Content

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MODULE CODE: ER3200

MODULE TITLE: Mechatronics

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Autonomous Trolley

There are different types of AT used in our life in many fields:

1. Medical AND Healthcare : (Dental implants AT - Ultraviolet AT- Air quality AT)
2. Manufacturing AND Industry : (Material handling AT - Construction AT)
3. Aerospace: (baggage handling airport AT - Scan and Fix Planes Exterior AT)
4. Life And Entertainment: (Electric golf AT - shopping AT – farming AT)
5. Cleanliness: (Electric bin-tugs AT - vacuum cleaner AT)

And many other fields But we will mainly focus on ATs used to support parcels handling in Warehouses and factories(Manufacturing)

The types of AT depend on its function and what we want it to do like

- Loading and unloading
- Sorting
- Picking
- Packaging & Storage
- Transportation & Delivery
- Replenishment

We can divide ATs to mainly three types and we will compare between them:

1) Automated Storage and Retrieval Systems (AS/RS) & Goods-to-Person technology (G2P)

Function:

They are logistics management systems used to provide users with increased control and tracking for loads by making three steps : Order picking – Transferring to a specific point – storing items in a specific location .
It consists of machines that move down and up on shelves to organize items.

- G2P is similar to AS/RS but it has goods-to-person picking robots which deliver items to the picking stations

- There are other types of AS/RS : VLSM - Deep-lane AS/RS , Unit load AS/RS and others

Advantages:

1) it can be completely automated or human workers can control it.
2) Order Accuracy even in tracking items

Disadvantages :

1) it is highly cost
2) it requires training and experience to know how to deal with it

Sub-systems & Elements:

1) **Storage structure**
   It has a rack to support and carry items and put them into chambers.
2) **S/R machine**
   It is the machine that carries the items and it can move in three direction to transfer items to its position.
3) **Storage modules**
   They are small rooms where S/R machine put the items in.
4) **Pickup-and-deposit station (P&D)**
   It is the stations where the items collected .If we want to save them the S/R will take them to the chambers and if we want to send them back ,the S/R will take them back to the station where AGV or a person will be waiting for items.

- **Pictures:**

	
AS/RS	**G2P**

2) Automated Guided Vehicles (AGVs) & Automated Guided Carts (AGCs)

Function :

AGVs such as self-driving forklifts are used to transport heavy items around in the large industrial building. They rely on tracks or other methods for navigation that will be discussed later.
They are many different shapes and applications of AGV used in industry like AGVs used in:
Handling raw materials, Roll handling, petrochemicals handling and others

- AGC has the same mechanism as AGV except that it carries smaller loads

Advantages:

1) Ideal for most types of material handling as it provides a safe transportation for some material like Chemicals and petrochemicals
2) It can be moved to another facility very easily
3) High availability and reliability.

Disadvantages :

1) Not Suitable for Non-repetitive Tasks
2) High Maintenance Costs
3) it needs to be guided by wires which can be disrupted during production ,not like AMRs
4) If AGVS detected obstacles in front of it ,it will stop without any behaviour. .

Sub-systems :

1) Safety Systems(avoidance system)

It is designed to avoid obstacles that could appear on the pathway
The safety system is composed of multiple E-stops, Collision detection sensor, drive contactors and brakes integrated with a safety controller device

2) Battery Charging System

When AGVs needed to be charged it automatically returns to the battery charging system and after it gets fully charged it returns to continue its function.

3) Communication System

The controller communicates with other devices like AS/RS by communication methods like :I2C,SPI or other communication protocols.

4) Navigation System(steering system)

The vehicles require a navigation system to identify its position in the warehouse. There are many navigation systems like :

Wired :

We place a wire under the ground. The wire sends radio waves. A sensor which is installed on the bottom of the AGV ,detects the relative position of the radio signal being transmitted from the wire.

Guide tape:

We can put colored or magnetic tape that the AGV can detect by its guide sensors

Laser target navigation:

We put some devices(reflective tapes) on the walls of the factory and the AGV has laser receiver and transmitter so AGV can know its position by comparing the distance with the map stored previously inside it.

Inertial (Gyroscopic) navigation:

We put transponders in the floor where Gyroscopic can detect it to determine the direction of the AGV

Natural feature (Natural Targeting) navigation:

It uses laser range-finder to find the way

Vision guidance:

It depends on computer vision that tracks the path and controls the movement of the trolley.

Geo guidance:

the AGV like forklift that contains geo-guidance tool that detects walls , within the warehouse so it can determine its path

5) Traffic Management System

It controls the movement of the AGVs around the area of operation without any accidents as the system makes sure that AGVs will avoid obstacles and avoid each other.

6) Job Control System (central controller)

It is not only controlling the vehicle but also it gives order and instruction to mange items like lifting them and transferring them to their position

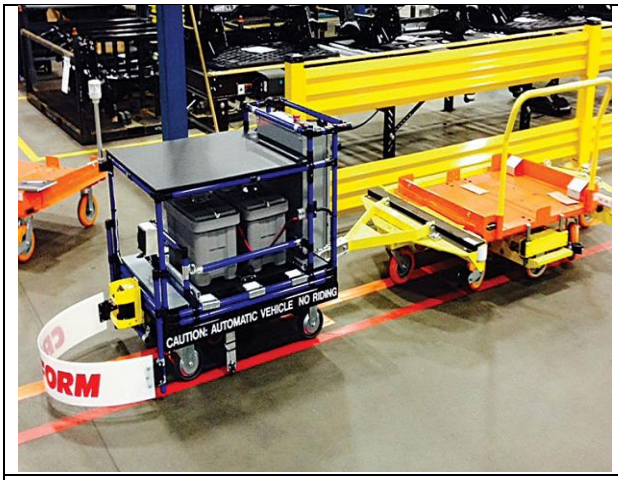
Elements :

- DC Motor(s)
- batteries

- controller
- shape of the machine which can be a fork, conveyor, platform or other different shapes
- buffer conveyors

Different sensors like ultrasonic sensors, cameras, radars, sonars, lasers

Pictures :

	
AGV	**AGC**

5) Autonomous Mobile Robots (AMRs)

Function :

It is a complex system but it is similar to AGVs in transporting materials throughout a warehouse autonomously but unlike AGVs, which travel fixed routes guided by tracks, AMRs depend on maps and sensors to navigate more flexible routes by interpreting the environment.
It is not only transporting product but it can also assist in the picking process and sortition

There are different type of AMRs :

	AMRs with Robotic Arms: Ideal for picking items or cases.
	AMR Pick & Put-Bot :it automatically picks and puts away totes and cases, up to four levels high, throughout a facility

	Stacker-Bot : The Stacker-Bot is similar to the Pick & Put-Bot (above), but with increased capacity.
	TiltSort-Bot : A high speed tilt tray robot designed to sort parcels, packages, and items.
	Hi-Tilt Bot: It's ideally used in sorting items and orders into totes, cartons, pallets, or gaylords.

	DP Cross belt-Bot : Ideal for sorting items and orders.

Advantages :

1) Increased Flexibility
2) Increased Safety
3) When AMRs detect obstacles ,it can change the route to avoid them
4) AMRs is complex but it is less expensive than AGVs

Disadvantages :

1) Limitations on Load Size

Sub-systems &Elements :

AMRs have the same subsystems and elements like AGVs except:

Navigation system(mapping)

AMRs navigate through maps using software with laser scanners. It's much like a car with a GPS and a pre-loaded set of maps. The AMR is taught locations to pick up and drop off parts via its intuitive interface, where it is also possible to define areas. It uses data from cameras and sensors to detect and track object so t can know where it is in the world

it uses different sensors:

- Proximity detection (infrared sensors, ultrasonic sensors, hall effect detectors)
- Range determination (radars, sonars, lasers, microphones, infrared sensors)
- Imaging (cameras, photocell arrays)
- Orientation (compasses, accelerometers, gyroscopes)
- Positioning (GPS)
- Contact detection (bumpers, limit switches, push buttons)
- Internal (rotary encoders, magnetic field, battery level sensors)

- Other detection mechanisms (for example gas detectors, humidity detectors, …)

Job Control System (central controller)

The complexity of the AMR controls and software system.AMR has to take decisions by themselves.

There are other different subsystems which depend on the type of AMRs (for example a robotic arm subsystem)

Pictures :

AMRs

DESIGN

I will design two subsystems for the AT responsible for localization and Obstacle Avoidance .They represent the eye and he backbone of the AT and they are the first step and the base towards Autonomous Vehicles as shown in the block diagram

1) Navigation system

This system is responsible for making the vehicle able to drive from point a to b with its self.

There are many types of navigation methods but I will use the most efficient one which is Computer vision using Camera. We will build a 3d map using the camera.

Elements

Controller:

1) ESP 32 S
   (as it supports wi-fi and Bluetooth communication. Also it can be programmed by Arduino code)

Sensors:

1) Camera (It will be much good if we used stereo camera) but in my case i will use my camera phone

Why Camera rather than the other sensors?
1)it has a near and far range
2)Some cameras have IR spectrum while night
3) It isn't only used in navigation but also tracking
However all of those advantages ,cameras affected badly with the weather

Actuators :

1) 4 dc motors connected through l298n motor driver module to allow us to spin motors in different directions

Software :

We will use two softwires:

1) Arduino IDE :

To control the motors just to make them on or off

To communicate with the camera through unity software

2) Unity:

It is the interface that connect Esp.32 and the camera and then control on the car

To control the logic of the vehicle and how to move it in different directions

We will make an independent scene for each step in the development

How will it work

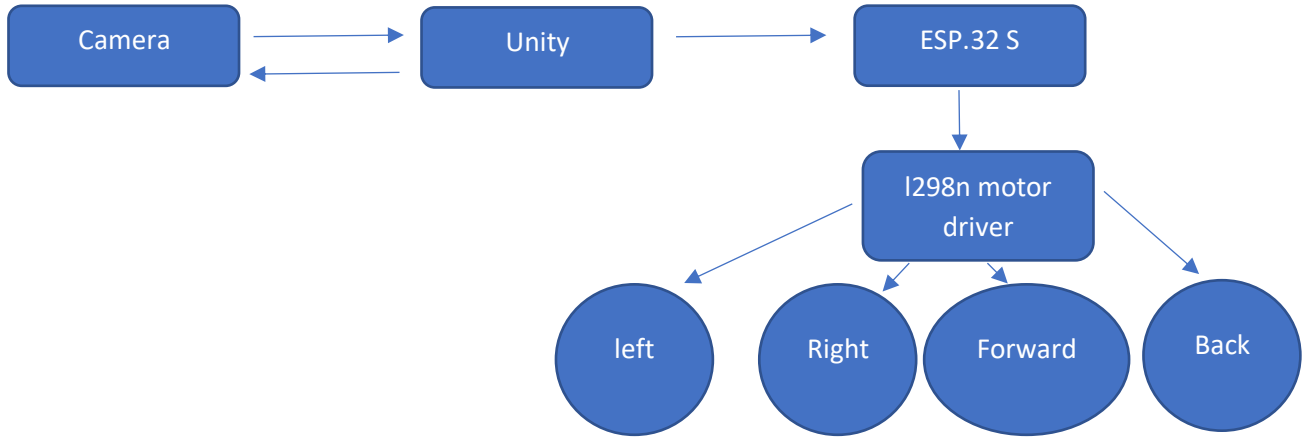
Simply through 3 steps

1) Unity will send the scenes and algorisms to the phone as an APK file and there will be a communication between them through Wi-fi

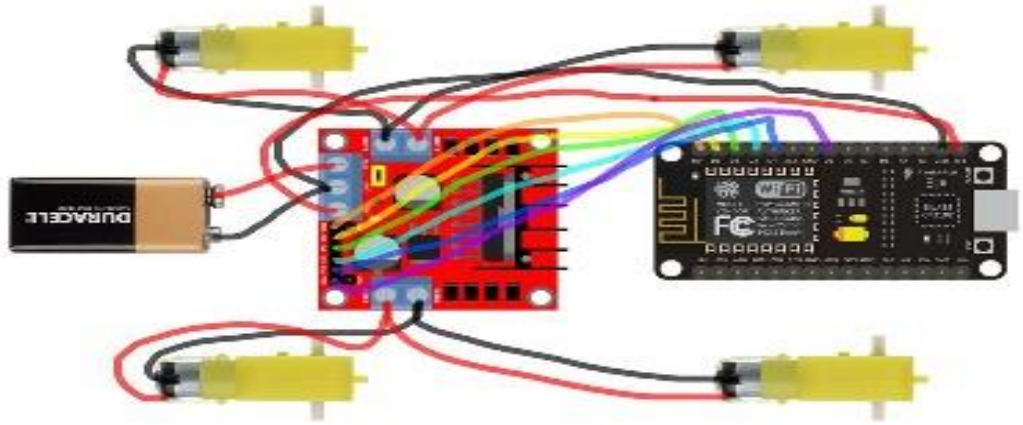
2)The camera will record a video feed and send it to unity where unity will control the motors through the micro controller(ESP.32 S)

3) the robotic car will move depending on the modes or different scenes applied on it. So we can make it detect any black tape to move on it or you can make a map through Place Note software which allow us to scan the place and turning it into a code that the microcontroller can move on without any need of GPS.

Block Diagram



Electrical Circuit



2) Safety system(avoidance system)

This system is responsible for avoiding obstacles that could appear on the pathway by applying different methods like forced stop or moving around the obstacles

Elements

Controller:

1)Arduino UNO board

Sensors:

1)Infrared Sensor

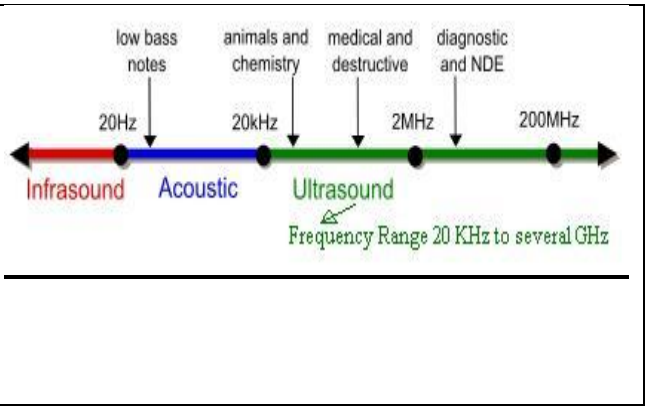
3)Ultrasonic sensor

Why using the two sensors?

- IR sensor has a high range than ultrasonic
- Ultrasonic can't run in factories where there are much noise as it will get distracted
- Ultrasonic is more accurate than IR sensor

I got an idea to use the two sensors togethers to benefit from them as they will give me a better values rather than using each one alone

Parameters	IR Sensor (SHARP GP2Y0A21YKOF)	Ultra Sonic Sensor (HC SR-04)
Range	10cm-80cm	2cm-10m
Beam-width	75 Deg.	30 Deg.
Beam Pattern	Narrow (line)	Conical
Frequency	353 THz	40 KHz
Unit Cost	~ 750 INR.	~ 130 INR.



Actuators

1) multiple E-stops,
2) drive contactors and brakes integrated with a safety controller device

3) 4 dc motors connected through l298n motor driver module to allow us to spin motors in different directions
4) Servo motor to put the Ultrasonic sensor on it to make it rotate 180 degree

Software

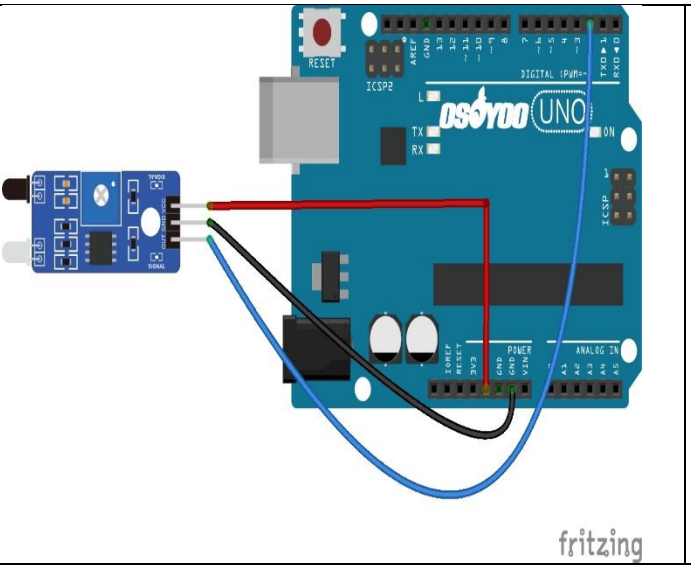
1) **Arduino IDE**

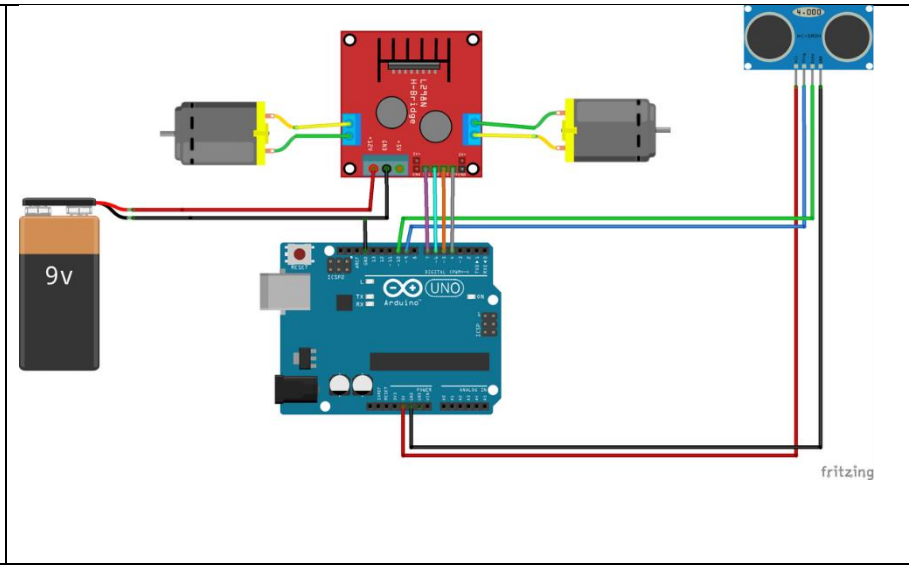
How will it work

1)When **Ultrasonic sensor or Infrared Sensor** object **an** obstacle, they will send signal to the vehicle .

to stop without any movement and if the object move out ,it will continue the path without any problem

Electrical Circuit



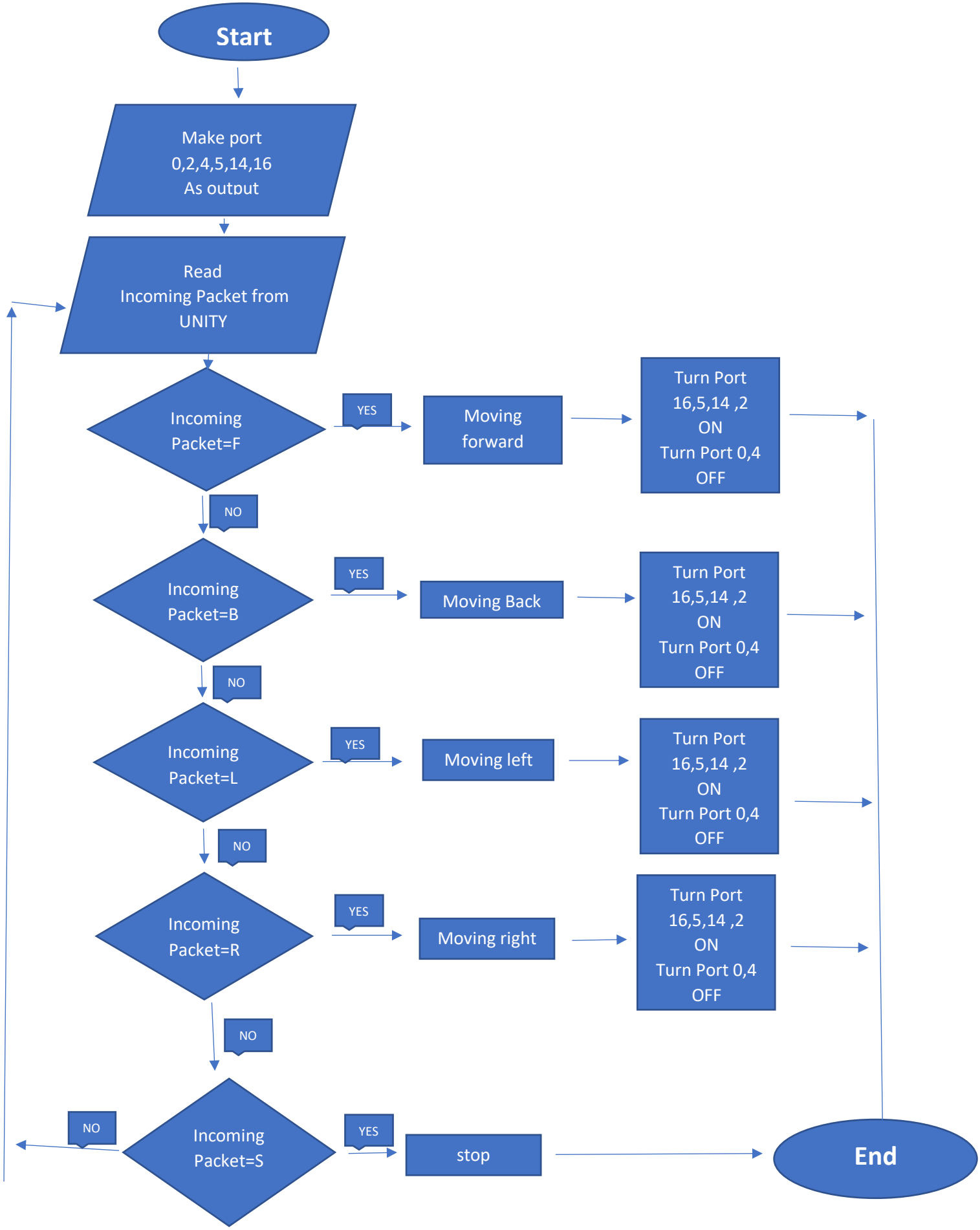


Development

I have put a plan to develop the Navigation system through three steps. In each step I go forward into Autonomous world

In all different steps ,I have programmed the microcontroller to receive packets from unity and turn the motors off and on through the code that you will find attached to this word file

the Arduino code is very simple and this is a flow chart that represent it


Start
Make port
0,2,4,5,14,16
As output
Read
Incoming Packet from
UNITY
Incoming
Packet=F
YES
Moving
forward
Turn Port
16,5,14 ,2
ON
Turn Port 0,4
OFF
NO
Incoming
Packet=B
YES
Moving Back
Turn Port
16,5,14 ,2
ON
Turn Port 0,4
OFF
NO
Incoming
Packet=L
YES
Moving left
Turn Port
16,5,14 ,2
ON
Turn Port 0,4
OFF
NO
Incoming
Packet=R
YES
Moving right
Turn Port
16,5,14 ,2
ON
Turn Port 0,4
OFF
NO
Incoming
Packet=S
YES
stop
NO
End

First step:(Drive the vehicle with the video feed on the computer)

I will connect the camera with UNITY with ESP.S 32 through Wi-fi. All must be in the same network and then build and run the APK file on the mobile and open the camera from the application and press play in UNITY and video will automatically run on unity(Laptop) .

I have programmed unity to control the car from the up, down, left and right keys on the keyboard. Inside UNITY , you will see many modes that I designed. firstly, we will work on AR camera and controller scene. So the car will respond to that and will move to any place within 150 feet (wi-fi range) in any direction you controlled with while you can watch the same things appears in front of it

Video(proof)

(https://youtu.be/DrzQ-9Zhw7o)

Second Step:(object tracking)

The most effective part in this step is the Algorisms that used to track an object as It makes a box around it and when the object go out from the box ,the camera keeps tracking it in a new box. the object has to contain features point that makes it distinct.

The algorism I use is good but it needs more development in the future.

How does it work?

Firstly, you need to click on the screen of the mobile to initialize the tracker on the object you want and it will tell you if it starts tracking or there are some errors. When we try to move the object, the algorisms in unity will make the car moves a frame towards the movement of the object in any direction

This is my unity project: (https://drive.google.com/open?id=1WWc7gZ3fcTbUnAQn-wwjmbBTg0AZEvmh) I can't upload it as the size was big

video(proof) (https://youtu.be/NkHKlL6bYnE)

Validation

critical analysis in step one:

the car responses well for my control from laptop but the video feed that appears on the laptops has a kind of lag Knowing that I have reduced the video resolution to make transfer data more easily. I thinks that happens because the connection of the internet as the network was from the hotspot of mobile. Rather than this problem, the performance was amazing with no lag and each button on the keyboard has worked perfectly .

critical analysis in step two:

I was hoping to make the car moves as the dynamic object moves like what happens in warehouses when the vehicle walks near by the worker so he can put the tools inside it. I know that they use different method rather than object tracking but I was hopping to do at least that.

Firstly, the car has some code errors as it was avoiding the object not tracking it so I edited the code (the follow Algorism) to make the car moves in the same direction that the object will move on .

Secondly, My second problem was that I am using a mobile camera not a professional camera so I had a problem with the frame size of the mobile. It was so small that when the object gets out of it ,the car didn't have the enough time to track it but I think this problem can be fixed by using a professional camera.

After editing again in the code, I made the car make perfectly but only in one direction .I put the object in front of the car and I moved it forward .The car response to that with high efficiency and moved forward towards the object.

Next phases of development

1) Hardware

- **Adding more sensors with the camera(Sensor fusion)**

If we used some sensors like Lidar or Radar next to the camera ,that will improve the navigation system . In case we worked with many sensors we will face a big problem that needs a huge effort to solve it .The problem is Sensor fusion and how can we run multi-sensors together with those challenges:

- Time synchronization: sensors have different FBS and HZ
- Calibration: knowing where the sensor is relative to the vehicle
- Weighting of sensors

All of that is under the concept of perception which is the way to understand the world around the vehicle so we can get deeply in localization loop closure.

COMPUTER PERCEPTION ANALYSIS

	Camera	RADAR	LiDAR
Object Detection	Medium	High	High
Classification	High	Medium	Low
Density of Raw Data	High	Medium	High
Velocity Measurement	Low	High	Low
Lane Detection	High	Low	Low
Sign Recognition	High	Low	Low
Rain, Fog, Snow Vision	Low	High	Low
Night Vision	Low	High	High
Cost	Medium	Low	High

Source: Loup Ventures

- **Raspberry Pi as a controller**

It can do more functions than Arduino and ESP. We can use it in Warning, interface of the camera. Also we can apply deep and machine learning in the vehicle movement to make it learn ,detect and track. It will be a great addition to use it in traffic control system as it will provide us with all the data of the vehicle that can help us to control many vehicles in only one system. Next step of using Raspberry is in ROS (Robot Operating System)

- **GPS for mapping**

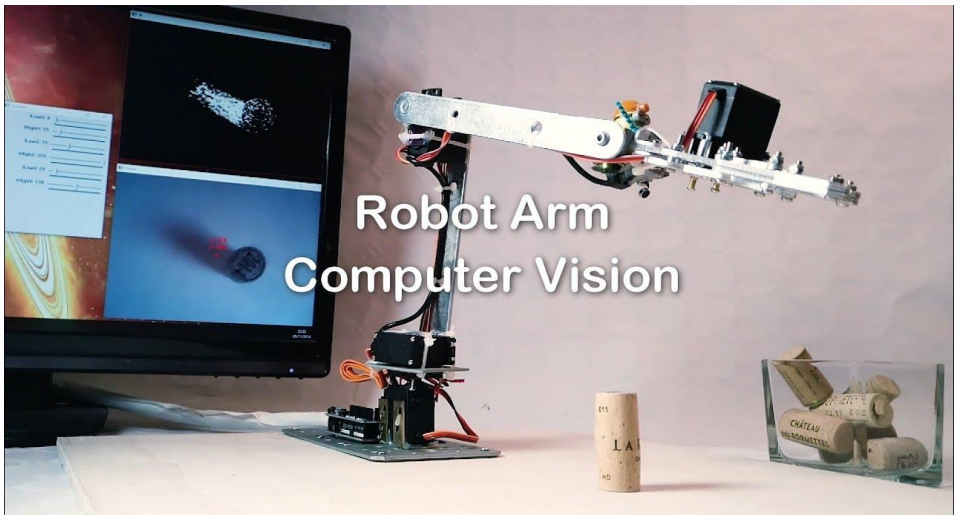
It will be a great addition if we use GPS as it will be very important to determine the vehicle place if we navigate using mapping.

GPS doesn't work in indoor places so it will be useless if we used it in places like houses.

- **Adding robotic arm that works with computer vision**

A system of a robotic arm will be very helpful in industry as we can connect it to the vehicle so that it can do several functions without any need for human workers.

The robotic arm will use image processing to know where the object is so it can deal with it and move it to the container or it can take the item from the container and put it into Shelves so we can get a n automated process picking system.



- Using Stereo 360 degree camera that works with IR

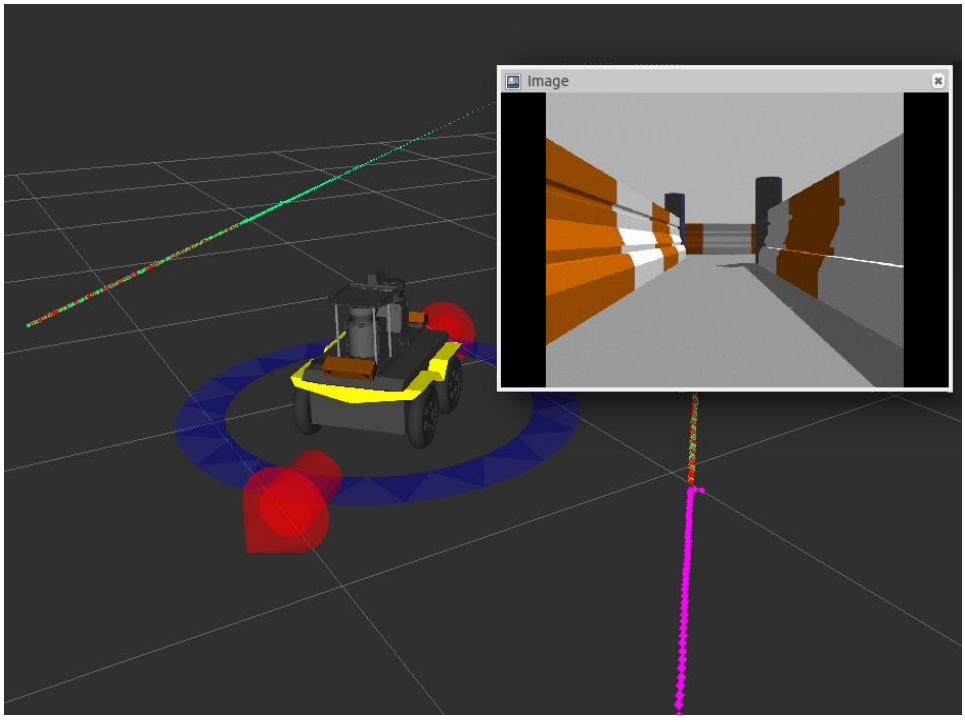
to avoid the weather problems and the night vision can be more accurate

2) Software

- Using ROS (Robot Operating System)

It is a software that allow us to control the robot behaviour with tools and libraries included in its environment. Also it is considered as the most easiest software that can used to make collaborative robotic system. ROS was designed specifically for that.

I can use it in my project to improve the car behaviour while it tracks objects.



- Using mapping navigation

There is no doubt that mapping is the best way for navigation .It depends on previous scanning or designing for the place the vehicle will move on. Then connect the vehicle with a GPS and gives it an order and it will navigate through the map.

I tried to apply mapping in my project but unfortunately I failed in this step but I will show you what I tried to do. It was so hard to navigate using map without GPS but I figure a solution for that which is using computer vision with augmented reality.

We will use two softwires:

1)ARcore :which allow you to scan the place you will move the car in

2)PlaceNote: which allow you to create destinations to the car to move in.

Then i will turn them into metadata so the software can understand them.

3) Communication and data transmissions

- **IOT (internet of things in automotive vehicles):**

IOT is growing rapidly and there is no doubt that it will affect the automotive industry through different ways

1)It will provide us with security and fast access for control

the AT will be connected to the internet so you will have a remote access to it .You will be able to watch its performance and test it. if it had some software errors ,you could fix it without getting it back.

2)It will provide safety and help solve traffic

By interacting with IOT sensors which are installed on the route ,it can determine when the AT go out from its route and we can reduce accidents.

Also with IOT you can easily control the traffic and manage each At to make them in a collaborative system. This field will improve the data transmissions to and from ATs .

How to use it in ATs:

We can use it with sensors so that it can be connected ,send and receive data from the controller without any wires. Also we can use it to make an interface between the At and the user.

If the data is huge, we can use IOT in Data Processing as we can send the data directly from sensors to the cloud where servers will process it and sent it again to the actuators like motors and the vehicle will move directly.

- **Wireless for controlling**

There are different wireless communication like wi-fi , Satellite Communication ,Bluetooth and others

I already used it in my project in ESP.32S .The microcontroller has been connected to the laptop and mobile using wi-fi.

wireless power transfer:

we can even charge the batteries without any need to connect it with wires

References:

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3) Bancroft, Allen J., and Daniel M. Daly. "Wide area navigation for a robot scrubber." U.S. Patent No. 6,124,694. 26 Sep. 2000.