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Automated Guided Robotic Armed Vehicle (AGRAV)

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Abstract

An automated guided vehicle (AGV) with a robotic arm mounted on top is the subject of this paper's prototype. "How to improve material handling in industries while reducing repetitive work and human involvement in pick and place applications" was the issue statement that was kept in mind. The fundamental issue in industries and warehouses where people work to choose and move goods is that their workdays are constrained by human work hours. Because they help with tasks like picking and moving goods from one location to another, robotic arms are essential to automation. A serial robotic arm can be used for a variety of tasks, including assembly, manufacturing, and automation processes. Its joints are connected in sequence, one after the other, to enable accurate movement. When a serial robotic arm is placed over an AGV, it may move more freely and make object transportation easier. Thus, the automated guided robotic armed vehicle (AGRAV) project's topic. After considering the torque calculations acting on each link in the robotic arm and the model's safety factor, the model was designed using Fusion 360 software. The model was then subjected to a finite element analysis using the stresses and deformations that were present in it. The model's line-controlled motion is made possible with sensors and an Arduino microcontroller. Additionally, in order for the robotic arm to identify which objects need to be handled at a given time, it uses a radio-frequency identification (RFID) system that combines an RF reader on the arm with an RF tag on the objects that need to be handled. The feasibility of an expanded version of this model that can be used in industries is also investigated in this research.

Keywords: Serial robotic arm, automated guided vehicle, material handling, warehouses, radio-frequency identification (RFID) system

INTRODUCTION

There are many different industrial applications for robots. The primary goals of robotic machinery are to improve production's precision, speed, and dependability. It ought to have a far higher efficiency than people. Based on their structural design, robotic arms can be classified as either parallel or serial. A serial robotic arm is made up of several links joined by joints to resemble a chain.

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These joints allow the arm to rotate or move in specific directions allowing precise manipulation of objects within its workspace. These are used in industrial automation, assembly lines, pick-and-place tasks and other such applications. A parallel robotic arm on the other hand has multiple links connected to a common base by separate joints at one end of each link. It has fewer degrees of freedom as compared to serial robotic arms and is mainly used in high speed and force requirement applications like machining, three-dimensional (3D) printing, packaging, etc. For material handling in warehouses, a serial robotic arm has to be used because in this case the arm has to pick objects from

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shelves, that is, precise vertical motion is needed, and serial robotic arms have more ease of vertical motion as compared to parallel robotic arms. In addition, it is not so practical to fix parallel robotic arms on AGVs because of their complex structure. A serial robotic arm is shown in Figure 1.

In big manufacturing plants some processes are repetitive which is nearly impossible to be done at a high speed by humans. Thus, these processes can be automated by the use of robotic arms as they play a key role in increasing the efficiency and productivity of a manufacturing process while reducing human efforts. A parallel robotic arm is shown in Figure 2. A pick and place robotic arm is a device used to grab objects (especially heavy ones) and move them to another place. Two of the main uses of the pick and place application are material handling and movement of objects from warehouses to other facilities [1].

Figure 1. Serial robotic arm.

Figure 2. Parallel robotic arm.

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The use of automation in every field works, is not something alien to industries in today's world. Material handling is one of the most important factor affecting productivity and by improving its efficiency, total productivity will increase. Business is transacted, minutes are created, and revenue is saved at all times in warehouses and logistics. Warehousing, along with inventory activities, accounts for about 50% of the overall logistic costs. This includes mainly transporting the raw materials in a warehouse to the required vehicle (mainly trucks) which takes it to the workshops, transporting the product, in the process of being made in a workshop, again to such vehicles that carry them to other workshops if necessary and also in inventories to sort out the final products into their respective selling trucks, vans, etc. [2]. For these purposes the most commonly used method is human labor which is a method being used since ancient times wherein at least 2 or 3 workers are needed to transport the material at various stages. Moving bulky or heavy items from one place to another is mainly done by using equipment like forklifts, conveyors and cranes. Human involvement not only costs a lot due to the high cost of labor but also, increases the time taken for material handling and indirectly for the total production by a lot. In addition, fewer production rates could be caused as there are chances of accidents occurring as well due to the carelessness and distractions in the human mind which could lead to injury of humans as well as broken materials [3].

Some industry leaders such as e-commerce and logistics giant Amazon have started using automated guided vehicles (AGVs) in some of their warehouses for the material handling process but these AGVs are only able to carry material that are placed on them by people/ fixed robotic arms and such help is also needed in placing the materials in trucks [4].

The main objectives of an AGRAV include: To enable working 24/7; to decrease the overall and long-term operational cost; to reduce the possibilities of work accidents; to reach vertically stored shelves with ease and finally to integrate a pick and place system that can transport the packages by itself [5]. Due do these demands, the in-house logistics sector is the focal point of physical automation. Also, the rapid advances in the robotic sector, computer vision, artificial intelligence, and edge computing capabilities lead to the formation of machines that can potentially think, see, hear and move at a faster rate and higher efficiency than human handlers [3].

DESIGN

Computer-Aided Design (CAD) Model

Autodesk Fusion 360 was used to make the robotic arm as well as the body of the AGV after which they were assembles. Holes of suitable diameters were added to the model for making attachments at various places and for fitting motors in it. An AGRAV with 6-axis rotation of robotic arm is shown in Figure 3.

Materials Employed

The arm's framework can be made of a robust, lightweight material. In order for the servo motor to draw up and turn the arm appropriately, this is necessary. Aluminum, Perspex, plastic polymer, and carbon fiber are a few materials that may be taken into consideration. The flowchart of working is shown in Figure 4.

Considering the aspects of availability, overall cost, and flexibility among the four materials considered, aluminum was found to be the best material for this job. An aluminum alloy was specifically used for the robotic arm and polylactic acid (PLA) was used for the body of the AGV as it was 3D printed.

Reach of the Robotic Arm

The arm has a horizontal reach of 15 cm from the outer most edge of the AGRAV and it can pick an object at a height of 25 to 30 cm from the ground depending upon the distance between the AGRAV and the shelf (from which object will be picked) [6].

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Components Used and Their Functions

Components used in the model and their respective functions are shown in Table 1.

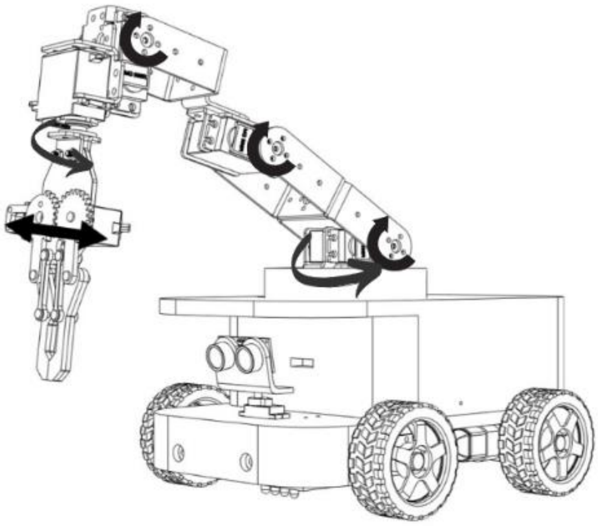

Figure 3. Automated guided robotic armed vehicle (AGRAV) with 6-axis rotation of robotic arm.

Table 1. Components used in the model and their respective functions [7].

Component	Function
Arduino Uno rev3	Microcontroller board
Arduino screw terminal	Wire connection
Arduino motor shield	Motor control
400 points half size solderless breadboard	Prototyping circuits
2 pieces 18650 2600 mAh lithium-ion battery	Power storage
2 x 18650 battery holder case	Battery storage
18650 polymer lithium ion charger type C to 4S 16.8 V, 2 A booster module	Battery charger booster
Jumper wires	Connections, bridging
PCA9685 servo motor driver	Converts 6 signal pins into 2
High conductance ultrasonic distance sensor (HC-SR04)	Distance measurement
Rocker button mini switch double pole double throw (DPDT) 3 position On-Off-On	Toggle switch
Mounted transparent case holder bracket for ultrasonic HC-SR04	Mounting bracket
Servo motor micro SG90-360-degree continuous rotation	Precision positioning of ultrasonic sensor
Digital metal gear high torque servo motor with 360-degree rotation (MG996R) 6 pieces	Precision positioning
Aluminum alloy based 6 degree of freedom (DOF) robotic arm brackets and 3D printing material	Structural support, high strength
Robotic gripper	Object manipulation
Direct current (DC) battery operated (BO) motor dual shaft smart car robot gear motor pack of 4	Drive mechanism.
80 mm – A Mecanum wheel compatible with 6.7 mm coupling (pack of 4) – black	Omnidirectional mobility
Infrared (IR) obstacle avoidance sensor module	Detects obstacles
1 W light emitting diode (LED) with heat sink 2 pieces	Cooling LEDs
5-V 1 channel relay module	Control high voltage
Radio-frequency identification (RFID) system	Scanning and identification

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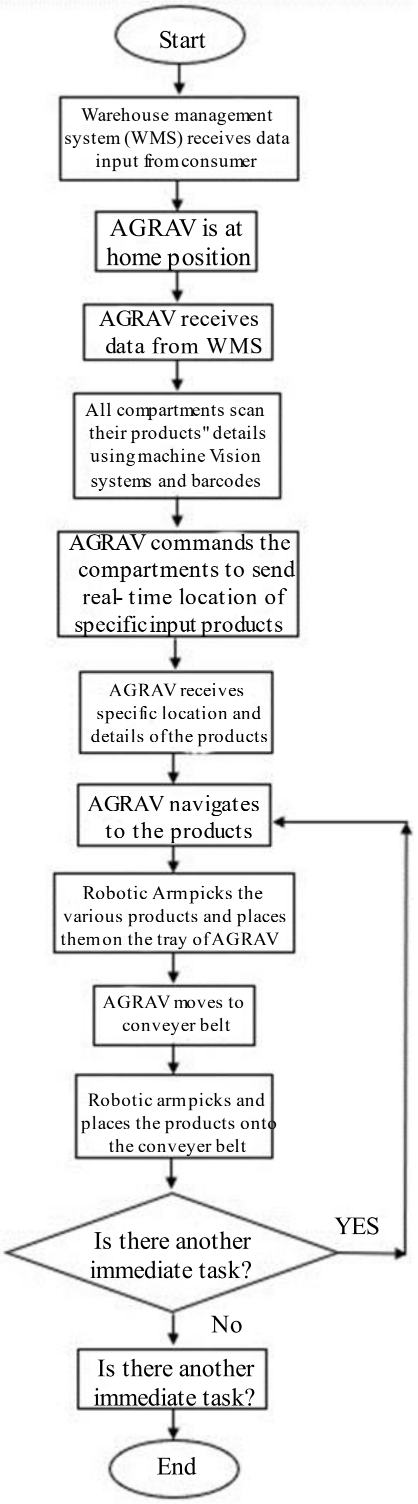

Figure 4. Flowchart of working.

Working of Futuristic Model

The futuristic model will use a guidance path system in which the AGRAV will choose the path to follow based on comparisons of measurements taken from its sensors to the values given to it by the programmer. It will use either of the three most used guidance technologies namely, landmark-based navigation (uses line follower concept), behaviors-based navigation (uses laser range navigation technology) and vision-based navigation (uses proximity measurement and visual images) [8].

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Torque Calculations

Calculations were done to find the torque requirements of each motor used in the robotic arm and the factor of safety. Equilibrium conditions were used for the same, starting from the gripper carrying a load of 20 g and ending with the H-link at the base. Line diagram of robotic arm is shown in Figure 5. A circular cross-section was assumed for these calculations and the weight of the motors are assumed to act at the center of each link, considering it along with the actual weight of the link. Free body diagrams of each link based on calculations are shown in Figure 6.

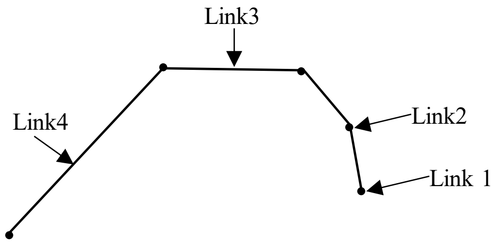

Figure 5. Line diagram of robotic arm.

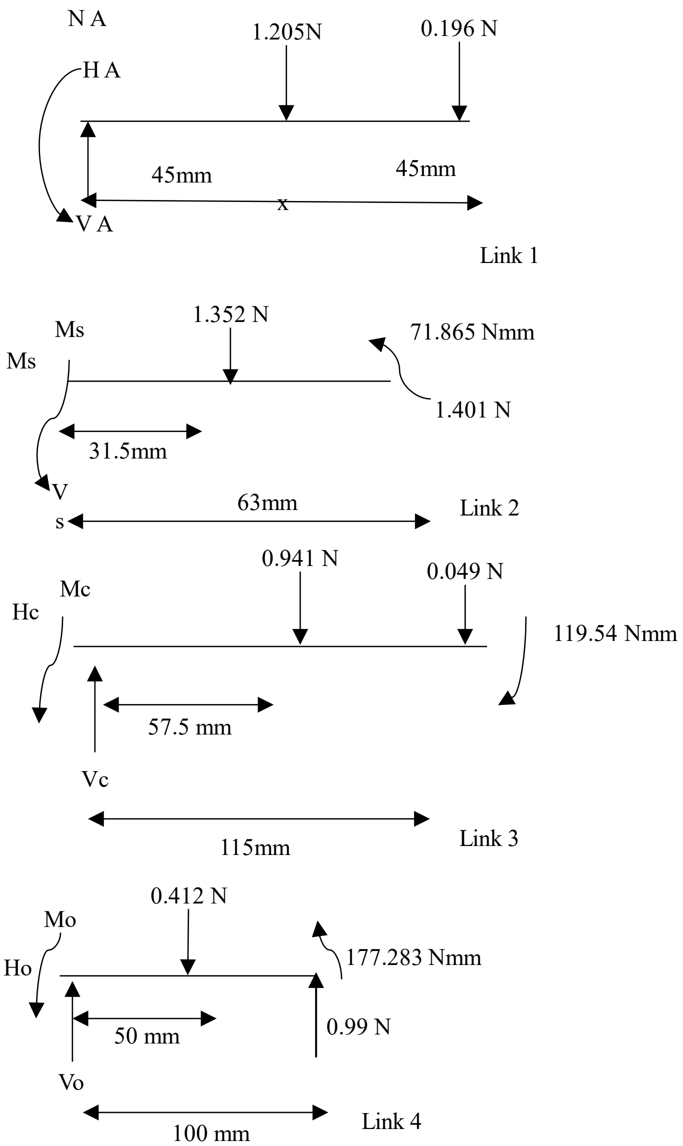

Figure 6. Free body diagrams of each link based on calculations.

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1st Link

Weight to be carried = 20 g = 10.196 N
Weight of gripper = 68 g
Weight of motor = 55 g
Total weight of gripper = 123 g =1.205 N
$\sum F_x = 0$
$\therefore H_A = 0$
$\sum F_y = 0$
$\therefore V_A - 1.205 - 0.196 = 0$
$V_A = 1.401\ N$
$\sum M = 0$
$M_A - (1.205*45) - (0.196*90) = 0$
$\therefore M_A = 71.865\ N.mm = 0.071865\ N.m$

2nd Link

Weight of the motor = 55 g
Weight of the holder = 14 g
There are 2 motors and 2 holders so total weight = 2*(55+14) = 138 g = 1.352 N
$\sum F_x = 0$
$\therefore H_B = 0$
$\sum F_y = 0$
$\therefore V_B - 1.352 + 0.196 = 0$
$V_B = -0.049\ N$ or $0.049\ N\ (\downarrow)$
$\sum M = 0$
$M_B - (1.352*31.5) + (1.401*63) + 71.685 = 0$
$\therefore M_B = -117.54\ N.mm = 0.11754\ N.m\ (\circlearrowright)$

3rd Link

Weight of the motor = 55 g
Weight of the holder = 14 g
Weight of L bracket = 6 g
Weight of U bracket = 21 g
Total weight = 96 g = 0.941 N
$\sum F_x = 0$
$\therefore H_C = 0$
$\sum F_y = 0$
$\therefore V_C - 0.941 - 0.049 = 0$
$V_C = 0.99\ N$
$\sum M = 0$
$M_C - (0.941*57.5) - (0.049*115) - 117.54 = 0$
$\therefore M_C = 171.283\ N.mm = 0.171283\ N.m$

4th Link

Weight of U bracket = 21 g
There are 2 U brackets, so total weight = 42 g = 0.412 N
$\sum F_x = 0$
$\therefore H_D = 0$
$\therefore V_D - 0.412 + 0.99 = 0$
$V_D = -0.578\ N$ or $0.578\ N\ (\downarrow)$
$\sum M = 0$
$\sum F_y = 0$
$M_D - (0.412*50) + (0.99*100) + 177.283 = 0$
$\therefore M_D = -255.683\ N.mm = 0.255683\ N.m\ (\circlearrowright)$

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Factor of Safety

Ultimate tensile strength (UTS) for aluminum alloy = 310 MPa

∴ Allowable shear = 0.18*310 MPa = 55.8 MPa

$$\text{Induced shear} = \text{Torque} * (\pi/(16 * (d)^3))$$
$$= 0.255683 * (\pi/(16 * (0.053)^3))$$
$$= 8746 \text{ kPa}$$
$$= 8.746 \text{ MPa}$$

Factor of safety = Allowable shear/Induced shear $= 55.8/8.746$ = 6.38

FINITE ELEMENT ANALYSIS

Finite element analysis was carried out on Ansys to find out the total deformation and equivalent stress induced in each link of the robotic arm and the body of the automated guided vehicle [9, 10]. The scale is shown at the left of each analysis in the figures which increases from shades of blue to red. Equivalent stress of each link and body of the AGV is shown in Figure 7.

The blue colored areas indicate minimum equivalent stress and total deformation whereas the red areas indicate maximum. A blue and red probe is included in each analysis to point out the exact point of minimum and maximum values respectively. Total deformation of each link and body of the AGV is shown in Figure 8.

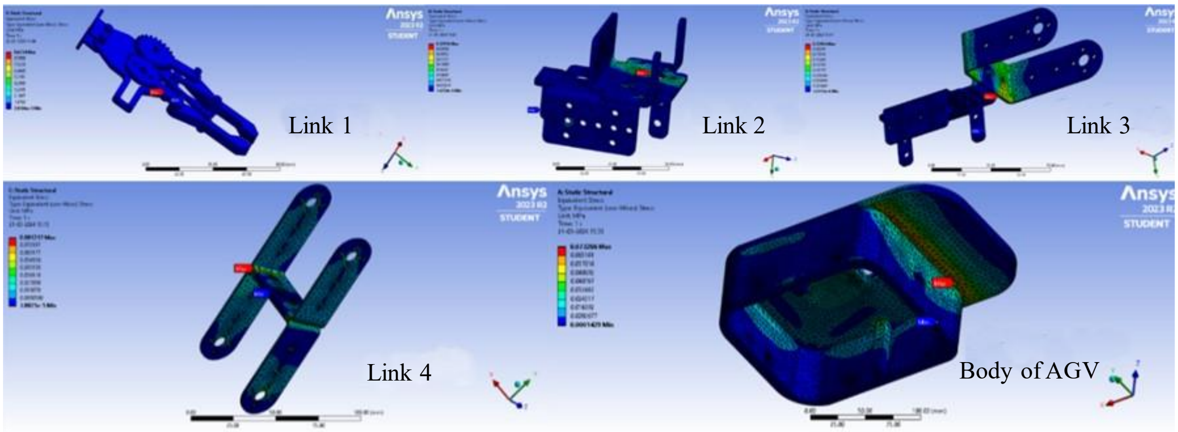

Figure 7. Equivalent stress of each link and body of the automated guided vehicle (AGV) [8].

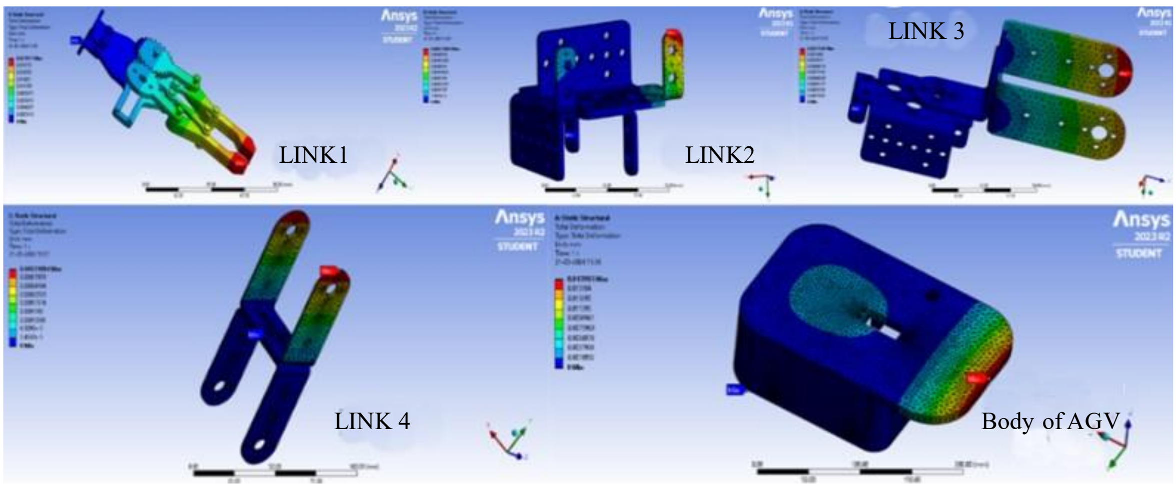

Figure 8. Total deformation of each link and body of the automated guided vehicle (AGV) [10].

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The maximum values of the equivalent stress from this analysis were found to be ranging between the order of 10^{-1} and 10^{-2} MPa for all links as well as the body of the AGV and the total deformation ranged between the order of 10^{-2} and 10^{-4} mm.

CONCLUSION AND FUTURE SCOPE

There can be significant advantage of using this system of AGRAVs in warehouses in the future as the maximum possible productivity will be achieved by implementing it. For practical warehousing processes a scaled-up version of this model can be made wherein there will be a proportionate increase in dimensions of the robotic arm and the body of the AGV. By connecting tray-like-features to the design of the AGV, which is much bigger in size and hence has more space compared to our model, multiple objects can be transported by this system. The manufacturing of the AGV starts by cutting the sheet metal plates according to the required dimensions on a circular saw. The AGV is then assembled by welding and using mechanical fasteners like rivets or nut and bolts. The whole production line is automated. The scaled-up version will use a programmable logic controller (PLC) which helps manage the control systems. The PLC will receive inputs from the communication and navigation system allowing it to make real time decisions to control the motors and other components. The cost of the product depends on three factors: the number of models being purchased, the payload capacity requirement of the model, and the dimensions of the robotic arm and AGV to be manufactured. The cost of an AGRAV will be around INR 20 to 40 lakhs, considering the cost of the industrial control systems (Automation Systems), which is justified over a long-term period as compared to having human labor. Many advancements are also being made about completely smart warehouses involving features like charging paths made of magnetic tape that would automatically charge the battery of the AGRAV, simultaneously while it operates, by inductive power transfer in which a magnetic field is used to transfer electrical energy without an electrical connection. Such advancements will also facilitate the best performance of the AGRAV as compared to it working only on a battery. Thus, the AGRAV system can potentially change the entire market of warehouses.

Declaration of Conflicting Interests

The authors declare that they have no competing interests.

Ethical Approval

Not applicable.

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Abbreviations

Abbreviation	Meaning
AGRAV	Automated Guided Robotic Armed Vehicle
AGV	Automated Guided Vehicle
RFID	Radio-Frequency Identification System
RF	Radio Frequency
3D	Three Dimensional
CAD	Computer-Aided Design
PLA	Polylactic Acid
HC-SR04	High Conductance Ultrasonic Distance Sensor
DPDT	Double Pole Double Throw

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MG996R	Metal Gear High Torque Servo Motor
DOF	Degree of Freedom
DC	Direct Current
BO	Battery Operated
IR	Infrared
LED	Light Emitting Diode
WMS	Warehouse Management System
UTS	Ultimate Tensile Strength
PLC	Programmable Logic Controller
INR	Indian Rupees

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