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A Review of Indoor Navigation Systems for a Bipedal Robot: Preliminary Results

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Abstract. The navigation process of human is quite different from robots. Semantic meaning is what we used to model the environment. One of the most important elements human uses to model the environment is the vision. The keyframes are the elements that human use to model the environment. Therefore, we do not need a specific coordinate to move around. We can only use vision to navigate to anywhere we want to go. To take advantage of the concept that human model the environment, we propose a method which imitates the mapping and navigation process of the human. We will use computer vision to do the mapping of the environment and wayfinding to navigate it. The environment model is created with data collected with an odometer that identifies the obstacles on the route of the robot. Our research proposal is to create an algorithm to avoid obstacles. In this paper, we focus on reviewing existing solutions to address our research problem which is a system mounted on a biped robot navigating indoor environments on its own, without having to use preset routines. We have reviewed existing literature and presented it to help future researchers who had the same goal and could be used as a starting point.

Keywords. Navigation, locomotion, mobile robot, biped robot, indoor environment.

1 Introduction

As more mobile robots start integrating in different areas of society they will need to operate in a wide variety of environments. Often, these environments will be dynamic; objects move and structures physically change. Less dynamic environments can be characterized by physical changes that occur over the course of days, weeks, or months, whereas more dynamic environments involve continuously moving objects, such as, humans or vehicles.

Mobile robots cannot assume the world is static if we expect them to work effectively. In order for a mobile robot to work autonomously in a dynamic setting it must have a way to sense its surroundings. Camera sensors are ubiquitous among modern robots and can provide a great deal of information about the environment. Robotics applications can employ techniques such as computer vision to accomplish tasks such as object recognition, 3D reconstruction, and mapping and localization [1]. Nowadays, most of the robots require moving and performing tasks in a variety of environments which are sometimes even unpredictable. Mobile robot navigation is a challenging problem in the robotics field and numerous studies have been endeavored resulting in a considerable number of solutions. The navigation problem consists of four integral parts namely perception, localization, motion control and path planning.

The path planning is the determination of a collision-free path in a given environment which is often a cluttered environment in a real world situation.

A lot of different path planning approaches have been proposed and tested in various environments with static [2, 3, 4, 5, 6, 7] and dynamic obstacles [8, 9, 10, 11, 12]. These include both classical approaches like potential fields, cell decomposition, bug algorithm, road map and heuristic approaches like neural networks, fuzzy logic, and wavelets [13]. The remaining of this paper is structures as follows: the review of the state of the art is presented in section 2, a review of navigation of mobile robots is presented in section 3, the proposed methodology is presented in section 4, a discussion of the advantages of walking mecnanisms are presented in section 5, the last section concludes with a discussion of the future work.

2 State of the Art

A mobile robot is a device that is capable of locomotion. It has the ability to move around its environment using wheels, tracks, legs, or a combination of them. It may also fly, swim, crawl, or roll. Mobile robots are used for various applications in factories (automated guided vehicles), homes (floor cleaning devices), hospitals (transportation of food and medications), in agriculture (fruit and vegetable picking, fertilization, planting), for military as well as search and rescue operations. They address the demand for flexible material handling, the desire for robots to be able to operate on large structures, and the need for rapid reconfiguration of work areas [14].

Generally, the first step to analyzing the robot gait on any surface is to analyze the gait on flat surfaces. The flat surfaces in this case mean the horizontal plane and the planes with different slope in relation to the horizontal. The ability to detect obstacles by the robot is closely related to sensors that allow to "see" them.

The analyzed type of gait is a statically stable gait. It means that the robot does not fall over if all motors are stopped at any time. For the robot to remain stable, it must have at least three support points [15].

An autonomous robot could define as a device with partial or complete autonomy, which can do specific tasks using one or several algorithms previously programmed.

A fully autonomous device may or may not be controlled by a user machine interface (IMU). The main motivations for the development of robots are based on: unlimited work space, free environment, and the permanent ability to adapt [16].

Robots can play a major role in navigating undulated landmine-infested terrains. Design of mine detection and clearance robots demand special types of locomotion for maneuvering on uneven surfaces. Various modes of locomotion are possible for robots for such special applications, such as legged movement, wheeled movement, track motion, and combinations thereof called hybrid locomotion. Hybrid locomotion uses the advantages of multiple forms of locomotion within a single robot and switches between the various types of locomotion according to the requirements and the terrain conditions. Most hybrid robots move on wheel-leg combinations and can be of two types. In the first type, the wheel is attached to the end of the leg. In this case, the robot is capable of walking using the legs with the wheel movement arrested. In the second case, the wheel and the legs are combined in such a way that they can be operated independently based on the requirement [17]. In the review of the literature, various investigations have been carried out on the navigation of mobile robots in indoor [18, 19, 20, 21, 22, 23, 24, 25, 26] and outdoor environments [20, 26]. Simultaneous Localization and Mapping (SLAM) [18, 19] and topological map [17] are mainly used to obtain an accurate position of the robot, using sensors, lasers [18] or cameras [24] to detect and recognize obstacles, even relying on a computer vision system such as Tensor Flow^{TM} [19, 22]. The projects are completely based on the open source software ROS (Robot Operating System) [19, 24], some authors propose a neural network to compare images [17, 18, 20, 22, 23] by using deep learning techniques [20, 23, 25]. Other works use a local Wi-Fi network to determine the locations of the devices based on the connection data provided by the access points as the devices move through the environment. Finally some authors present a direct method of navigation that uses gradient descending on the difference between two points specified in the space of slow characteristics [27] and an autonomous local navigation and positioning system based on an artificially established magnetic gradient for in-grid or desktop applications [28].

3 Navigation of Mobile Robots

Navigation is essential for a mobile robot and mobile robot navigation is a challenging problem in the robotics field and numerous studies have been endeavored resulting in a considerable number of solutions [31]. It is hard to imagine a mobile robot without the ability of navigation. For example, if a mobile robot wants to search an object in an indoor environment, it has to move around in different rooms without collide into any furniture. Navigation gives a mobile robot more freedom to complete tasks, and makes it more useful and intelligent. If a mobile robot lacks of the ability of navigation, the functions will be highly limited.

The term navigation refers to the guidance of the mobile robot from the starting position to the target position avoiding collisions and unsafe conditions. It consists of three major steps, self-localization, path planning, and map building. Three main anxieties concerning robot navigation problems are efficiency, safety, and accuracy. Path planning is a vital step of the motion control and navigation of the mobile robots. Path planning is categorized as an NP-complete problem and several heuristic based methods have been implemented, such as the application of artificial neural networks, particle swarm optimization (PSO), genetic algorithm (GA), and hybridization between them.

One of the main benefits of heuristic based methods is that it can yield satisfactory results quickly, which is particularly appropriate to solve NP-complete problems.

The path planning is separated into two main fields, global and local path planning. On the first hand, in path planning with local path planning, the calculations of the path are achieved when the mobile robot is in motion; that means, the calculation is fit for generating new paths as the environment changes. On the other hand, with global path planning, the environment should be totally recognized and identified, while the terrain must be static. Path following problems are primarily concerned with the design of control laws that steer an object to reach and to follow a geometric path, while a secondary goal is to force the object moving along the path to satisfy some additional dynamic specifications.

Mobile robots systems are highly dynamic systems that end up inserting several constraints in the control system, such as response speed, precision, mobility constraints, computational cost, computational power, maneuverability, and control stability issues.

As a matter of fact, navigation for robots is complicated. It involves mapping, localization, and path planning. Mapping nowadays highly relies on Simultaneous Localization and Mapping (SLAM), which is used to create high precision metric maps. This kind of map can be presented in 2D or 3D. Metric maps are dedicated to provide rich details and model the environment as precise as possible. Different navigation methods are:

SLAM: A kind of map that robot can use to model the environment is metric map, which is created by SLAM method. Metric map is normally consist of a good number of pixels, and each pixel is marked as an obstacle, a free space or an unknown area. This kind of map tries to be as precise as possible so that robot can do navigation based on it safely.

Semantic Map: One of the most important drawback of a metric map is that it lacks of semantic meaning. Robot can only use this kind of map to model the environment instead of understanding it. Kitchen, living room or restroom cannot be efficiently represented by metric map because a metric map is composed of lots of coordinates. The similar situation is that normally longitude and latitude is not helpful for people who want to reach a place. Therefore, semantic map is a kind of map which tries to store as many semantic meanings as possible.

Topological Map: Another drawback for a metric map is that it needs high computation power because it models the environment precisely. However, topological map is known as its lightweight data usage. This kind of map integrates semantic meaning with space relations together [14].

3.1 Legged Robots

Most mobile robots used wheels or tracks and the limitations of these wheel and track vehicles when on tender ground or tough terrain have been acknowledged ever since they displaced horses and mules. Six-legged robots can be used as search and rescue robots, space robots and discover robots. Legged robots can be used for rescue work after earthquakes and in hazardous places such as the inner of a nuclear reactor, giving biologically stimulated autonomous legged robots terrific potential.

Legged locomotion is fine if there are many depressions and rises that require leg lifting motions to overcome them, given that legged locomotion can move forward by striding over obstacles at how the robot climbs up the steps and its navigation in an unknown environment, observed with the aid of a discussion on the experimental results before concluding [30].

3.2 Walking Mechanisms

Modern humanoid robots can already execute such tasks autonomously, providing the approximate state of the environment is known in advance. However, it is still difficult for modern humanoid robots to perform such tasks without some prior information about the environmental conditions that can be exploited by a programmer to prepare the humanoid robot for the execution of multiple tasks. Integration and continuous sequencing of multiple robot actions remains a problem and some degree of teleoperation is still needed when performing longer task sequences.

There are several reasons why humanoid robots are thought to be interesting:

- Human environments are built for humans, therefore a general-purpose robot designed for human environments, e.g., homes, factories, hospitals, schools, etc., should have a form similar to humans to successfully operate in such environments.
- It is more natural for humans to interact and communicate with robots that look and behave in like humans.
- A humanoid robot can serve as an experimental tool to test the theories about human behavior created by computational neuroscientists, interested in how the human brain operates.

The foremost is the problem of biped locomotion and balance. Unlike other robots, humanoid robots must walk and keep balance during their operation. In the afore mentioned robotics challenge, locomotion turned out to be one of the biggest issues. The basic indicator that describes the balance of a humanoid robot is the concept of zero-moment point, usually abbreviated as ZMP. The concept of ZMP was introduced by Miomir Vukobratovi´c in 1968. It is still the most widely used approach for generating dynamically stable walking movements in which the supporting foot or feet keep contact with the ground surface at all times. This is important to prevent the robot from falling.

Biped Locomotion: It is an important topic in humanoid robotics. Here we focus on walking, which is distinguished from other forms of biped locomotion such as running by the constraint that at least one foot must always be in contact with the ground. Most of the modern humanoid robots exploit the zero-moment point principle to generate stable walking patterns.

Based on the concept defined in Fig. 1 there are two distinct phases in the gait cycle: when both feet are in contact with the ground, the robot is in double support phase. The feet do not move in this phase. Once one of the feet starts moving, the robot transitions from double to single support phase, in which one of the two feet moves. The single support phase is followed by another double support phase once the foot in the swing phase establishes a contact with the ground.

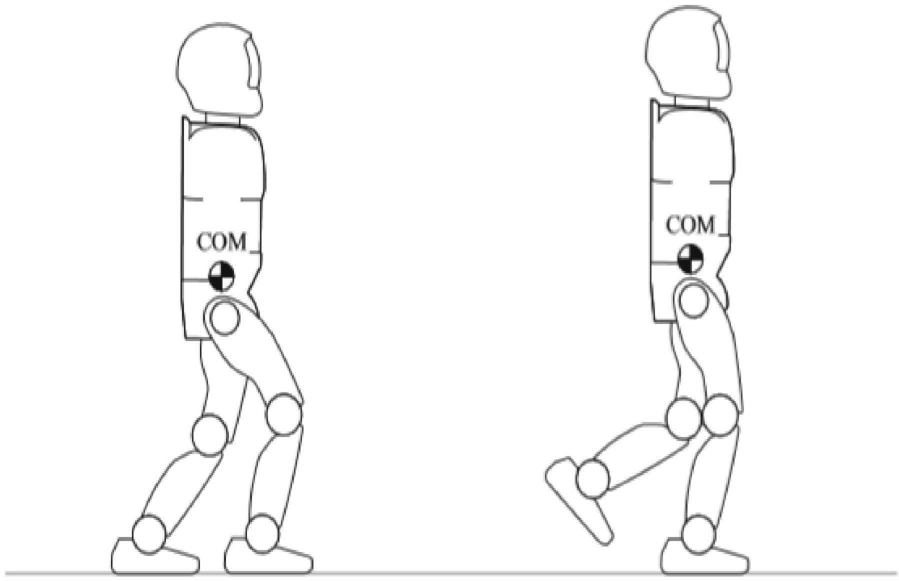

Fig. 1. Single and double support phase. In the double support phase, both feet are in con-tact with the ground and the robot's weight is supported by both legs. In the single support phase, one foot is in motion, whereas the other foot supporting the robot is in contact with the ground [14].

Walking mechanisms are suitable for applications that require movement across rough terrains, especially if compared to conventional wheels. They consist of links and joint, and are intended to simulate walking of human or animal. These linkages can be planar with single degree of freedom, or they can have a more complex motion in 3 dimensional space. Some can have multiple degrees of freedom.

4 Proposed Methodology

The main objective of this work is to develop an autonomous navigation system that integrates elements of the model of bipedal gait, stability and navigation that allows a biped robot to explore indoor environments with a level of autonomy similar to or greater than that reported in the literature. Based on the material provided in the previous section and our experience, the following requirements are defined to the methodology.

a) Select a commercial biped robot, as well as study and analyze its operation.
b) Select and apply a bipedal gait model for the selected robot (Fig. 2).

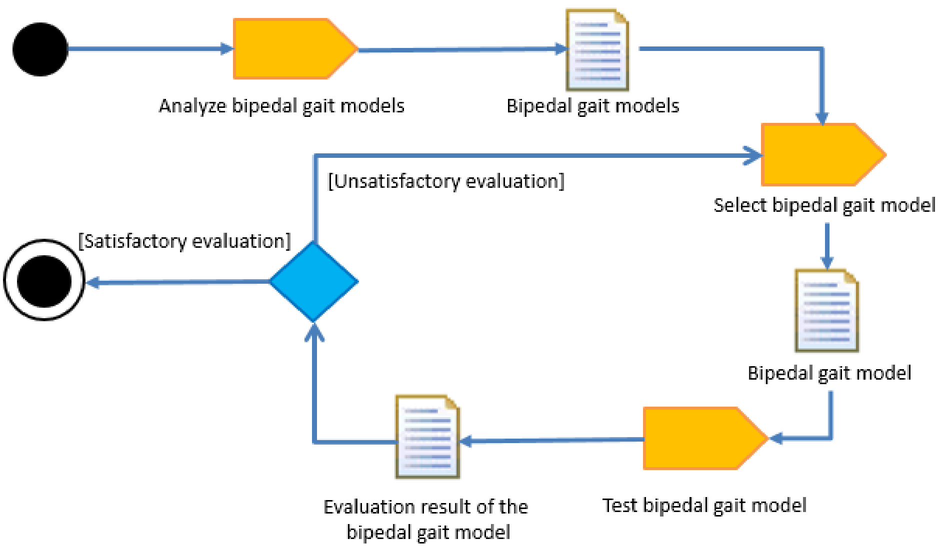

Fig. 2. This diagram shows the process of selection and evaluation of the bipedal gait model for the robot.

c) Select and apply a stability technique for the selected robot (Fig. 3).

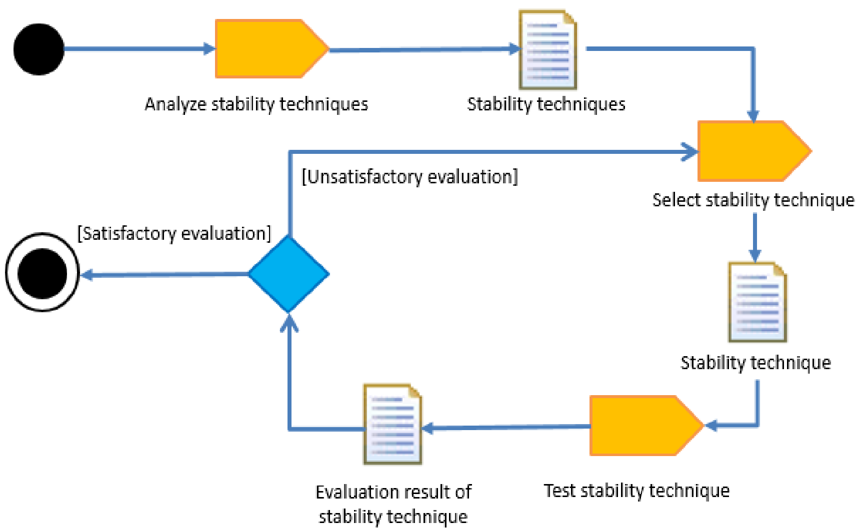

Fig. 3. This diagram shows the process of selection and evaluation of the stability technique for the robot.

d) Select and apply the indoor navigation method for the selected robot (Fig. 4).

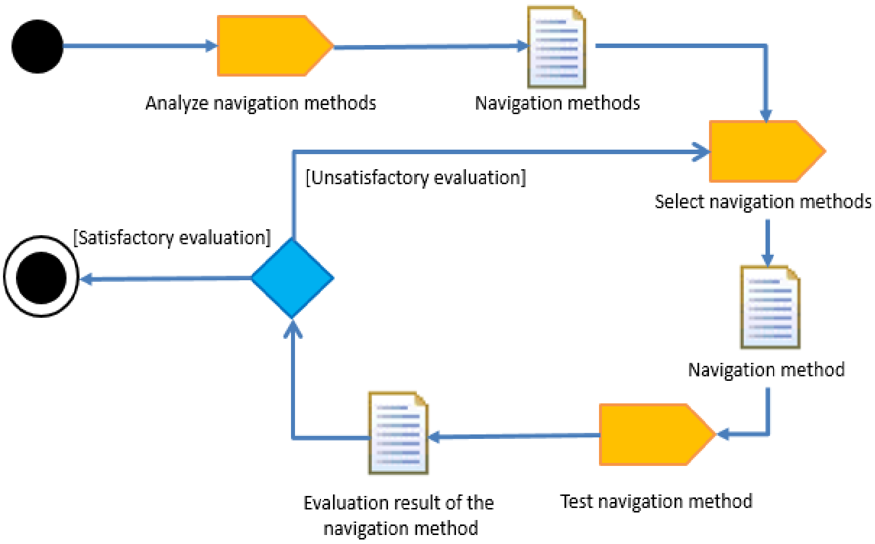

Fig. 4. This diagram shows the process of selection and evaluation of the navigation method for the robot.

e) Evaluate the integration of the bipedal gait model, the stability technique and the indoor navigation method in the selected robot.
f) Select an automatic learning method and implement it in the selected robot.
g) Evaluate the integration of machine learning to clause e).
h) Design the autonomous navigation system for the selected robot.
i) Validate the level of autonomy in the navigation of the selected robot in indoors (Fig. 5).

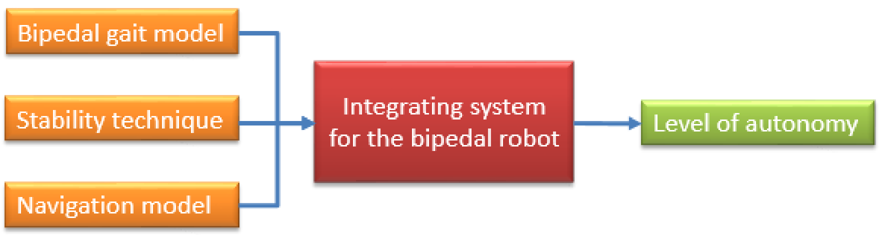

Fig. 5. This diagram shows the integration of the elements of bipedal gait, stability and navigation to obtain the level of autonomy of the bipedal robot.

5 Discussion

In the light of our proposal and based on the literature review we highlight the following elements:

- **Flaws of walking mechanisms**. The shortcomings of the walking mechanisms identified are: a driving member rotates in an unequal speed to obtain a unique speed of robots, or vehicles that are driven by a walking mechanism; the length and height of the steps are fixed; inertial moments and forces cannot be balanced in a satisfied way.
- **Advantages of walking mechanisms.** When it comes to the advantages of walking mechanisms, first of all, it is necessary to mention the movement on rough terrain. It can move on all types of terrains like desert, mountains, snow, rocky. It can be even used in planetary exploration because it has maximum payload to weight ratio. Also it has maximum efficiency for moving. These benefits of using walking mechanisms include higher speed, better fuel economy, greater mobility, better isolation from terrain irregularities, and less environmental damage.
- **Advantages of walking mechanisms when passing an obstacle.** If we compare this mechanism with a common wheel, it is obvious that the walking mechanism will overcome an obstacle much easier by just crossing it. Consider a moving wheel with a constant angular velocity ω, each point on the circumference of the circle will have a velocity ν, in the direction tangent to the circle. It is clear that the leg will have an advantage over the wheel, because it will be easier for it to overcome the obstacle. This way you can reduce the consumed energy [29].
- **Indoor versus outdoor configuration.** Balance is usually not a research problem in wheeled mobile robotics because robots are almost always designed so that all of the wheels are generally in contact with ground. When more than three wheels are used, a suspension system is required to allow all wheels to maintain ground contact when the robot encounters uneven terrain. Therefore, wheeled robot research tends to focus on the problems of traction and stability, maneuverability, and control. This can be further analyzed regarding the environment they are. Regarding outdoor mobile robots, usually researchers need to take into account problems such as the following: higher sensor noise, e.g., in vision systems due to illumination variation; weather variation, such as fog, snow, wet floors, mud, sand; floor irregularities; localization and state estimation issues.

All above-mentioned issues affect directly the mobile robot trajectory tracking control system. Only a few works in literature uses outdoor WMRs with model predictive control that make this an open topic for researchers. In contrast, although indoor mobile robots are often studied, they are always in controllable environments [32].

6 Conclusions

During the review of the literature, it has been validated that the majority of mobile robots are related to image processing and the use of artificial vision to detect and recognize obstacles during navigation, some others use presence sensors, such as ultrasonic or infrared sensors. Even some of these works employ automatic learning techniques, such as reinforcement learning, Q-learning or convolutional neural networks to perform navigation successfully and also be able to memorize the paths made by robot, so that its next journey is more efficient than the previous one. It is important to point out that most of the works related to the navigation of robots use wheeled robots for their simplicity when modeling and controlling their displacement, therefore there is the importance of developing an autonomous navigation system for a biped robot in indoor environments, using any type of sensors or artificial vision for the robot is able to move through a horizontal plane, detect and avoid static or dynamic obstacles.

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