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# Implementation of AGVs Indoors to Transform Warehouses to Fully Autonomous Environment

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## Abstract

Mobile robots are becoming more and more part of our industrial world. With the development of robotics, the design of the mobile robot has become conditioned to the function it has to fulfill. It is important to make a study and understand the difference concepts found in robotics in order to design the most suitable mobile robot for a certain industry. Holonomy is one of these concepts discussed in this paper. Holonomic and non-holonomic mobile robots use different wheels where the first is omnidirectional and the latter is limited with its movement. And thus, which robot to use remains a question in the minds of those running warehouses. In addition to that, it is worth to explore the different sensors used on vehicles in order to covert them to automated guided vehicles. Understanding the concept of holonomy, knowing the difference in the performance of holonomic and non- holonomic robots , as well as AGVs systems help in making the decision suitable for the warehouses.

**Keywords:** Mobile robot • Holonomic • Non- Holonomic • Mecanum wheel • Standard wheel • Indoor navigation • Automated guided vehicles • AVGs

## Introduction

Originally, the word “robot” has come from the Czechoslovakian word “robota," meaning forced labor. It has first appeared in “Rossoum’s Universal Robots” play by Karel Capek in 1921. Since then, robots have been depicted as mechanical men in science fiction. It was but obvious to later use it as a term in science [1].

Taking a retrospective tour around the history of robotics, some claim that humans have been trying to build “automata” for centuries, dating back to as early as 300-400 BC. The first major step in the development of robotics is the Industrial Revolution. By the 1950s, engineers have been designing and developing automatic machines in order to increase the speed of production, perform tasks humans could not do, and take the place of humans in dangerous situations.

These robots have become human assistants and have not fully taken the people’s place. By the 1960s, the industrial robot has been identified as a unique device and its market has been growing and growing to this day. While the development of industrial automation has its ups and downs, due to certain causes such as economics, the main reason for industrial robots’ rapid growth has been the decline of their cost. Meanwhile, human labor has become more expensive, especially that people are needed as expert specialists to manage these robots that are more efficient, accurate and flexible, as well as faster than humans in performing tasks. For example, robots such as manipulators have taken the place of humans in warehouses where they could have roles in assembling, sorting, moving material, packaging, etc…

However, stationary robots are no longer enough. A more advanced robot is needed that can move around and operate independently of humans.

Thus, the mobile robots have been the next step in the development of robotics. It is a robot that can follow a path and avoid on its way obstacles it detects through sensors installed on it. Mobile robots have been sent to Mars for space explorations.

Other mobile robots were designed to explore locations humans can’t reach or too dangerous to wander through themselves. Mobile robots are also used in warehouses where, for example, they transfer material from one place both another making it easier for people to access everything without the need to leave their place [2](Figure 1).

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**Figure 1.** Kiva robot in amazon warehouses.

## World Deforestation

As per Teacher Norman Myers, one of the principal experts on paces of deforestation in tropical backwoods, "the yearly devastation rates appears to be set to quicken further and could well twofold in one more decade" [3]. For the most part deforestation has happened in the calm and sub-tropical regions. Deforestation is never again critical in the created calm nations now and in actuality numerous mild nations presently are recording increments in timberland zone [3]. In many cases created countries are situated in mild areas and creating countries in tropical spaces. Anyway deforestation was fundamentally less in tropical wet deciduous woods in 1990-2000 than 1980-1990 however utilizing satellite symbolism it was discovered that FAO overestimated deforestation of tropical rainforests by twenty three percent [4]. Anyway the meaning of what is and what isn't a wood stays disputable. The tropical rainforests catch most consideration yet sixty percent of the deforestation that happened in tropical woodlands during 1990-2010 was in wet deciduous and dry timberlands.

However extensive tropical deforestation is a relatively modern event that gained momentum in the 20th century and particularly in the last half of the 20th century. The FAO FRA 2001 and 2010 reports indicate considerable deforestation in the world during 1990-2010 but this was almost entirely confined to tropical regions [3].

## Locomotion

For a mobile robot to move around with no restrictions, it requires locomotion mechanisms. In manipulation, the robot arm is stationary but moves objects around. Contrary but complement of manipulation, in locomotion, the robot moves around but in a fixed environment. When designing a mobile robot, it is important to take a few points into consideration. The first is stability, which addresses the number and geometry of contact points, the center of gravity, static or dynamic stability, and inclination of terrain. The second is characteristics of contact which deals with contact point or path size and shape, the angle of contact and friction. The third is the type of environment which considers the structure and medium, like water, air, soft or hard ground.

Since a robot has many possible ways to move, it is important to take into consideration while designing the robot, its approach to locomotion. Most of the moves that a robot does are inspired from nature. Some robots are designed to walk, jump, run, slide, skate, swim, fly and roll. There are also mobile robots that use the wheels, a human invention [5].

Wheeled mobile robots are considered the most popular locomotion mechanisms. A mobile robot could have two or more wheels. Balancing a mobile robot is not an issue when it comes to wheeled robots since having a minimum of three wheels allows a robot to balance. When a robot has more than three wheels, suspension systems are adapted to allow the wheels to remain in contact with the ground when moving on uneven surfaces. However, the main challenges in wheeled robots a r e t r action and s t ability, maneuverability, and control.

### Holonomy

In mobile robotics, the concept of holonomy is used when describing the path space of a mobile robot. It refers to the kinematic constraints of the robot chassis. A robot is said to be holonomic when it has zero non- holonomic kinematic constraints. Meanwhile, a robot is said to be non-holonomic when it has one or more non- holonomic kinematic constraints. It refers to the relationship between controllable and total degrees of freedom (DOF) of a robot. Furthermore, the main factor that distinguishes whether a robot is holonomic or non- holonomic is the type of wheels used, such as standard or Swedish wheels [6].

**Non-holonomic robots:** Non- holonomic robots are the most commonly used because of they have a simple design and are easy to control. Non-holonomic drive occurs when the controllable degree of freedom is less than the total degrees of freedom. It becomes difficult for the driver to stir the vehicle in any direction. It usually moves forward and backward. When it needs to make a turn, it stops, turns to a specified angle either clockwise or anti-clockwise, then continues moving forward or backward. The configuration of a non-holonomic robot is obtained by two coordinates (X, Y) which specify the location of the robot.

**Holonomic robots:** When the controllable degree of freedom is equal to the total degrees of freedom, the robot is considered to be Holono micoromnidirectional. The robot can move freely in any direction, forward, backward, rightward, leftward, clockwise, anti-clockwise and diagonally. This makes it easy for the driver to control it and stir it immediately in the direction needed. The configuration of a robot is obtained by more than three coordinates (including x, y, and θ) where the first two coordination's specify the location and third coordination specify the orientation of the robot, while the rest describe the internal geometry (Figure 2).

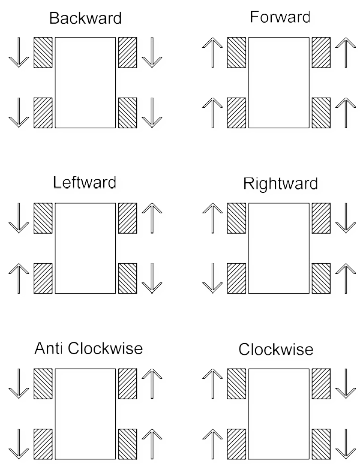


**Figure 2.** The movement of mobile robot using 4 mecanum wheels.

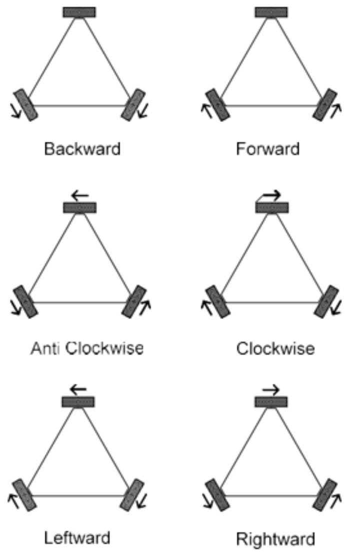


**Figure 3.** The movement of mobile robot using 3 omni-wheels.

### Standard wheel vs swedish wheel

When building a robot, it is important to take into consideration the type of wheels that is going to be used since each has different kinematics.

There are four major classes of wheels:

- Standard wheel,
- Castor wheel,
- Swedish wheel, and
- Spherical wheel.

Some robots may include one type of wheels while others might include two types of wheels. It is also important that the designer of the mobile robot considers the arrangement of wheels and the wheel geometry.

In order to observe the difference between non- holonomic and holonomic robots, the focus will be only on the standard wheel and Swedish wheel [5].

**Standard wheel:** The standard wheel is a highly directional fixed wheel installed directly on the robot body. It has a roll axis parallel to the floor and its orientation can be changed by an axis perpendicular to the ground through the contact point. To move the robot in a different direction, the wheel must first be steered along a vertical axis.

**Swedish wheel:** The Swedish wheel includes two types of wheels, Mecanum wheel and omni-wheel. The Mecanum wheel is invented by Bengt Ilon in 1973. It consists of a central wheel surrounded by a number of small rollers placed at a certain angle depending on the design. Its only actively powered joint is the wheel's primary axis and it does not have a vertical axis of rotation. As for the omni-wheel or ply wheels, similarly to the Mecanum wheel, around the main wheel, it has small discs, perpendicular to the rolling direction. Both wheels act as normal wheels but with very little friction and both have three degrees of freedom. They can also move in any direction including sidewards, making them omnidirectional thus their manoeuvrability is better.

## NAMLA: A Case Study

In order to put these two concepts into test, a research has been conducted and a mobile robot has been designed. NAMLA, an Arabic word for an ant, is known for its ability to go on long distances carrying on its back loads of food that is more than its weight, while using its sensory skills along the way. Similar to the ant, NAMLA robot can receive an order to go to a specific place while carrying some loads and return back to its home (Figure 4).

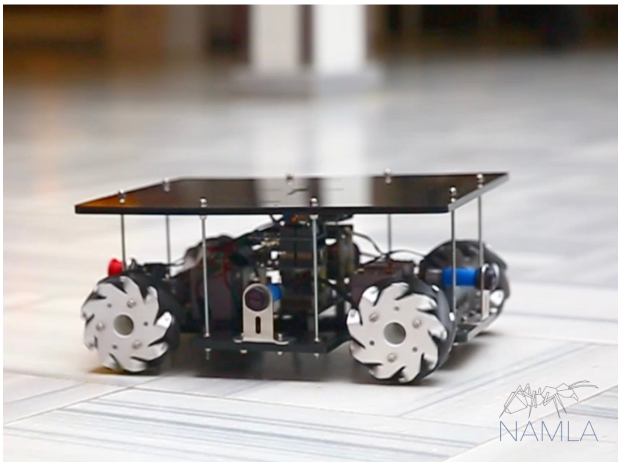


**Figure 4.** NAMLA 1 with swedish wheels.

Two versions of NAMLA have been designed. The first one, NAMLA 1 is an omnidirectional autonomous or semi-autonomous mobile robot AMR. It has four motors and four Swedish Mecanum wheels, with an embedded control system. It also has ultrasonic sensors and Initial Measurement Unit IMU 6 DOF. It has a navigation system for indoor, moves from point to point (PTP), avoids obstacles, and can be controlled manually through a joystick. It can move on flat surfaces as well as even paved roads. It can carry a payload of 11 kg and lift loads and move them to another place. It can perform path planning so the map of a facility can be imported into its system. The second one, NAMLA 2, has the same features except, instead of Swedish Mecanum wheels, standard wheels are used [6].

Both NAMLAs have received the same orders in order to observe their performance on the level of time, efficiency, battery consumption and torque. First, they have been given the order to go forward and backward. Then, they have been ordered to move clockwise and anti-clockwise. Finally, they have moved sidewards and diagonally. In the first two cases, the standard wheel has been able to perform these moves faster, with less battery consumption. However, it is not able to move sidewards and diagonally like the Swedish wheel (Figure 5, Figure 6).

**Figure 5.** NAMLA 2 with standard wheels.

| | | Standard Wheel | Mecanum Wheel | Omni-wheel |
|---|---|---|---|---|
| Kine-matics | V$f$ | $w . r$ | $w . r$ | $w . r . \sqrt{2}$ |
| | V$r$ | - | $w . r$ | $w . r . \sqrt{2}$ |
| | V$d$ | - | $w . r / \sqrt{2}$ | $w . r$ |
| Force | F$f$ | $4\mathcal{T}/r$ | $4\mathcal{T}/r$ | $4\mathcal{T}/(r\sqrt{2})$ |
| | F$r$ | - | $4\mathcal{T}/r$ | $4\mathcal{T}/(r\sqrt{2})$ |
| | F$d$ | - | $2\mathcal{T}/r$ | $2\mathcal{T}\sqrt{2}/r$ |

**Figure 6.** Kinematics and force of standard wheel, mecanum wheel, and omni-wheel.

The figure above includes three columns that show the standard, Mecanum and omni-wheeled vehicles respectively. All have the same diameter. The omni- wheels are mounted at 45 degrees.

The first three rows are vehicle velocity: forward, strafe, and diagonal, for the wheel speed w. The second three rows are vehicle total pushing force: forward, strafe, and diagonal for a given wheel torque. The three rows assume frictionless Mecanum and omni roller bearings and sufficient traction to support the floor reaction forces.

Taking NAMLA to the next level, AGVs are explored. AGVs or Automatic Guided Vehicles are fully automatic unmanned vehicles. AVGSs date back to 1953 starting in America, implemented by Barrett-Cravens, and few years later Europe followed America. With the proper transport system, AGVs can safely move objects without the intervention of humans. It is suitable for environments such as production, logistic, warehouse and distribution. An automatic guided vehicle can lift, rotate, shift, fetch from racks, and store objects in deep lanes. It can also transport loads across long distances, delivering them to certain locations or people (Figure 7).

**Figure 7.** Power pallet jack.

An example of a vehicle that can conduct such tasks with the implementation of AGVs system is a power pallet jack. This vehicle handles pallets that tasks with the implementation of AGVs system is a power pallet jack. This vehicle handles pallets that come in different sizes and dimensions that need to be approved by the International Organization of Standardization (ISO). So, it is important to take into consideration the CAD drawing of the warehouse. Furthermore, pallets are manufactured either from wood, plastic, metal, paper/cardboard, or recycled materials.

To conduct this research, a warehouse was designed, consisting of shelved aisles with the width of 300 cm, on which 100x100 cm pallets were placed. Then, on a power pallet jack of dimensions 220x91cm, a LIDAR, Inertial Measurement Unit IMU 9 DOF, and a cam vision are installed for navigation (Figure 8).

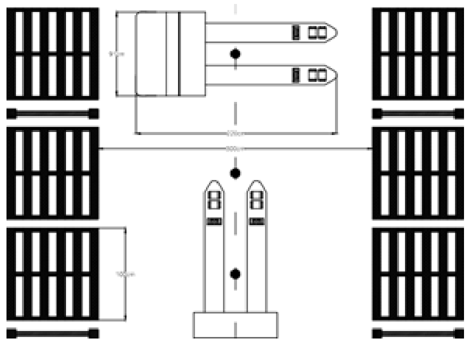

**Figure 8.** Dimensions of the power pallet jack, pallets, and aisle.

For the navigation system, Cartesien coordinate system (X, Y) is used along with RFID tags. This allows the robot to navigate easily and decreases the possibility of errors. Also, A genetic (A*) algorithm is used for path planning. To define the track of the power pallet jack, RFID tags are used. At the center level of each pallet, an RFID tag is placed in the middle of the aisle, as shown in (Figure 9) [7].

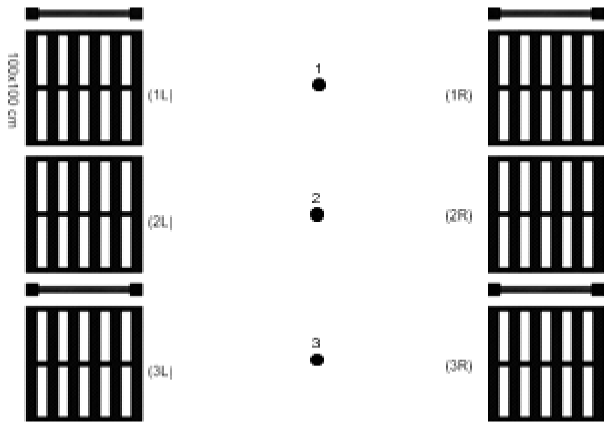


**Figure 9.** RFID tags in the middle of the aisle.

As the power pallet jack moves along this track of tags reading them, it will recognize the presence of pallets on both sides of the aisle. Each shelf has a barcode label as an identification, previously imported into the warehouse's system. When the cam vision on the power pallet jack reads the barcode, it contrasts it with the data in the system, if the data matches, the autonomous power pallet jack handles the goods; if the data doesn't match, the power pallet jack proceeds in finding the requested barcode (Figure 10, Figure 11).


**Figure 10.** Barcode of a shelf.

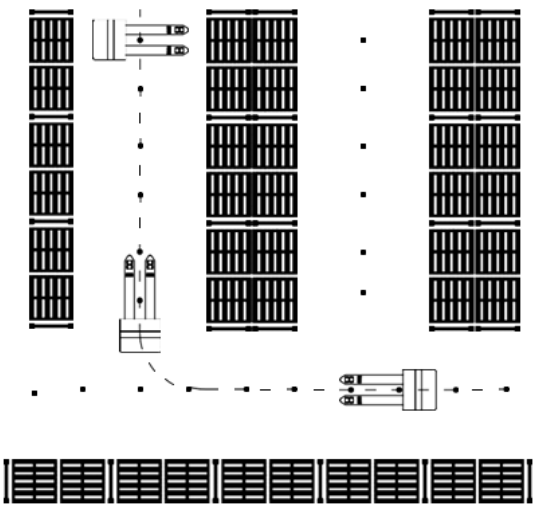

**Figure 11.** The movement of the power pallet jack following the track of RIFD tags.

## Conclusion

After conducting this research to check which is more efficient for warehouses, non-holomic or holonomic, it is clear that non-holonomic is suitable for those who seek to save time and battery. Non-holonomic robots are able to go on full speed and torque, while in holonomic robots, when going side wards, its torque becomes weaker. It also results in loss of battery. This could be inconvenient for warehouses that need efficient and sustainable solutions. In case a robot is needed to go sidewards, it is faster for it to turn clockwise or anti- clockwise, and then move forward rather than moving leftward, rightward or diagonally.

As for AGVs, it can be a very convenient solution for warehouses since it is more efficient and less time consuming since it can perform multiple tasks that usually need a team of workers. A warehouse can also have a group of autonomous power pallet jacks that follow more than one track of RFID tags to get the tasks done even faster. With the proper AGVs system designed to meet the needs of the warehouse, a company could ambitiously increase and improve its performance. It is thus fair to say that autonomous mobile robots are the future.

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