THE ROBOTIC CHARGING CHALLENGE

INTER-IIT TECH MEET 11.0
Team ID: 23

INTRODUCTION:

The Robotic Charging Challenge is a mid-prep problem statement released as part of inter-IIT Tech Meet 11.0 by JAGUAR LAND ROVER.
This solution consists of a robotic arm that automatically inserts the charger into the charging port of a generic electric vehicle (EV), waits till the car is fully charged, and then removes the charging gun after the process. The robot uses image recognition technology to detect the charging port.

Image recognition is a very popular and rapidly developing technology that is being used in a variety of fields like speed detection, image search, and many more. It deploys complex algorithms to extract useful data from an image which can then be used to compare with an existing database or to train the algorithm itself.

WORKING:

TASK 1: Locating the charging port

As per the problem statement, we assume a cuboidal area of operation for the robot 1.0mX0.7mX0.4m, at a height of 0.5m from the ground. When the car is low on battery and the driver parks into the required parking space, they get notified on the car's electronic dashboard/infotainment system or their smartphone whether to start charging. Once the prompt is given, the car's charging flap automatically opens. Simultaneously, it sends a signal to the robot through Bluetooth®, which activates it. Also, using the Jaguar Remote App available on Android and iOS, the charging status can be viewed, and the robot can be triggered on and off.

Method 1 – The specific case

Here, we make use of radio direction finding (RDF) technology to accurately find the location of the charging port.

Two receivers are placed above and below the charging gun at the end effector of the robot, and two are placed at the front and end of the car. The four transceivers communicate with each other once the car is parked. Now, since for a specific model of vehicle, the charging port will be at the same location for all vehicles, it is possible to find out the exact coordinates of the charging port on the car along with its alignment and inclination with respect to the vertical, with the help of pre-fed data. This is then fed to the computer system in the robot. Here is some explanation of the specific case

Localization of Charging port using TDOA, TWR and Hall Effect:-

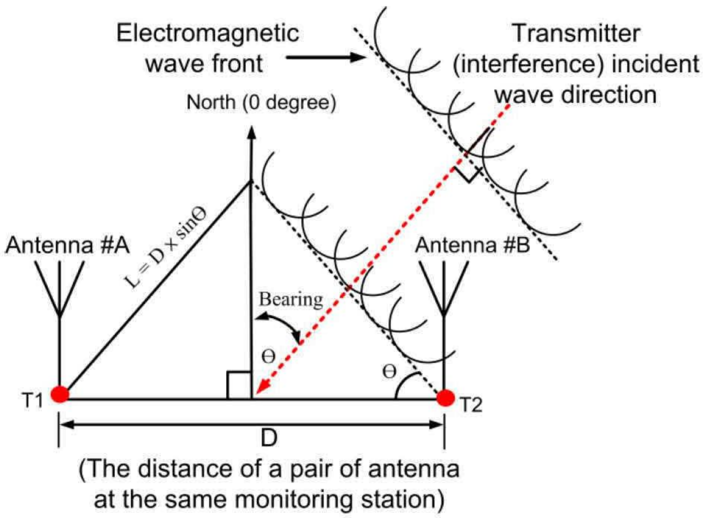
This approach requires the installation of specific devices inside the car's charging port. The methods proposed here can be installed in a production car.

The localisation of the port is achieved utilising two methods:-

1. UWB-based TDOA and 2-way ranging(time of flight) approach implemented using ESP32 DW1000 transceiver IC. (Link to Datasheet)
   Alternative Device – BU01 Module (Dw1000 with built-in antenna) Cost – $ 35
2. 5D Localization using Hall Effect Sensor Array(32 sensors) Estimated Cost - Rs. 1000
   Reference
   The BU01 DW1000 module has a range of 20 metres and can localise the transceiver(anchor tag placed in the car's charging port) with a precision of 5 to 10 cm. Hall Effect Sensor array can localise with the precision of around 2 mm linear and 4 degrees angular to accurately spot the charging spot.

i) FINDING THE LOCATION OF CHARGING PORT USING TDOA:-

We will be able to determine the position of the Charging Port Using DW1000 and TDOA Radio distance Finding Algorithm.TDOA stands for Time Difference of arrival method. Basically in this method, we use one DW1000 as a transmitter and two synchronised DW1000 as a receiver. Here we use UWB or ultra wideband signals short-range wireless communication protocol. DW1000 supports 6 RF bands from 3.5 GHz to 6.5 GHz [3] . They have a very low noise margin when compared to Wi-Fi and Bluetooth. TDOA is a result of the difference in the path length or range between transmitter(Tx) and receiver(Rx) sites and therefore corresponds to the propagation time difference between the Tx and a pair of synchronised Rx sites.



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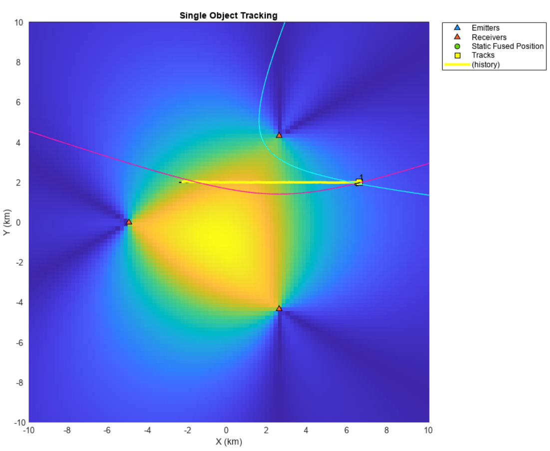
Here as we see in the figure the receivers form an area of the field with different uncertainty. As the distance from the receiver field is increasing the uncertainty of finding the point is increasing.



As we can see in the plot each receiver grazing the locus of the position of the transmitter as Hyperbola as shown in the fig2. Ideally, the intersection of two such contours can establish the emitter's location[5]. As shown in the figure. In practice, equations are formed with the TDOA measurements from several pairs of receivers for outdoor or large-scale object location but for the indoor environment, we can use two receivers for finding the location and charging port.

Two DW1000 which act as the transmitter are placed on the vehicle and the other two receivers are on the charging robot and the TDOA process mentioned above is performed. The transmitters on the vehicle will be also able to send digitally stored information like

i)Height of charging port

ii)orientation of charging port w.r.t car

This low-power system consumes 55mw power, has an accuracy of 5-10 cm and has a range of operational frequency from 3.5 GHz to 6.5 GHz.

ii)MOUNTING OF CHARGING PORT AND END EFFECTOR USING HALL EFFECT SENSORS:-

5-D localization of a magnetically manipulated system using an Array of Hall Effect Sensors An array of 32 Two-dimensional mono-axial Hall-effect sensors and a permanent magnet of dimensions 20 mm X 20 mm X 40 mm.

Hall effect sensors are used to determine the strength and direction of the magnetic field produced by a magnet.

TABLE III

Comparison of the Magnetic Localization Methods

	Popek *et al.* [23]	Di Natali *et al.* [24]	Yim *et al.* [25]	The proposed method	Than *et al.*[*] [30] [31]
Internal Sensor(s)	6 Hall-effect sensors	6 Hall-effect sensors + 1 tri-axial accelerometer	1 Hall-effect sensor	None	None
External Sensor(s)	None	None	None	64 Hall-effect sensors	2 pairs of gamma ray detectors
Position Error (mm)	11	3.4±3.2	2.0	2.1±0.8	0.4
Orientation Error (°)	11	19±50	5±1.2	6.7±4.3	2
Real-time (Loop speed)	No	Yes (14 ms)	No	Yes (5 ms)	Yes (2–3 ms)
Effective localization Range (mm)	136.0 – 144.0[**]	0 – 150	44.2 – 57.2	5 – 50	200 – 400

[*]Non-magnetic localization method (positron emission marker dectection).

[**]Range in the experiment. Effective localization range is not shown explicitly in the paper.

The precision of localization is independent of the size and strength of the magnet that is put in the charging port and also independent of the number of hall effect sensors.

Using a real-time methodology as proposed in [2] with 6 hall effect sensors and 1 tri-axial accelerometer, communicating the data of the accelerometer over RF communication module DW1000 gives the range of 0 to 150mm. (ideal for our case).

Using the 6 hall effect sensors with magnet size 6.4×6.4×12.8=524.3 mm3 gives the effective localization range of 13.6 to 14.4 cm. Instead, taking 20 × 20 × 40 = 16000 mm3 takes the effective volume to 30 times of original volume which can increase the span to at least 15 times, roughly taking the range to 70 to 160 mm. Further, using a 32 hall effect sensor array can take this range down to approximately 30 to 150 mm, while keeping the position error within 5 mm and orientation error within 6 degrees. These calculations are done according to the approximate relations suggested in [1]

Power consumption and cost calculation:-

Component	Cost(Rs)	Power(MW)	Quantity
ESP32	390	240	2
Hall beck sensor	40	7	6
LDS331DH	262	0.9	1
DW1000	460	55	4

Method 2 - The generic case

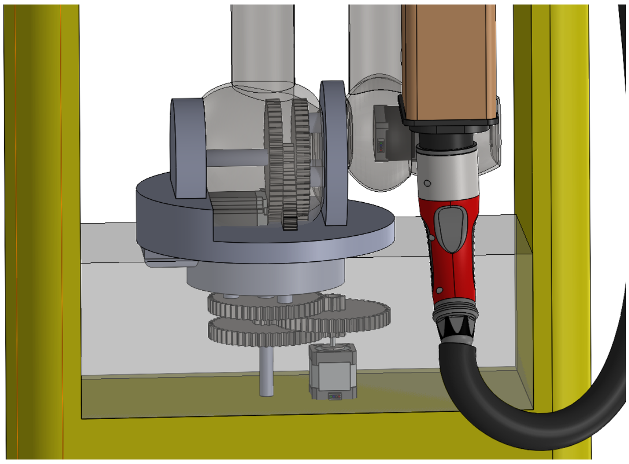
In this method, we make use of image processing technology to measure the exact location of the charging port with respect to the initial position of the robot's end effector. This is achieved by attaching a Raspberry IR Night Vision Camera, an ultrasonic range finder and night vision infrared light emitter on the end effector. The computations are done using a Raspberry Pi 3 Model B processor.

Using Oriented Fast and Rotated BRIEF(ORB) or Accelerated KAZE(AKAZE), we can program our model to detect the charging port by feature matching its external contours against a preloaded set of data.

Arm movement:

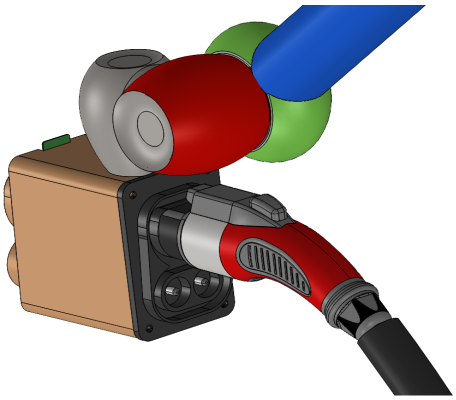
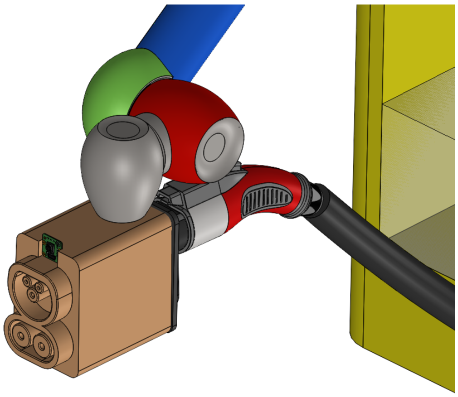
The Robotic Arm condenses to 5 DOFs, 3 primarily for reaching the target location, and the rest two for adjusting the face for the insertion of the End-Effector.

Since a small twist in the first few actuators can move the End effector to a significant distance and the target position requirement of the End-Effector is very strict and can afford only micro-level errors, therefore stepper motor of high resolution and a high gear reduction in it is essential. Two nema-23 and 3 nema-17 have been incorporated. A gear reduction of 125 (5 X 5 X 5) has been done to the first 3 motors to give a highly precise position up to 0.0144 degrees, generating a maximum torque of over 18Kg-m, and high accuracy in position for the End-Effector up to 0.3 mm. The gears also make the step motion looks continuous for a small position change. The system would not require a torque of more than 40% of its full capacity at practical working conditions, thereby removing any vibrations and keeping a good factor of safety.



The closest face of the boundary box is at a distance of 0.76 meters from the charging body and the farthest at 1.16 meters fulfilling the problem requirements, however, the arms are capable of plugging into the car present anywhere in its wide vicinity, allowing 120-degree reach and variation in horizontal distance from nothing till 1.4 meters and in vertical as well.

The charging end is made such that it can be connected to the main charger or removed for both automated and manual plugging, providing flexibility.

Trajectory estimation

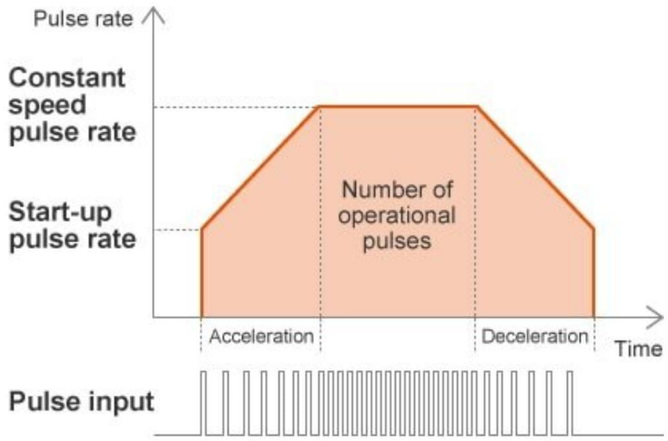
The arms are designed in such a way that they release a unique solution for the desired End-Effector position. A minimum jerk polynomial trajectory has been used to reach a point before the target location, in the smoothest possible way. The function for joint angles takes position in cylindrical coordinates as the input and returns for every joint, the joint angles, for the configuration just before aligning the face for the insertion of the End-Effector. Since, every time the solution is unique, the final joint angles can simply be calculated through a pre-defined function, which might be interpolated with the required waypoints to find the trajectory offering fixed waypoints, which offers the minimum jerk to the motion, thereby eliminating any bad velocity or torque likelihoods. Excellent position control is always there which will suffice and compensate for lags of any kind. Since stepper motors are used, there is very fine control in position.

Advantages of the system

1. No need for inverse Kinematics, thereby saving hefty computations and time.

2. No PID controller for the desired End-Effector position, as there is always a fine position control.

The motions of the actuators are achieved through variable pulses as the input.



Acceleration/deceleration motion profile

The total number of pulses gives the final position of the motor.

The drivers used are **TB6600** for nema-23 control and **A-4988** for nema-17 and will be integrated with raspberry pi.

The final linear motion for insertion can be done by calculating every angle's dependency on time by knowing the position dependency on time(motion in a line) for the End Effector.

A final linear degree of freedom instead, for the End-Effector might be employed if needed. PID is not needed but might be employed if there is a necessity. After all these, Inverse Kinematics or different approaches can also be employed on the arms depending upon the actual necessity which we might have missed.

Assumptions

1. The End-Effector position coordinated on the arm to be inputted for the joint angles calculation for the simulation is in accordance with our needs for make-up and testing, and would necessarily require an offset during practicals.

2. Even though the calculation being simple, the last linear insertion of the End-Effector was difficult to append with the previous trajectory, despite both motions being completely independent and the restraint can be pointed to the limited facilities of Simscape. Therefore the final position of the End-Effector is considered to be the plugged state.

3. The weight of the arms includes both, the weight of the arms and the weight of the charging cables inside or outside.
4. We are assuming that the charging port is not tilted more than 10 degrees in the vertical plane.

Packaging

The arms of the robot has been packed in the most efficient way possible eliminating any possible wastage of volume. The two main arms are kept parallel and vertical and the charging end is at rest at the initial time. The robotic system requires a ground of 43 x 20 cm and 1.2 meters in height.

BILL OF MATERIALS:

Robotic system:

Sl. No.	Unit	Quantity	Cost per Unit(Rs.)	Net Cost(Rs.)
1	A4988 driver Stepper Motor Driver- Normal Quality	3	85.00	255.00
2	TB6600 Stepper Motor Driver Controller 4A 9~42V TTL 16 Micro-Step CNC 1 Axis	2	499.00	998.00
3	42HS48-1684 NEMA17 4.4 kg-cm Stepper Motor – Round Type Shaft	3	602.00	1,806.00
4	Nema 24 21 kg-cm Bipolar Stepper Motor (2.8 Amp Motor) 60HS65-2804AF	2	1,189.00	2,378.00
			Total Cost	5,437.00

For specific case (using RDF):

Sl. No.	Unit	Quantity	Cost per Unit(Rs.)	Net Cost(Rs.)
1	DW1000-I-TR13	4	634.92	2,539.68
2	KY-024 Linear Magnetic Hall Effect Sensor Module	6	46.00	276.00
3	LIS331DLH	1	307.34	307.34
4	JacobsParts NodeMCU Lua ESP8266 ESP-12E cp2102 WiFi Development Board	2	390.00	780.00
			Total Cost	3,903.02

For generic case (image processing):

Sl. No.	Unit	Quantity	Cost per Unit(Rs.)	Net Cost(Rs.)
1	Raspberry Pi 3 Model B	1	3,200.00	3,200.00
2	Raspberry Pi IR Night Vision Camera	1	1,000.00	1,000.00
3	Ultrasonic Range Finder	1	70.00	70.00
4	IR Light for Night Vision	1	270.00	270.00
			Total Cost	4,540.00

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