Charging Port Locating System Using 4 DoF Robotic Manipulator for Automatic Charging Station

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Abstract— This project emphasis on developing the Automated Charging Station using a 4 DoF Robotic Manipulator. The robotic arm is equipped with a camera, laser detection system and the ultrasonic sensor. The combination of all these systems allows the robotic arm to carry out the charging process completely autonomously. To recognize possible obstacles and to react to these depending on the size of the car, multiple charging robotic arms can be employed so that several vehicles at a time can be attended to. The camera placed on the unit is used to detect the charging port on the vehicle using a computer vision algorithm and the working of the whole charging unit is validated using an electric vehicle model. This project the automated charging station follows a futuristic approach, it is optimized for faster charging, data communication between robotic charging unit and the BMS, cost effective and economically viable and it is the optimal solution for future luxury electric vehicle to achieve the autonomous charging process.

Indexed Terms— Charging Station; robotic arm; electric vehicle; IoT; autonomous charging; BMS

I. INTRODUCTION

The proposed project is particularly curated to solve the supposed future problem dealing with EV's and their charging system. Electric vehicles are supposed to be the future of locomotion. These electric vehicles are immensely efficient and environment friendly. The whole system will be automated, as whenever a vehicle crosses a threshold line, a Laser based sensory mechanism will detect the motion and turn ON the system. A 4 DoF robotic arm with a camera and connectors is used in this prototype. The robotic arm will detect the charging port on the vehicle and charge till the battery completely charges. To model the vehicle, a battery pack of 25.9 V 15 Ah is used with optimized BMS and protection circuit with a buck converter and a PMDC motor of rating 24V, 250W. This motor will be controlled using a throttle. A Luo-converter is used to provide the input voltage to the battery of modelled vehicle. An ultra-lift Luo converter is a DC-DC boost converter with a high voltage transfer gain in comparison to other Luo converters. The main objective of the proposed project is to design an offboard battery charger or a charging station which is automated and charges the vehicle by sensing its approach using a 4 DoF robotic arm with a camera and connector coupling attached. This acts as a convenient technology for future luxury electric vehicles.

II. PROJECT DESCRIPTION

Automatic charging is especially important for autonomous vehicles; that is, cars that operate without human drivers. Although it'll still be a few years before we see driverless vehicles in normal road traffic, they're already standard in demarcated facilities like container port loading areas. We're also seeing applications for normal electric cars. For example, drivers with physical limitations will find it extremely helpful if they can charge their cars without having to get out of the vehicle. These electric vehicles are immensely efficient and environment friendly. The whole system will be automated, as whenever a vehicle crosses a threshold line, a Laser based sensory mechanism will detect the motion and turn ON the system, the port flap opens. From this point on, a fully automatic charger for electric cars takes over. A robotic arm that moves in all spatial axes connects to the vehicle's CCS charging connector in less than a minute and charges the batteries. After a certain amount of time, which depends on the capacity and state of charge of the batteries and the vehicle's maximum permissible charging power the robot breaks the connection and the car can continue on its way fully charged.

A. *Breakdown Of the Proposed Model*

In the proposed system, we have bifurcated the entire system into two model. The first one of them being the Ultra-Lift Luo converter Robotic Charge Control Unit and the second one is prototype of EV model. The supply is taken from the 230V AC into the Luo converter via the AC-DC converter and then it is then supplied to battery pack. Further the voltage is step down to 24V as per the requirement of the PMDC motor which is used in the EV model.

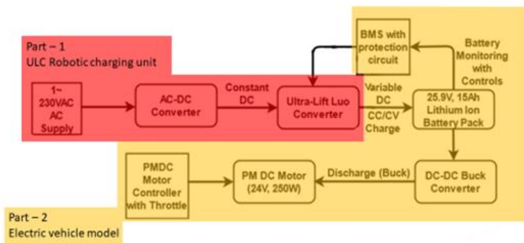

Fig 1. Component Breakdown of the Proposed System

Fig. 1. represents the breakdown of the proposed model in Part 1 and Part 2. Part 1 represents the ULC Robotic charging unit- 1-phase supply, AC-DC converter and the Ultra-Lift Luo converter. Part 2 represents the Electric vehicle model- BMS, Battery pack, Buck Converter, PMDC motor and motor controller.

B. Block Diagram of Electric Vehicle Model

The battery pack receives a voltage of 25.9 V from the robotic charger and further it is stepped down to 24 V in order to meet the requirement of the motor. The motor then is connected with the controller.

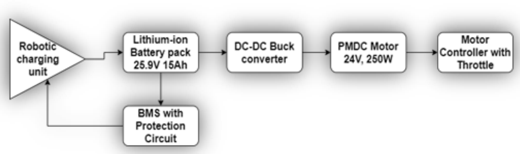

Fig 2. Block Diagram of electric vehicle model

Fig. 2. represents the block diagram of the Electric Vehicle model, here Battery Management System will act as a communicator between the robotic charging unit and the battery pack to avoid overcharging of the battery.

III. ROBOTIC CHARGING UNIT

The robotic arm, which can drive automatically, is equipped with camera, laser detection system and peripheral systems. The combination of these systems allows the robot to carry out the charging process completely automatically, to recognize possible obstacles and to react to these depending on the size of the car, several charging robots can be employed simultaneously so that several vehicles can be attended to.

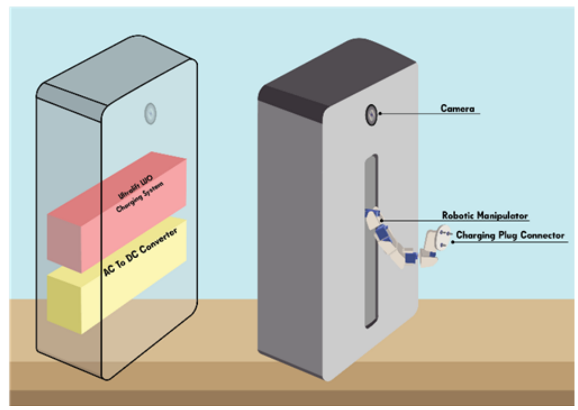

Fig 3. Robotic charging unit

Major Components used in the Robotic Charging Unit: -

- 640 x 480 (30 FPS) Camera.
- Servo Motors.
- PCA9685 Servo Motor Driver.
- Raspberry pi 3B.
- 12V 10 Amp Switched Mode Power Supply (SMPS).
- Luo-convertor based charger.
- XY-L30A Battery Charge controller.
- 3D printed robotic joints and Charging Plug Connector.

A. 4 DoF Robotic Arm

The Robotic arm is used to automatically place the charging plug connector, which is attached to its end effector.

All the parts of the Robotic arm are 3D printed using Polylactic acid (PLA) filament, which is strong, reliable and economically viable. The Degree of Freedom (DoF) depends on the number of servo motors used, in our project, 4 Servo motors are used. A camera is placed on the unit to detect the charging port on the vehicle. A Custom charging plug is designed and 3D printed, which is attached as the end effector of the robotic hand.

Fig 4. Hardware Prototype of the Robotic charging unit

Fig.4 depicts the hardware prototype for the Robotic Charge Unit having 4 Degree of Freedom. The robotic arm in front will detect the vehicle once the EV crosses the laser module and once connected to the port, the charging will start. The whole system will be automated, as whenever a vehicle crosses a threshold line, a Laser based sensory mechanism will detect the motion and turn ON the system.

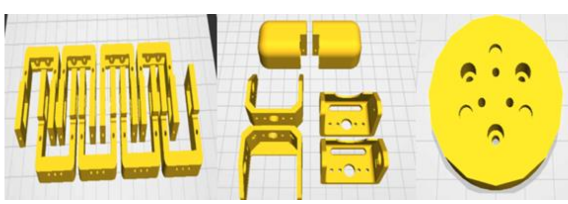

Fig 5. 3D model – Robotic arm parts

Fig.5 shows the 3D printed parts used in the robotic arm model. The 3D printing was done to ensure the correct functionality of the model without any losses.

B. Computer Vision Logic

In order to track the vehicle charging port once it has entered the system we have used computer vision logic which will tell us the exact point of location of the charging port in an Electric Vehicle. As our model is built where there is no human intervention it was expected to auto detect the charging port.

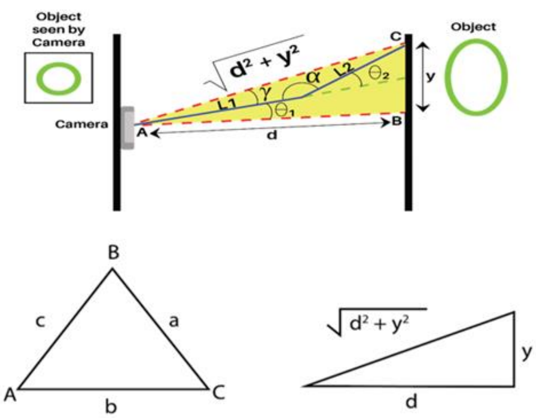

Fig 6. Computer vision logic to calculate the position of the charging port

In Fig. 6. using the cosine law, we will find the distance of the charging port from the robotic arm and camera module which is placed at the top of the model. As the height and distance of the port forms a right angle, hence the angle and shortest distance has been calculated.

$a2 = b2 + c2 - 2bccosA$

$\llcorner A = \cos^{-1}(b^2+c^2-a^2) / (2bc)$

Now for our triangle,

$\Theta = \cos^{-1} (d^2 + d^2 + y^2 - y^2) / (2*d^2 * \sqrt{d^2} * y^2)$

$\Theta = \cos\text{-}1 (2d^2) / (2*d^2 * \sqrt{d^2} * y^2)$

$\Theta 1 = \Theta - y$ $\quad\quad$ $\Theta 2 = 180 - \alpha$

So, to get the angles for the servo motors, the parameters of Θ1 and Θ2 are needed, and given equation helps to get the angles based on the location of the charging port.

C. Luo Converter Based Charger

The novel approach of Ultra-lift Luo converter is designed and implemented for electric vehicle application to maintain the stable DC output with reduced ripples. In this proposed system has PI controller and PWM controller to improve the static and dynamic performance of the converter and to get stable DC output.

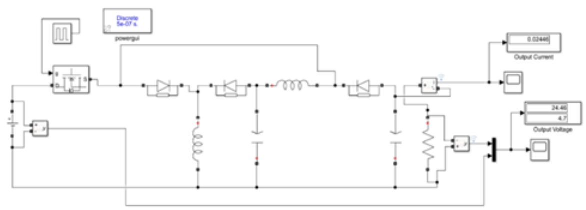

Fig 7. Simulation of Ultra-Lift Luo converter

For the purpose of optimizing the stability of Ultra-lift Luo converter dynamics, while ensuring correct operation in any working condition, a PI control is a feasible approach. The PI control has been presented as a good alternative to the control of switching power converters. The advantage of PI control method is insusceptibility to system parameter variation that leads to invariant dynamics and static response in the ideal case. It ensures the specifying desired nominal operating point for Ultra-lift Luo converter, then regulate the converter output, so that it strays very closer to the nominal operating point in the case of sudden disturbance, noise, modelling error and component variation.

D. Custom Designed Connector

A custom charging plug is designed and 3D printed using Polylactic acid (PLA) filament, which is strong, reliable and economically viable, which is attached as the end effector of the robotic hand.

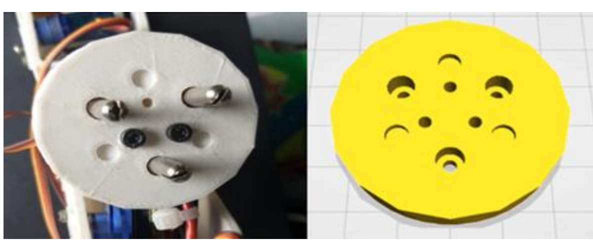

Fig 8. Custom Designed Connector

Fig. 8. represents the Cad sliced file of the custom designed connector and the real 3D printed connector which can also communicate with the BMS data.

IV. LASER VEHICLE DETECTION SYSTEM

The Laser Vehicle Detection System uses the simple principle of LDR. The whole Charging system will get activated only when the Laser Detection system detects a vehicle. The LDR is used in combination with the laser to form the light sensor and source.

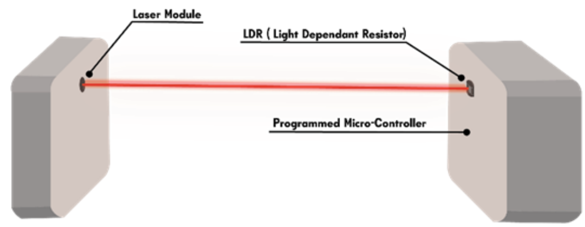

Fig 9. Laser Vehicle Detection System

The whole Charging system will get activated only when the Laser Detection system detects a vehicle. It includes a laser on one end and the receiving LDR with programmed microcontroller and Relay modules on the other end. When the laser is interrupted, the relay module will turn ON the charging supply, and the whole system will get turned on.

V. ELECTRIC VEHICLE MODEL

The Electric vehicle model is designed to replicate a basic electric vehicle mechanism. The main motive of this Vehicle model is to justify the working of the proposed charging station.

The main parts which are included are: -

- 25.9 V 15 Ah Lithium Ion Battery in 7S6P configuration.
- Buck converter to equalize with the rated motor voltage.
- PMDC Motor (24 V, 250 W)
- Motor controller
- Throttle to accelerate the motor.
- Mainly, the Charging socket connector to charge the battery.

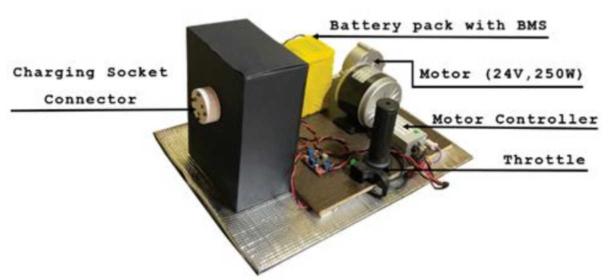

Fig 10. Electric vehicle model

Fig. 10. shows the electric vehicle model consists of battery pack, PMDC motor, buck converter, BMS, motor controller, charging port and throttle etc. All the hardware components used are commercially

available. The model is used to validate the charging system. Electric Vehicle Model

VI. PROTOTYPE

The model before detection is somewhat like this. Here the entire system is in OFF stage as there is no detection of incoming vehicle.

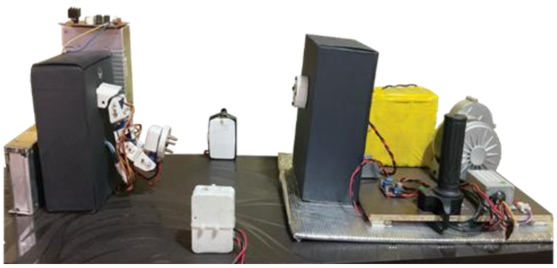

Fig 11. Full System Prototype Before Detection

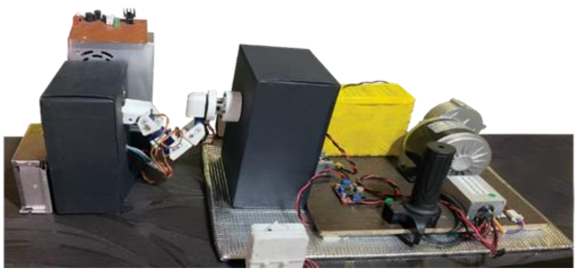

Fig 12. Full System Prototype After Detection

Once, a vehicle crosses the laser, the system gets activated and then the charging port locator gets activated. With the help of computer vision, the arm detects the vehicle's charging port and connects the arm to the port in order to charge the EV. Once the EV is charged the arm gets detached to stop the charging. The entire process is automated and does not involve any human intervention.

VII. RESULTS AND ANALYSIS

A. 4 DoF Robotic Arm

Fig.13. represents the position of Robotic arm when it is in off state.

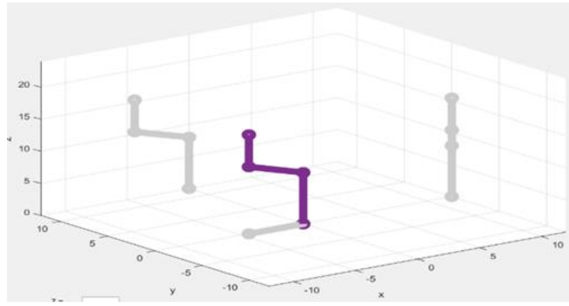

Fig 13. Home Position

Fig. 14. represents the position of Robotic arm when it is activated (on state) due to signal from Laser Detection System.

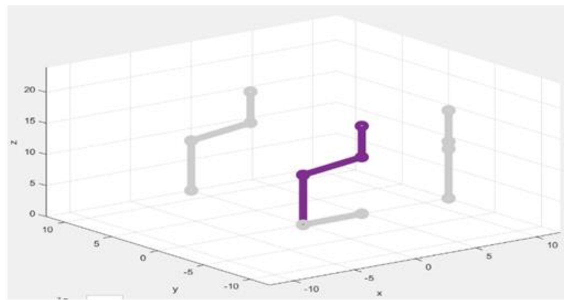

Fig 14. Detecting Position

Fig. 15. represents the Placement position of the Robotic arm when it comes forward to push the plug into the charging port by locating its distance and angle.

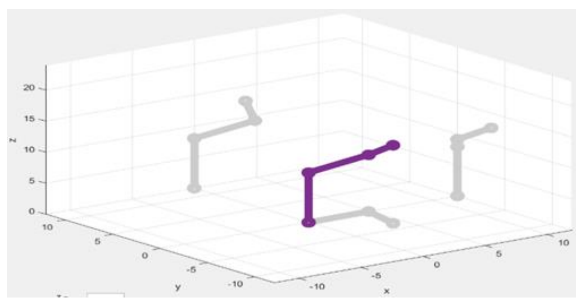

Fig 15. Placement Position

B. Luo Converter Based Charger

Luo-Converters are a series of new DC-DC step-up (boost) power conversion circuits, which are developed from a prototype of the boost converters. These converters perform positive to positive DC-DC voltage increasing conversion.

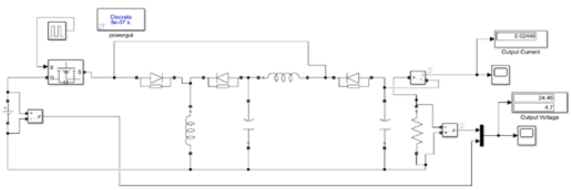

Fig 16. Ultra-lift Luo Converter Simulink Diagram

The simulation of the ultra-lift Luo converter is being shown above in fig. 16. The Luo converter is being used in the robotic charge controller in order to charge the EV.

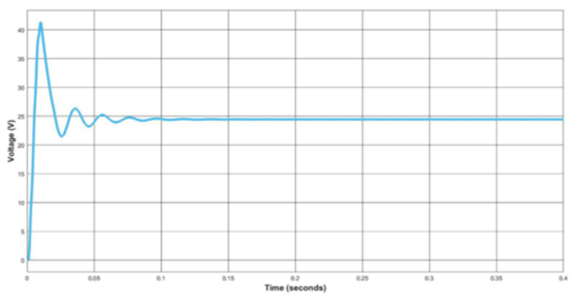

Fig 17. Output Voltage of Ultra-lift Luo Converter

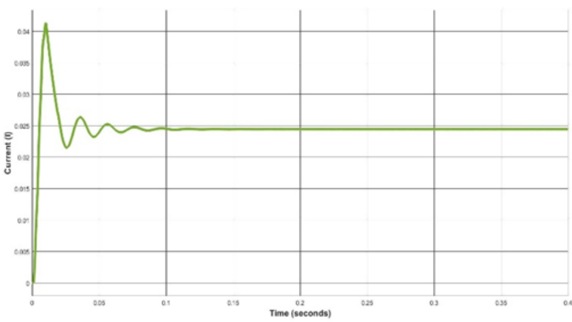

Fig 18. Output Current of Ultra lift Luo Converter

These are the simulation result obtained from the simulation of Luo converter. This is the ideal charging condition for an Electric Vehicle (EV). Fig. 17. represents the output voltage of the ultra-lift luo converter and fig. 18. represents the output current of the ultra-lift converter.

C. Electric Vehicle Model (Discharging System)

This is the simulation of the EV model prototype. Currently this is in discharging state. It receives the input from the Luo converter and the buck converter steps it down to a certain voltage needed by the DC motor.

Fig. 19. represents the closed loop simulation of Discharging circuit of the electric vehicle model which includes Battery pack 25.9 V, connected with a buck converter to reduce the voltage of battery from 25.9 to 24 V and then fed the supply to PMDC motor of 24 V and these are the output parameters of the simulations.

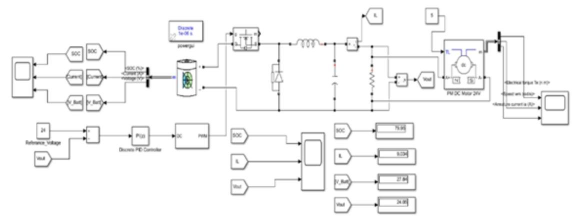

Fig 19. Simulation of Electric Vehicle Model

The Fig. 20. represents the battery parameter State of Charge of the battery pack during its discharging operation.

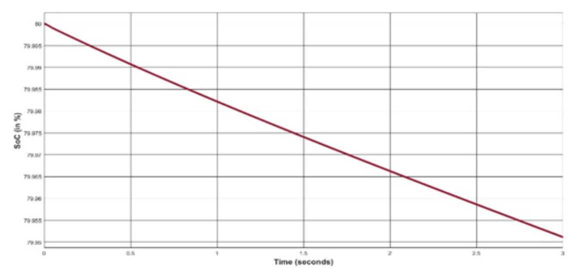

Fig 20. SoC % of Discharging System

Fig. 21. represent the current drawn by PMDC motor from the source i.e., battery pack 25.9 V which is again reduced using buck converter to 24 V.

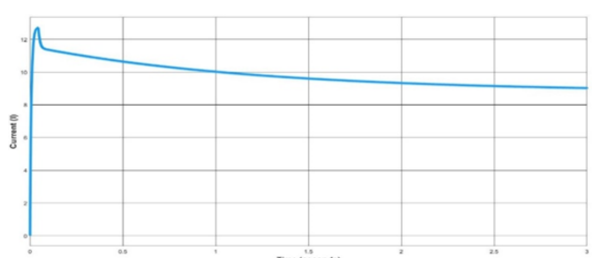

Fig 21. Load Current Graph of Discharging System

The Fig. 22. represents the input voltage fed to Load i.e., PMDC motor of 250 W, 24 V from the buck converter 24 V.

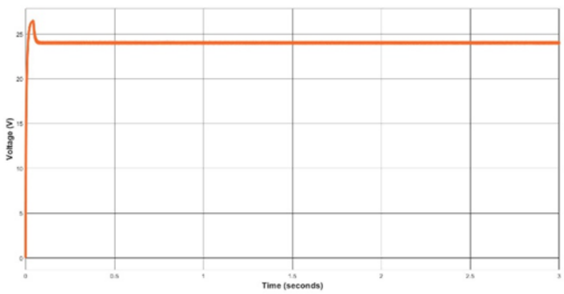

Fig 22. Load Voltage Graph of Discharging

VIII. CONCLUSION

Considering the futuristic approach, the proposed idea will benefit people having automatic driver-less vehicles as it will remove the need of humans to charge the vehicle manually. It has been tested using an electric vehicle prototype to verify the proper working of the robotic charging system. It is optimized for faster charging, have cost effectiveness and economically viable and it is the optimal solution for future luxury electric vehicle to achieve the autonomous charging process.

IX. FUTURE WORK

The system is incorporated with a charge monitor and other monitoring systems. The charge monitor is depicted in Fig. 1

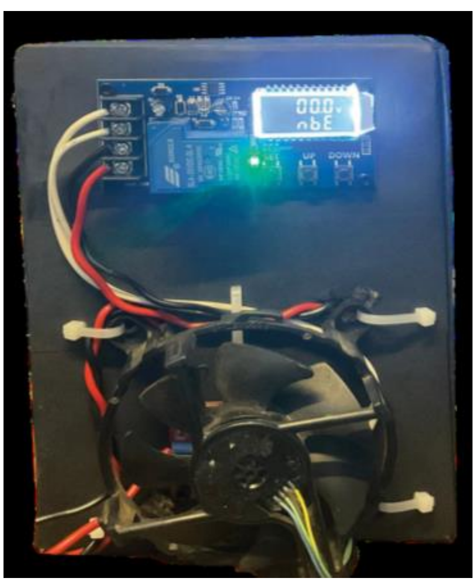

Fig 23. Charge monitoring system

The future system will have an amalgamation of IoT and these monitoring systems to help create an user friendly and interactive platform.

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