system) [11], despite the fact itself is a **holonomic** robot type [9].

Those characters comprehend a set of special characteristics need to be part of the spherical robot family, this means, it is not just part merely thus its geometry form, because, even a fixed robot arm can be part of [10].

2 Work Context

2.1 Spherical Robots Family

A spherical robot is rawly defined as the robot who posses , like its denomination could look like, a spheroidal work envelope.

In a general way, every robot that posses an spherical work envelope is an spherical robot, this includes also fixed that like the **Standford Arm** design and build by the Standford University circa 1969 [10].

One inner property to spherical robots are they Holonomic Classifications [9], this means every degree of freedom its posses is also a reachable spacial reachable path [5].

Considering every spherical robot would have a similar geometry-like work envelope **and** is holonomic, every spherical robot could be kinematic describe using *spherical coordinates* [9].

2.2 Holonomic Robots

A Holonomic Robot is the one that has the same amount and *kind* of freedom degree and available displacement axis.

Uranus was an omni-directional robot used for almost 20 years in research reference to Holonomic Robots and its propriety In its particular case , the robot is using **mechanical wheels**; this kind of wheels provides him the ability to move 360° over its own and a full 2-D movement.

Figure 2: Uranus, Omni-directional Robot [7]

In the case of a Spherical Robot , this classifications applies with clarity in the case of the **Sphero robot**, 360° of superficial rotation and a fully 2-D movement [12].

2.3 Non-Holonomic Systems

Figure 3: Sphero , famous commercial spherical robot [12]

Is denominated Non-Holonomic a kind of system which even having the fully space information generated for it the best possibility to describe it is differential [11].

This means, the best system model is a differential relation between the last state (input) and its actual state (output).

In a non mathematical way , this could be understood as a system where every event is only dependent of its last state, because its last state was also dependent of the ulterior, but in every new state a complete set of parameters is established, being the next state dependent of this "new output".

2.3.1 Example

When a dog is trying to catch its owner, it tries always to track him in a straight path, but , if the owner is moving , in every new state of him , the dog "resets" its coordinate system, creating a curve path instead of a straight one. [11]

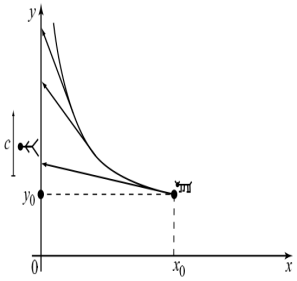

Figure 4: Man vs Dog, Curve Trazed [11]

2.4 Parallel Transport

The parallel transport problem covers the main idea of the invariability of a vector when transported over a sphere or in general any non regular space [6].

This implicates that when a point on a sphere posses a velocity $\vec{v}$; later , when the sphere rolls, the same point (at the same position) could have a $\vec{v}'$, even if the full sphere has the same resultant velocity $\vec{V}$, that point doesn't

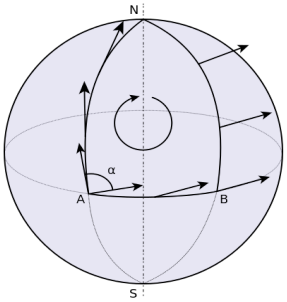

Figure 5: Transportation of a Vector over a Sphere [13]

3 Description and Details : BB - 8

3.1 Equilibrium

The BB - 8 uses its head as a counterweight [1] , this idea has its basis in the pendulum.

When the main frame (big sphere) goes in one direction, by intuition one could think the best way to slow down momentum is push the head in the opposite direction; but this is not how a pendulum works.

When the pendulum body archives its minimum regarding of its pivot, the gravity leads to and reverts its velocity direction ($\vec{v} \rightarrow -\vec{v}$) , in this scenario having a secondary body pushing in the opposite direction ends with an addition of velocities

$$\vec{V}_{before} = \vec{v} - \vec{v}_{counterweigth} \wedge \vec{V}_{after} = -\vec{v} - \vec{v}_{counterweigth}$$
$$\Rightarrow |\vec{V}_{before}| < |\vec{V}_{after}|$$

Generating additional movement, ending in a more unpredictable system[2.3].

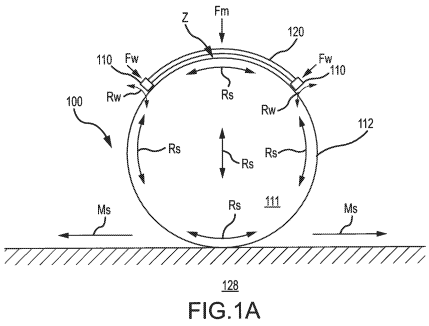

FIG.1A

Figure 6: Pendulum Counterweight , with Magnetic Couple [1]

3.2 Displacement System

Because BB 8 is an spherical robot, all its work envelope needs to be spherical , this implicates his actuators[3.3] can move him in the same range of freedom degrees [2], every actuator resides inside of an spherical capsule; this works as an omni-wheel

Having an exterior work as full time wheel solves the *parallel transportation problem* and guarantees its *holonomic robot classification.*

Is important to consider the external sphere rolls, it doesn't slide, but the orientation of the external frame (sphere capsule) doesn't matter, the robot it self resides in it.

For it roll purpose, the inner robot frame uses a low gravity center, which is always perpendicular to the floor and to its head.

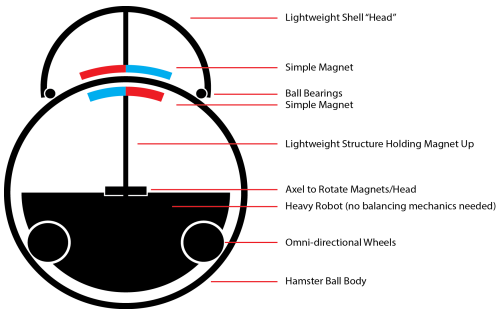

Figure 7: Axial Cut of BB 8 general design idea

This kind of set up allows more control over movements, because the inertial momentum resides in the same spot where the actuators (approximately) and the

above of the equilibrium device (head). Avoiding slide is primordial, when the system stars slides the internal sensors lost its reference frame.

3.3 Actuators and Sensors

3.3.1 Inertial Sensor

Having an external sphere as omni wheels requires every process (calculations and balancing countermeasures) being made inside of him even the equilibrium control, this requires know the orientation and acceleration in every axis available

An Inertial Sensors provides information about angles and velocities,knowing this is helpful to pre-calculated the *correction speed* for the head, making the move more smooth.

Is also important to know the orientation because the gravity center needs to be close to the floor, keeping the motors at maximum stability [8]

3.3.2 Motors

This motors serve to roll the external frame, which the actual wheel, in this case, when the motors are active , its behavior is similar to a differential wheeled robot.

The head doesn't have any motor, the bottom of it has some bearings and a magnetic couple system, giving it a fully motion range and a low dependency of inner control.

For the head , at inside range spherical frame has one solid pendular shaft, with a rotor at top, making the head rotation and the head balancing.

3.4 Movement Planning and Software

Being a Non-holonomic System have its benefits, the main of them are : The robot doesn't "care" about its general placement, it is say, his position relative in the fully space doesn't matter for his movement planning [2]

At a software level, this means every time the robot makes some movement , it tries to return at its "default" position (Gravity center horizontal and the head perpendicular to the floor)

This way of function provides it the ability of being fully autonomous in its movements. But in the case of *Path Planning/ Finding* it depends of the external

(a) Alternative Head Rotator (b) Pendular Head Rotator

Figure 8: Motors and Head [8]

operator, being at the end a Hybrid Robot. [8]

3.5 Robot Classification

- By Its Work Envelop : **Spherical Robot**
- By Its Mobility : **Mobil**
  - By Its Wheel Type : **Single Omni-wheel / 4 Cylindrical Differential Wheel**
- By Its Autonomy : **Hybrid**
  - Self-Orientation but remotely guided [11] [3].
- By Its Main Work Field : **Education / Entertainment** [12]
- By Its Copyright : Closed Robot (The original version is register [12])
- By Its Energy Source : Battery Powered

References

[1] Magnetic spherical balancing robot drive, 2012-09-18.

[2] Alizadeh, H. V., and Mahjoob, M. J. Effect of incremental driving motion on a vision-based path planning of a spherical robot. 299–303.

[3] Allain, R. The physics of star wars bb 8 bouncing around the millennium falcon. Online, 2015.

[4] BB8. Walt disney studios motion pictures, 2015.

[5] Campion, G., Bastin, G., and Dandrea-Novel, B. Structural properties and classification of kinematic and dynamic models of wheeled mobile robots. *IEEE Transactions on Robotics and Automation 12*, 1 (Feb 1996), 47–62.

[6] Guggenheimer, H. W. *Differential Geometry (Dover Books on Mathematics)*. Dover Publications, 1977.

[7] Gwpcmu, G. P. Uranus, 1985.

[8] INC, D.

[9] Joshi, V. A., Banavar, R. N., and Hippalgaonkar, R. Design and analysis of a spherical mobile robot. *Mechanism and Machine Theory 45*, 2 (2010), 130 – 136.

[10] Standford, U.

[11] Swaczyna, M. Communications in mathematics 19. 27–56.

[12] Toys, C. Sphero, 2011.

[13] wikisource.