Bangladesh University of Engineering and Technology

Course Name: Control Systems I Laboratory (EEE 318)

Project Name:

Automated Level Crossing System: A Computer Vision Based Approach

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Abstract

In a rapidly flourishing country like ours, accidents in the unmanned level crossings are increasing day by day. Our paper deals with **Automatic Level Crossing System** i.e. automatic junction barrier control at a level crossing replacing the gates operated by the gatekeepers. It deals with two things, Firstly it detects the incoming train by a camera module placed at a certain distance. Secondly, it provides safety to the trespassers and vehicles by automatically closing and opening the junction barrier. We also worked on different safety measures with alarms and planning on adding much more in it.

1. Introduction

Bangladesh Railway (BR) is the state-owned rail transport agency of Bangladesh. It operates and maintains the entire railway network of the country. BR is controlled by the Directorate General of Bangladesh Railway under the Ministry of Communications along with Bangladesh Railway Authority which works for policy guidance of BR. Bangladesh Railway covers a length of 2,855 route kilometers and employs 34,168 people (Banglapedia, 2006). BR operates both inter-city and suburban rail systems on a multi-gauge network of broad, meter and dual gauges. There are 2187 level crossings in Bangladesh among which 1512 are authorized and 675 are unauthorized

Now, Level crossings are supposed to ensure trains safely pass. Till now, this job of lowering the barrier was done manually. But this is not a very reliable method as many accidents happen due to negligence. While working on this project, On 19th Dec due to the negligence of a gatekeeper in Joypurhat cost 12 lives and left injured a few.

Tragically this is nothing new. Train accidents led to 1,546 recorded casualties over the last 10 years from July 2007 to June 2017, including 365 deaths and 1,181 cases of injury, according to Bangladesh Railway. The highest recorded compensation paid to victims amounted to 5 crore BDT for accidents that occurred in 2007-2008.

Here are some data to further understand the problem:

Accident Type	Injuries	Fatalities	Total Casualties
Head-on Collision	100	13	113
Rear-end Collision	13	8	21
Side Collision	0	1	1
Averted Collision	0	0	0
Collision at Level-Crossing	421	225	646
Derailments	122	8	130
Train Parting	0	0	0
Signal Disregard/Over-Shooting	0	0	0
Fire in Trains	6	5	11
Train Running into Obstruction	1	2	3
Others	3	0	3
Total	**666**	**262**	**928**

Table: Distribution of accident casualties according to accident type

We can see from the table that Collisions at level crossings is clearly one of the top reasons for deaths/injuries by rail accident.

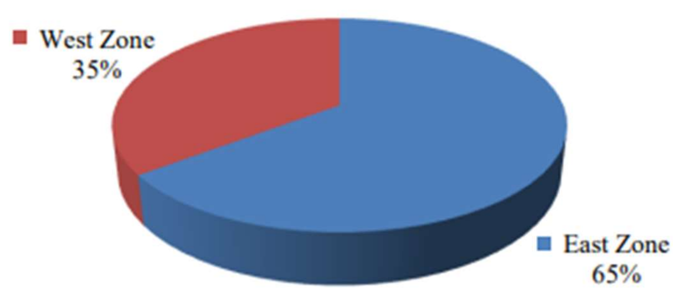


Figure: Distribution of accidents according to zone (%). Year 2008-2015

We can see that the East Zone of Bangladesh Railway is where almost ⅔ rd of all accidents happen.

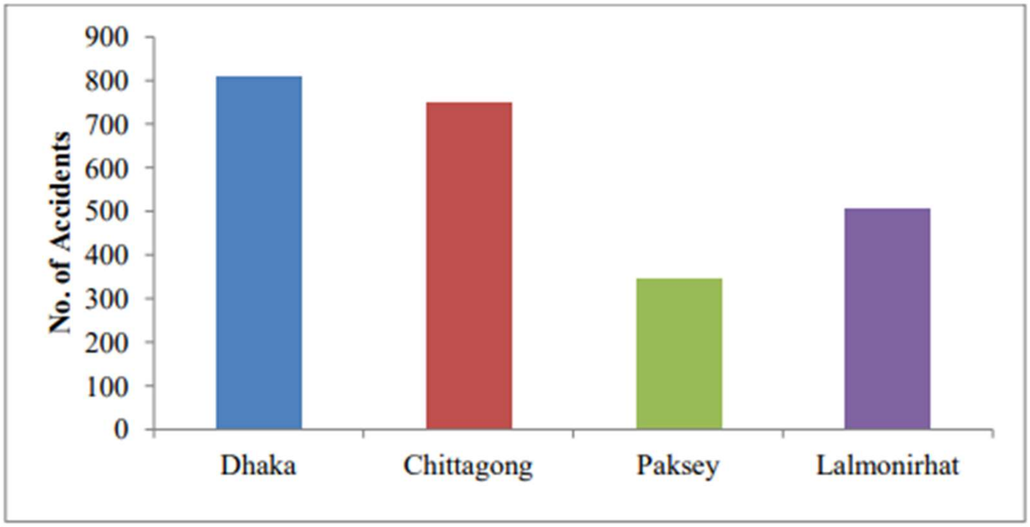


Figure: Distribution of accidents according to railway divisions , Year 2008-2015

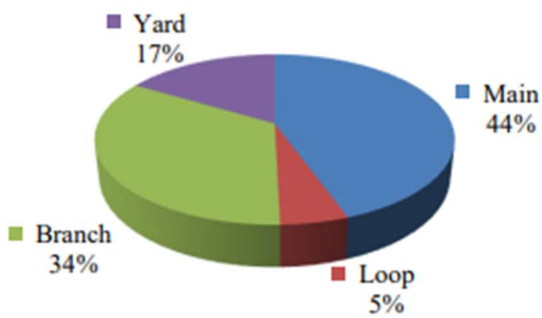


Figure: Distribution of accidents according to line type (%) , Year 2008-2015

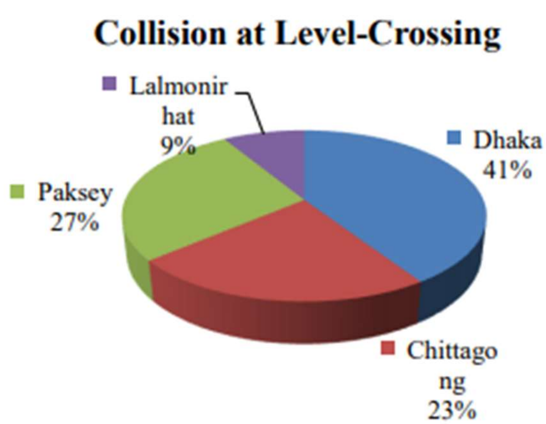


Figure: Distribution of level crossing accidents according to division (%) , Year 2008-2015

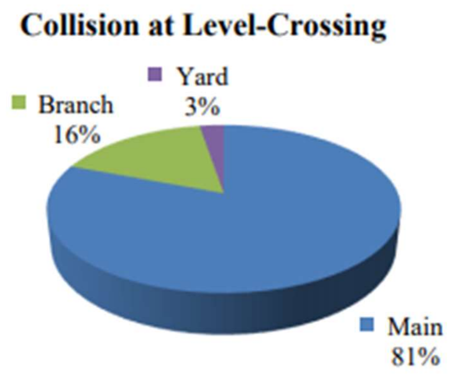


Figure: Distribution of level crossing accidents according to line type (%) , Year 2008-2015

As of now, there hasn't been any attempts to automate the process. Currently in all parts of Bangladesh the system is managed manually by a gateman who is after all a human and humans make mistakes. This project work is conducted to propose a futuristic solution to the ever increasing problems associated with level crossing junctions to improve the performance and lessen the casualties across the board.

2. General Overview

Our main focus of this project is to efficiently design a level crossing system which will be easy to monitor and cost efficient considering us as a developing nation. We are using a Deep Learning Algorithm known as SSD MobileNet to detect incoming trains. Then our peripherals would react and control the shaft of the level crossing bar with that information. We also developed some safety measures for the trespasser and traffic to prevent accidents.

We expect to accurately detect an incoming train and get as little false positive as possible. After detecting a train, we expect to rotate the servo motor which will close the level crossing junction. We also hope to detect other nearby vehicles and humans so that we can ring an alarm when a train is approaching but the junction is not maintaining safety protocols. The Flow chart of our project is given below :

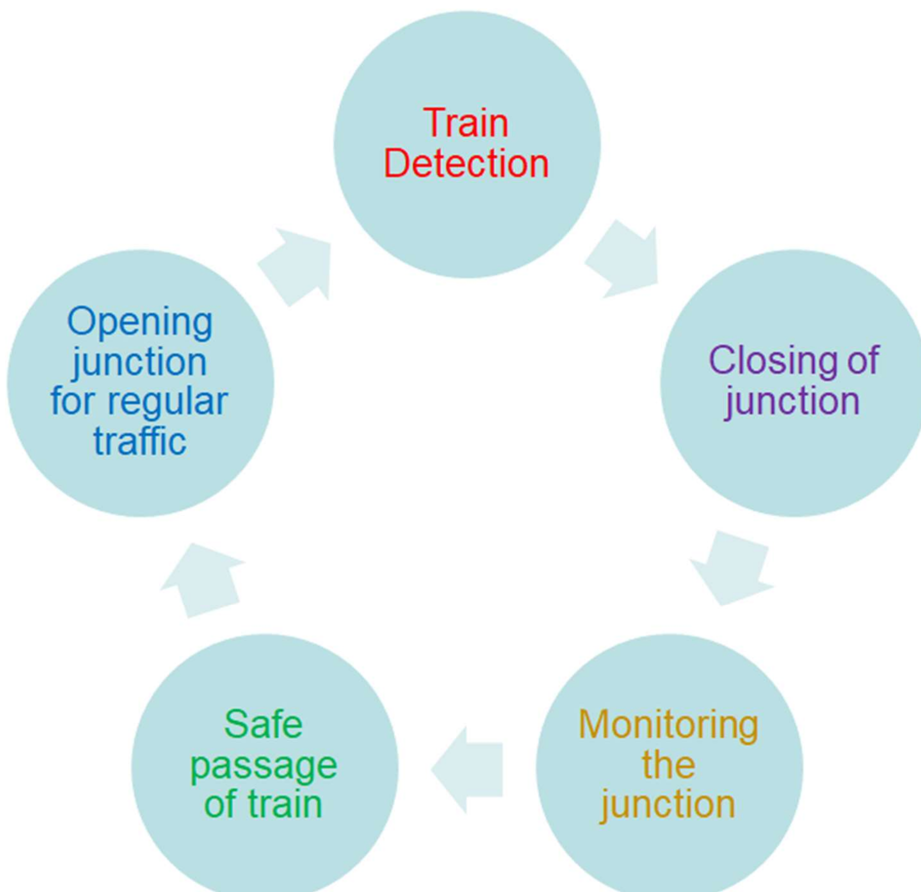


Fig 1 : Flow chart of the project

Existing Level Crossing Detection Technologies:

Object detection technologies have been used in ensuring safety at level crossings for a few decades now. Some of these technologies have had a profound impact in this sector. Although they have to some extent made level crossings safer, they are still far from being perfect. A brief description consisting of their pros and cons is given below:

1. Optical Beam Detector: Optical emitters are placed on one part of the crossing, each one emitting a directed optical beam with a defined field of emission. Then a photon detector having a defined field of view intersects the field of emission of the emitter. If the beams are interrupted, it means that an object is located on the crossing.

   Figure 1. Optical beam method

   This technique has the advantage that it is easy to replace, but it has many important drawbacks: very expensive cost for installation, need to have several detectors along the crossing, traffic needs to be stopped for installation, and it is unusable in periods of heavy snow. Electronic waves passing between transmitters and receivers can detect obstacles in a similar manner to the optical beam method. However, the optical beam method cannot detect pedestrians.
2. Ultrasonic Detector: ultrasonic detectors (Figure 2) which rely on differences in ultrasonic reflection times for detection. They transmit pulses of ultrasonic energy towards the roadway. The pulse is then reflected back more quickly when a vehicle passes through. As an advantage, sonic detectors have the advantage that can detect both stationary and moving vehicles. However, the disadvantages reside in their price and installation cost. Additionally, they are extremely sensitive to environmental conditions (inaccurate in congested conditions). Furthermore, the common drawback of these systems is that they do not detect objects with low metal content.

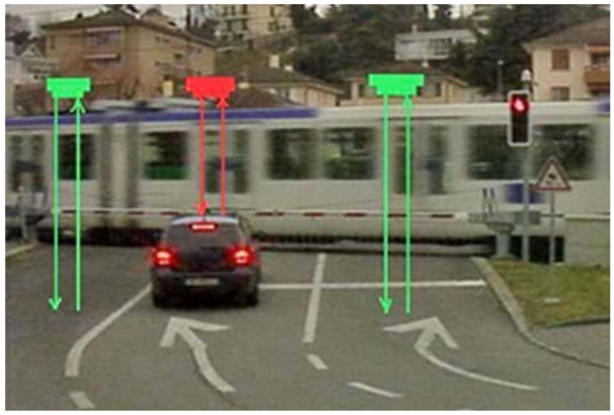


Figure2: Ultrasonic Detector

3. Radar Detector: Microwaves are sent from a transmitter based at the side of the roadway. The microwaves are reflected back to a receiving antenna with a different frequency. This change is picked up and reflects the presence of an object. Radar presents a lot of advantages such as the fact that traffic does not need to be disrupted for installation and it is immune to electromagnetic interference. The disadvantage is that it is hard to maintain.

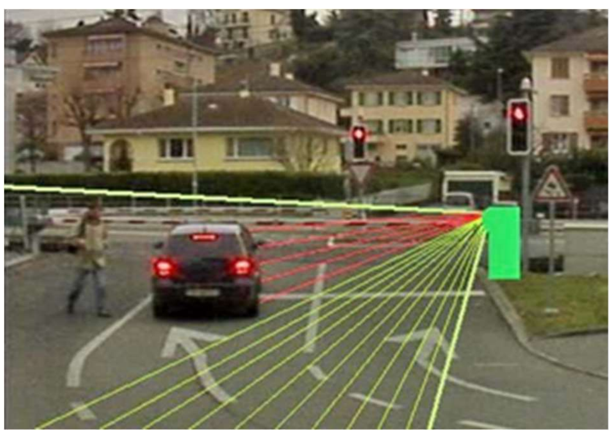


Figure 3. Radar method.

4. Induction Loop Detector: The inductive loop is probably the most common form of vehicle detection. A wire is embedded under the roadway. A magnetic flux is generated around it. When a vehicle is passing over the wire, the flux is cut causing an increase in inductance, and the detection of an obstacle. This is what happens when a car pulls up to the intersection. The huge mass of metal that makes up a car alters the magnetic field around the loop, changing its inductance. This system is easy to install and is not subjected to environmental conditions. The main drawbacks are that it cannot detect pedestrians, and the high cost of installation and maintenance, because it needs a large number of loops to be efficient.

5. 3D Laser Detector: 3D laser radar emits a laser pulse to an object, and measures the time that it takes for the reflected laser to return to the radar (time-of-flight method). It acquires the distance from that object. Figure 4 shows the object detection method used by the 3D laser radar. A laser pulse is emitted in a way that it scans the entire area of a level crossing in the horizontal and vertical directions. The 3D coordinate values of each point measured from the reflected laser are returned to the 3-D laser radar.

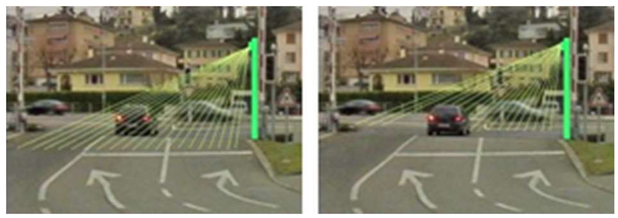


Figure 4. Laser method

Summarizing, optical beam and sonic detectors are definitely too expensive and not accurate enough because they need a high number of sensors. They are also too sensitive to environmental conditions. The most relevant technologies for object detection at level crossings are radar, inductive loops and video imaging. The problem with inductive loops is that they detect only metal objects. Nowadays, many vehicles use fiberglass and aluminum, which are not well detected by the system. Afterwards, the maintenance of such a system is hard because it is located below the road. That is why we are focusing on video and now present some realizations and utilizations of these technologies.

3. Object Detection Tasks

3.1 Video classification & Localization

Object detection refers to the tasks to locate the presence of the objects within a bounding box and classify the classes of that located object. To break it down, an object detection algorithm consists of two things. An object localization task and a classification task.

Image classification involves predicting the class of one object in an image. Video is nothing but the collection of images arranged in a specific order. These sets of images are referred to as frames. That's why the video classification problem is not that different from an image classification problem. For an image classification task, we take all the images , use feature extractors (Convolutional Neural Networks or CNNs) to extract the features from images and then classify those images based on their extracted features. For video classification tasks, an extra step involves extracting the frames from the video feed and doing the same as an image classification task.

Object localization means locating the presence of an object in an image and marking their location with a bounding box. For this task, we are using the same technique as previously mentioned. We feed the video input by extracting it into frames. We localise the objects in that frame and draw a bounding box associated with that object.

A Bounding Box can be initialized using the following parameters:

- bx, by : coordinates of the center of the bounding box
- bw : width of the bounding box w.r.t the image width
- bh : height of the bounding box w.r.t the image height

The core concept deals with finding the correct bounding box is a regression problem. At the beginning we return four numbers (bx,by,bw,bh) that are related to this bounding box and we train our model with an image which provides ground truth bounding box coordinates. We simply calculate the euclidean distance (L2 distance) to calculate the loss between the predicted bounding box and the ground truth. With this we train the model till we get an accurate prediction for the bounding box.

There are several state of the art object detection algorithms like YOLO, SSD, MMDetection . But for the purpose of simplicity of our task, we choose the SSDLite which is a lighter model to train and computationally less expensive than other detection algorithms out there. And definitely well enough for our task.

3.2 Developing Detection Algorithm

For our task, we didn't find any perfect dataset to classify the images. So, we worked hard to build one for ourselves. By now, our collected dataset consists of ---- images of trains sub categorised into different train types.

For detecting trains in an image we used the algorithm **MobileNet-SSD.** Mobilenet architecture is the backbone of the algorithm and SSD architecture is a single convolution network that learns to predict bounding box location and classify these locations in one forward pass.

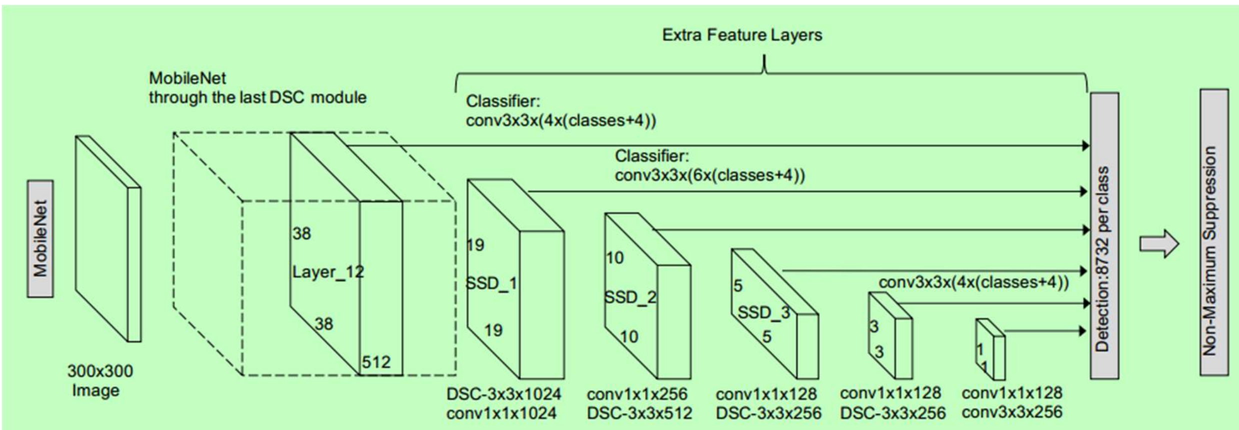
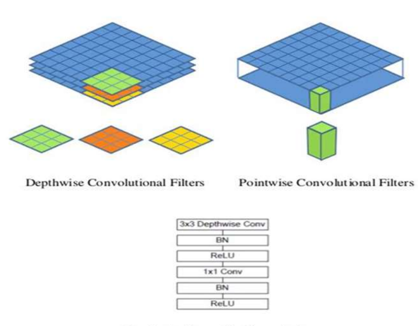


Figure 6. Mobile-Det: SSD-based detection with MobileNet as backbone, modified based on [14]

SSD operates on feature maps to detect the location of bounding boxes. A feature map is of the size Df * Df * M. For each feature map location, k bounding boxes are predicted. Each bounding box carries with it the following information:

- 4 corner bounding box **offset** locations (cx, cy, w, h)
- C class probabilities (c1, c2, …cp)

SSD **does not** predict the shape of the box, rather just where the box is. The k bounding boxes each have a predetermined shape. The shapes are set prior to actual training. For example, in the figure above, there are 4 boxes, meaning k=4.

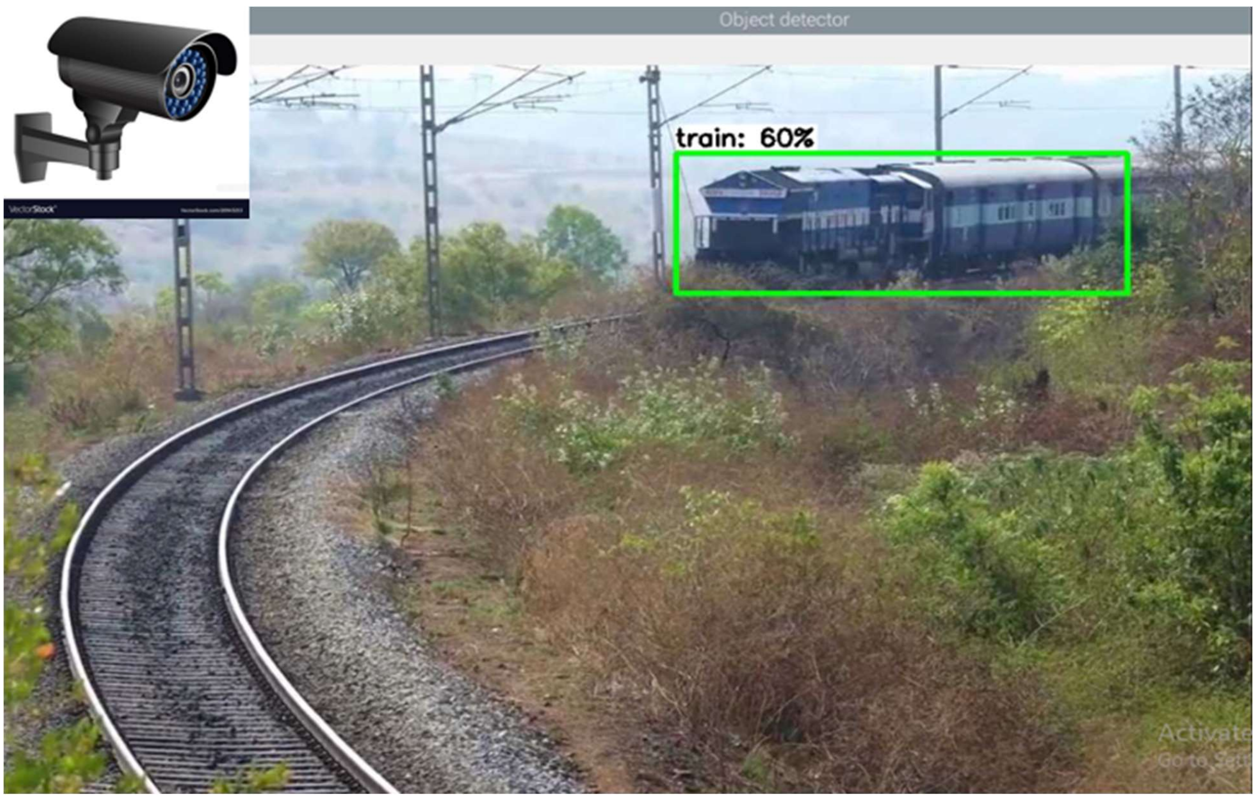


The MobileNet model is based on depth wise separable convolutions which are a form of factorized convolutions. These factorize a standard convolution into a depthwise convolution and a 1 × 1 convolution called a pointwise convolution.

For MobileNets, the depthwise convolution applies a single filter to each input channel. The pointwise convolution then applies a 1×1 convolution to combine the outputs of the depthwise convolution.

A standard convolution both filters and combines inputs into a new set of outputs in one step. The depthwise separable convolution splits this into two layers – a separate layer for filtering and a separate layer for combining. This factorization has the effect of drastically reducing computation and model size.

3.3 Train & Trespasser Detection



A camera pointing towards the railway line sends a video feed to the raspberry pie. Then the raspberry pie runs inference on the video feed using SSD mobilenet to detect any incoming train. If it detects a positive match, then it sends a control signal to the peripheral actuators and sounds an alarm to alert nearby pedestrians and traffic. Receiving the control signal from the pie, the junction barrier starts to close and the traffic in the vicinity is immobilized.

3.4 Activity Monitoring and Alarms

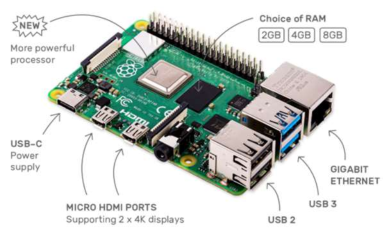
The junction is monitored for any unwarranted trespassing once the junction barrier is closed. No regular traffic, nor any pedestrians are allowed to cross the junction while the barrier is closed. If any trespassing activity is detected, the pie will sound a pre-recorded voice alert repeatedly and will also activate an emergency siren. If the junction is not cleared even after the warnings have been activated, the pie will send a distress signal to the nearby emergency services (police, fire brigade etc.) for an emergency rescue operation. Also, an emergency signal shall be sent to the incoming train to alert it about any possible fetal collisions.

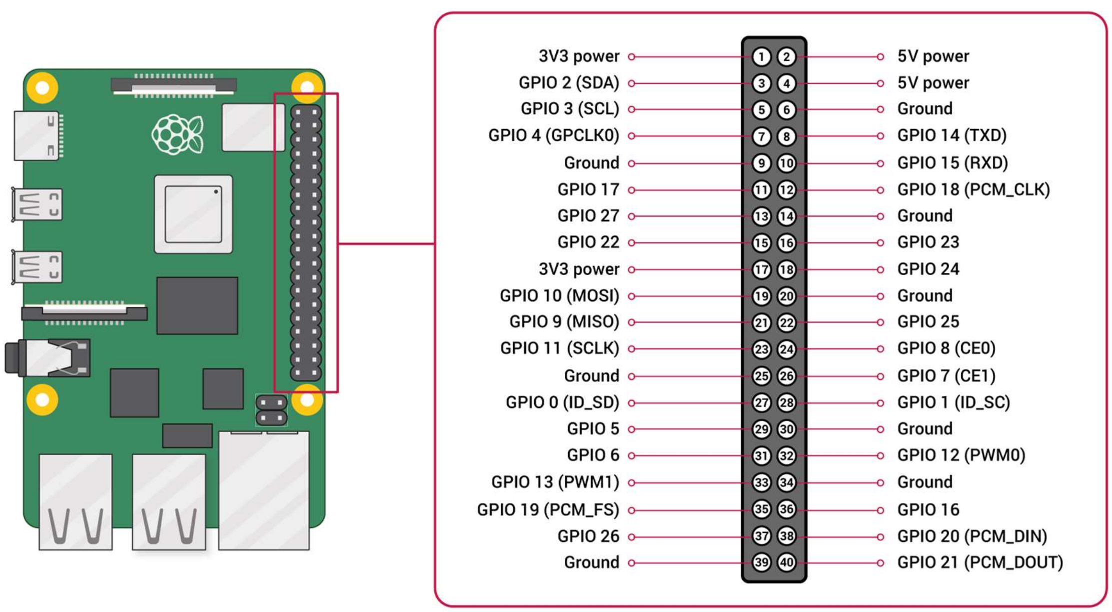
4. Experimental Setup & Results

4.1 Components

Raspberry Pi 4 Model B (4GB RAM):

The Raspberry Pi is a low cost, credit-card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. It is a capable little device that enables people of all ages to explore computing, and to learn how to program in languages like Scratch and Python. The Raspberry Pi has the ability to interact with the outside world, and has been used in a wide array of digital maker projects, from music machines and parent detectors to weather stations and tweeting bird houses with infra-red cameras. This is a perfect go to for our project instead of arduino for support TensorFlow API for several object detection algorithms out there.





There are many types of pins in the pie:

General Purpose Input/Output

General Purpose Input/Output is what GPIO stands for, and describes the jobs of the pins on Raspberry Pis perfectly. They are very similar to Arduino pin ports as they can be configured to either read inputs or write outputs. These pins let your Pi interact with different components such as buttons, potentiometers, and buzzers.

There are two naming schemes: WiringPi and Broadcom numbering. The latter is what each pin is officially called, displayed in green for the pins in the image above. WiringPi, the GPIO interfacing library you will most likely be using, has its own hardware-independent numbering system internally.

Power and Ground Pins

The power and ground pins are used to power external circuitry. All Raspberry Pis with the standard 40 GPIO pins will have two 5V pins and two 3.3V pins, always in the same place.

Along with the 5V and 3.3V pins, 8 ground pins are available. Power and ground pins are what let our Raspberry Pi power components like LEDs and motors in your project. However, remember that the proper HAT or external circuitry should always be installed ***before*** attempting to power anything through these pins. Powering something with too much current draw or significant voltage spikes, like a motor without the appropriate motor controller, will damage the pins and could render them unusable.

Alternative Functions

While many projects can get along with power and input pins, sometimes different abilities are required from a Pi. Luckily, some GPIO pins double as I2C, SPI, and UART interfaces. The Pi 4 has expanded the capability of many pins by supporting these interfaces on more of them than the Raspberry Pi 3b+ before it. Below is a brief description of each.

I2C

I2C, or the Inter-Integrated Circuit protocol, allows your Raspberry Pi to control multiple sensors and components, known as slaves. The communication is done through the SDA (data pin) and SCL (clock speed pin). Each slave device is created with a unique address to allow for fast communication with many devices. The ID_EEPROM pins are also I2C, but are used for communicating with HATs, not slave components.

SPI

SPI, or Serial Peripheral Interface, is also used to control components with a master-slave relationship, though it is not as compact. It requires clock (SCLK), Master Out Slave In, and Master In Slave out pins to function. The pins do what their names imply, with SCLK regulating data speed, MOSI used to send orders from the Pi to attached devices, and MISO doing the opposite.

UART

Universal Asynchronous Receiver/Transmitter is used to hook up Arduinos to the computers that program them and also for communication between other devices with the receive and transmit pins. These pins can be used to control our Pi through another computer if the serial console is enabled in raspi-config or to control an Arduino directly if you are not able to use a USB cable for your project.

PWM

Along with these functions, all pins are capable of software PWM while GPIO12, GPIO13, GPIO18, GPIO19 are capable of hardware pulse-width modulation.

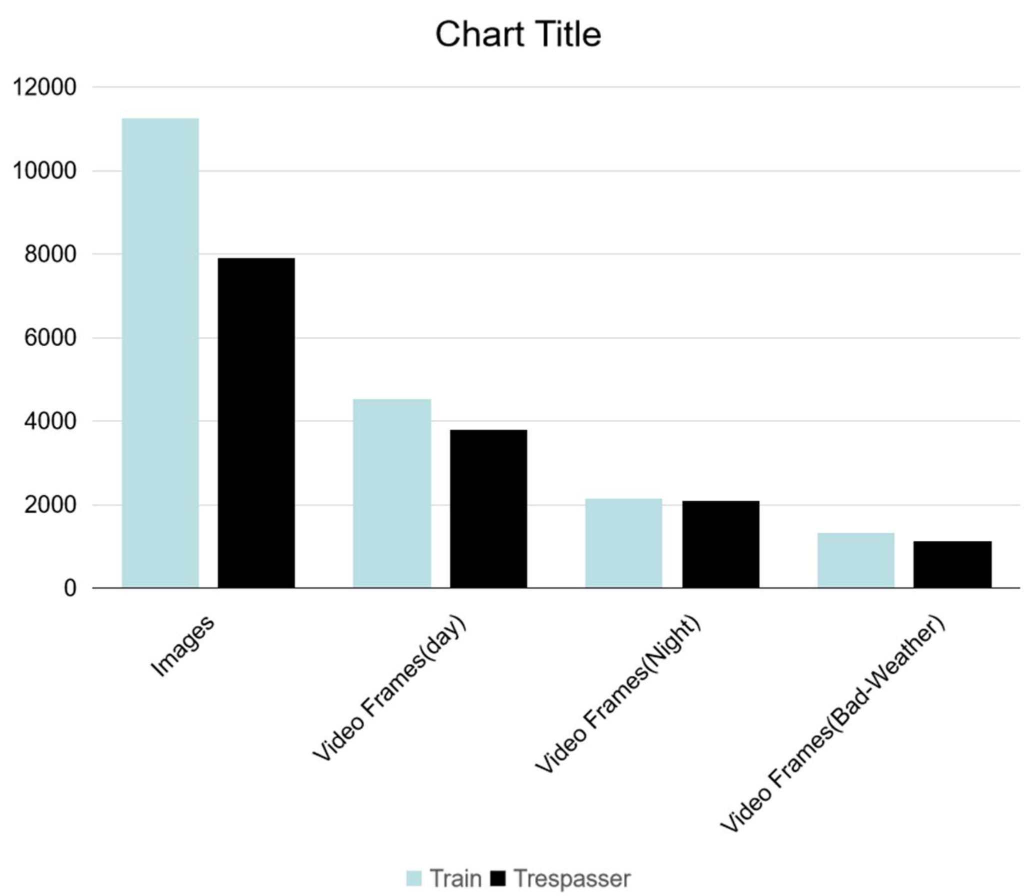
Servo Motor:

A servomotor is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity and acceleration. It consists of a suitable motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servomotors. For this project demonstration we used this motor as this is a cheap and convenient peripheral for our project.

Other Peripherals:

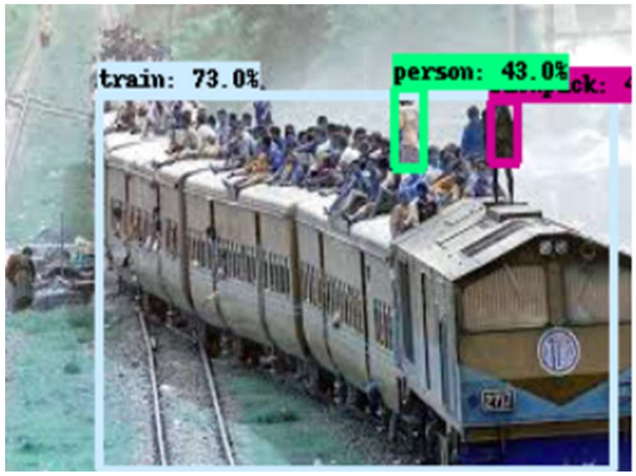
- Basic camera module
- Buzzer / Alarms
- Connecting wires
- Monitor / Laptop to view the micro-controller’s desktop

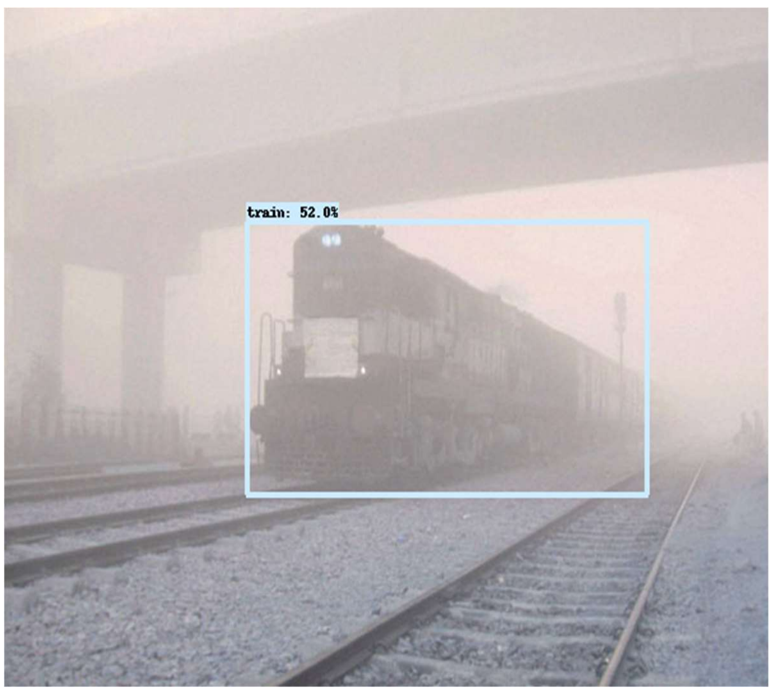
4.2 Setup and Data Collection



4.3 Detection Result

In order to verify the performance and robustness of our model, we have tested it with various images ranging from images of trains, humans, cats , dogs, cars. buses. trucks etc. Some of the extremely challenging images classified and localized perfectly by our model are given below which shows almost human level performance.






train: 52.0%
person: 52.0%


train: 90.0%

4.4 Overall System Performance:

Detection Categories	Number of Analyzed Frames	Detection Accuracy	False Negatives	Inference
Train (Day)	4533	95.6%	49	Human Level accuracy in Video inference
Train (Night)	2158	89.3%	57	Slightly High Bias, more training data needed
Train (Bad-Weather)	1326	88.6%	71	High bias, sensors needed
Trespasser (Day)	3783	91.7%	125	Almost Human Level accuracy
Trespasser (Night)	2078	87.5%	114	High Bias, more Training data needed
Trespasser (Bad-Weather)	1129	81.3%	146	Very High Bias, sensors needed

5. Comparison

Classifications of Protection Systems at Level Crossings

Railway safety is a crucial aspect of rail operation the world over. Malfunctions resulting in accidents usually get wide media coverage even when the railway is not at fault and give to rail transport, among the uninformed public, an undeserved image of inefficiency often fueling calls for immediate reforms. The crossing protection system can be classified broadly into 3 categories (KRCL, 2009):

a) **Manned or operated level crossing protection system:**

In case of Manual operated Level crossing protection system, the man at the gate actuates the Level crossing protection, acts when he receives communication from the signal room by means of a telephone call. Since it is mainly based on human operations, there is every likelihood that it may fail due to human errors. Our project gives a solution to this problem as our proposed system is automated.

b**) Train Sensor Based Automatic Level Crossing Protection System:**

This system is based on Rail wheel sensors viz., Track Circuits, Proximity Sensors etc., which are located at about 2 kms from the Level crossing and provides a time lag for about 2 kms for a bullock-cart in rural areas to cross the Level crossing, but the system has no parameters which make the system cumbersome and available. The system demands extension of power supply to remote places to run long cables from sensor to the system, which is expensive and reduces reliability where our proposed system is cost effective and reliable.

c) **Radio based Level crossing protection system:**

Radio based level crossing protection system, such as ACD (Anti Collision Device) provides safety at level crossings, in addition to other features such as anti collisions on track. This network based radio system keeps communicating with Gate ACD 19 system (either manned or unmanned) and indicates the train arrival by wireless. With this information, Level crossing protection system then start activation by lowering the barrier, flashing the road side lights and sounding alarm bells etc., The Architecture of a typical railway level crossing is given below:

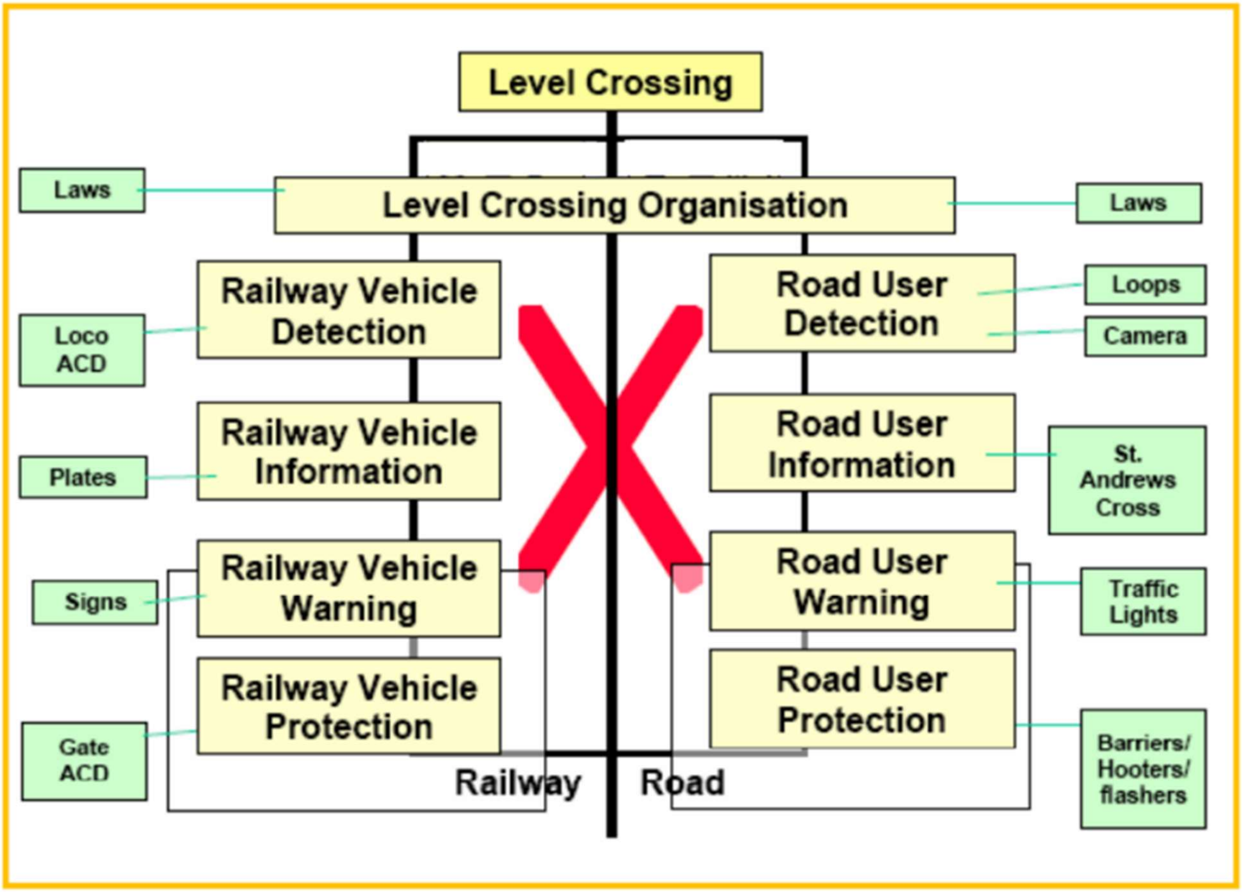


Figure 2.4: Architecture of a Typical Railway Level Crossing (Source: KRCL, 2009)

Currently Available Level Crossing Protection Systems

(a) **Crossing Warning Signals:**

In general, these are of two types: automatic and manually operated signals. Manually activated signals are operated by level crossing staff, on instructions transmitted by telephone or telegraph signal from the nearest station (KRCL, 2009). Automatic warning signals need short track circuits or markers which detect trains and activate warning indications at level crossings. These warning indications are usually flashing lights, or sounds emitted by bells or claxons (horns), or a combination of these two. If visibility at a crossing is a problem, then flashing lights may be increased in intensity and may be installed so as to suit the layout of the surrounding land and buildings. Similarly, audible-warning devices may be increased in frequency and amplitude, to compensate for the sound absorption qualities of the physical environments of level crossings. From experience, the level of safety afforded by these devices on their own is insufficient. This is particularly true in the case of level crossings accommodating two or more tracks. If unmanned level crossings are to be contemplated in these situations, then some form of train approach indication becomes very essential.

(b**) Mechanical Crossing Barriers:**

Mechanical crossing barriers are operated by level crossing staff using hand or electrically powered levers, winches or windlasses. In addition, mechanical barriers providing complete protection of level crossings are connected to manually operated warning signals. Combination systems of this type are widely used within the developing countries of Asia since they may be manufactured inexpensively within the region. By contrast, automatic electronic crossing devices are wholly manufactured within developed countries and must be imported at substantial cost for installation within the developing countries of the region. There are three main types of mechanical barriers: lifting booms, swinging booms or gates, and trolley gates. Of these types, the trolley barrier provides the most effective form of protection against break-through by heavy goods vehicles. However, of necessity trolley barriers are of heavy construction and are best deployed by means of remotely controlled electric motors. This type of barrier is used at a major level crossing intersection in Hanoi, Vietnam. Swinging type barriers afford a generally greater level of protection than lifting barriers against breakthroughs, but particularly when installed at double track level crossings they must be equipped with efficient locking systems.

(c) **Train Detectors**

Automatic devices of this type detect the presence and speed of a train in block sections at the approach to a level crossing. They are installed only near unmanned level crossings and usually consist of a series of transponders inserted in track at certain intervals and interlocked with level crossing barriers and warning signals. Such devices must be capable of detecting train speeds since the elapsed time between a train's detection and its arrival at a crossing will be a function of its speed. The alternative to installation of automatic train detectors is to have train starting signals at stations interlocked with level crossing barriers and warning signals. These signals have the capability of identifying the type and hence speed of different trains and will transmit the appropriate signal to the level crossing protection system in order to activate it at a specified time before the arrival of a train. In the case of manned level crossings the function of the train detector is substituted by level crossing staff, who receive advance warning by telephone or telegraph from the nearest station of the arrival of a train.

(d) **Obstruction Warning Devices for Level Crossings:**

These types of devices are generally installed at unmanned level crossings. Their function is to provide signal warnings to train drivers when level crossings are blocked by motor vehicles or other obstructions. They mainly consist of phototubes, supersonic wave emitting devices or laser beam transmitters which detect obstructions on crossings and are interlocked with distant signals before level crossings. When activated by the presence of obstructions (e.g. stalled motor vehicles), they transmit a flare indication to distant signals via short track circuits, allowing train drivers to apply emergency braking and to stop their trains short of the crossing.

(e) **Automatic Crossing Barriers**

These have multiple functions, including provision of:

- a physical barrier to prevent or (perhaps more realistically) to dissuade motorists from entering a level crossing into the path of an oncoming train;
- a crossing warning signal, indicating the presence of a level crossing;
- a train approach indicator warning of oncoming trains; and
- a crossing failure indicator warning of mechanical or electrical failure of level crossing equipment.

If desired, train detectors and obstruction warning devices based on a phototube system may be connected to automatic crossing barrier mechanisms. There are many types of automatic level crossing barriers, the most commonly used types being swinging or lifting booms. Automatic trolley gates exist and a small number in fact have been installed within the region (mainly in Viet Nam), but in general use of the trolley gate system is restricted to manned level crossings. Automatic swinging boom barriers have a greater number of mechanical parts than automatic lifting boom barriers and thus are exposed to greater risk of spare part shortages. Automatic half barrier level crossings are found in many countries of Europe. This system functions satisfactorily when the road carriageways may be physically segregated. In the case of many two lane rural roads in Europe, however, lane segregation has not been possible and accidents caused by motorists making slalom (or S pattern) moves through half barriers are frequent. Despite the relatively low cost of the half barrier system it has not been widely used in Asia. Indeed, Japan withdrew from use of this system several years ago. To enhance the visibility of barriers to motorists, a number of different methods have been devised including painting in tiger stripes and use of large diameter booms, double booms and high positioned booms (for trucks).

Item	Description	US$
A	Cost of Manual Barrier Installation	
(i)	Capital Cost – lifting barrier with flashing light and block signal	38600
(ii)	Present Annual Value of (i) [15 year life; 12 % discount rate)	5667
(iii)	Annual staffing cost	5682
(iv)	Annual Maintenance Cost (assume 10% of staffing cost)	568
(v)	*Total Annual Cost*	*11917*
B	**Cost of Automatic Barrier Installation**	
(vi)	Capital Cost – Automatic Lifting Barrier with flashing Light & Block Signal	53900
(vii)	– Optical Sensor Obstruction Detector	81600
(viii)	– Sub-total	135500
(ix)	Present Annual Value of (viii) [15 years life; 12% discount rate]	19895
(x)	Annual Opening & Maintenance Cost (assume 2 x maint. cost of manual system)	1136
(xi)	*Total Annual Cost*	*21031*
C	Net Cost Advantage for Manual Installation	9114

Table : Financial Comparison of Manual and Automatic Barrier System(Source: KRCL, 2009)

6. Challenges

There are several challenges implementing this project in real life:

- Object detection model will perform poor in certain weather conditions like foggy, heavy rainfalls etc.

- The model will not perform accurately enough at night. Though we may introduce audio signal feeding into our neural network to improve our detection better and more accurate.

- Large scale implementation requires a huge R&D and monitoring.

- Hardware malfunction or software integration can result a major accident.

7. Conclusion

Every year, many lives are lost due to level crossing accidents. The goal of this project was to find a cheap simple solution to this problem. But we have discovered that many other aspects of the Bangladesh Railway system can be automated through deep learning and so the potential is limitless. In the future, we hope to explore these problems further and apply the solutions in real life scenarios.

Link for codes:

https://drive.google.com/file/d/1kUEjSMD-v_77bexs90Gmc8xvrtZ038MA/view