Automated Mask Enforcement

ECE 445 Design Document Spring 2021
Team 29

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1 Introduction

1.1 Problem and Solution Overview

With the current pandemic, masks have become part of the new normal. There are studies demonstrating reduced rates of infection in areas where mask mandates have been implemented [1] as well as the efficacy of masks at blocking droplets [2]. Despite the vast amount of scientific evidence in support of masks, there is still a minority of people in the United States that are vehemently against masks. Groups such as The Free Face Society and Umask America are encouraging Americans to go without masks [3]. According to a Pew Research study, only 65% regularly wear masks when going outside to stores [4]. While most Americans are taking the necessary precautions, there is still a fairly large minority that refuse to follow the guidelines and laws that have been set. These individuals not only pose a risk to themselves but to those around them as well.

Our goal is to create smart locks to keep such individuals out of buildings ensuring the safety of those inside. These systems will use cameras to track individual participants entering a building and detecting if they are wearing masks or not. If it detects approaching mask wearers, it will unlock the door, otherwise it will remain locked thereby preventing persons without a mask from entering.

While many stores and buildings may have an employee stationed at the entrance to monitor mask-wearing of customers who enter the building, this practice poses a risk of infection to the monitor and imposes an additional salary cost. Additionally, for buildings where there are multiple entrances, such an arrangement is not practical.

1.2 Visual Aid

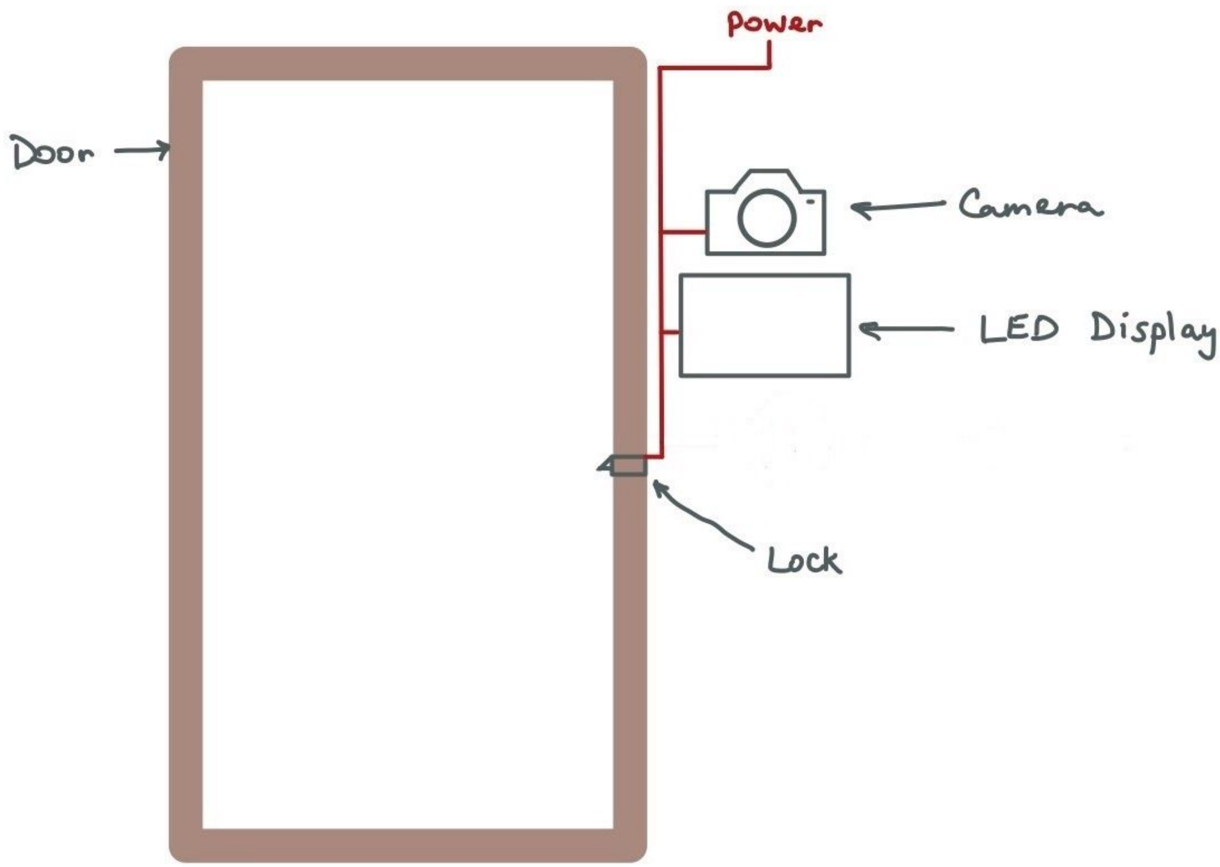

Figure 1. Sketch of Proposed Project

Figure 1 gives a general sense of how our proposed project will look. The door we want this system to attach to will be a single wing door similar to a home exterior door that you may be able to find. We want to have a LED Screen and camera attached to the frame on the side.

1.3 High-level Requirements

- Must be able to detect people not wearing/wearing masks with a test accuracy (# test samples classified correctly/ # test samples) >80% using computer vision with the OpenCV and TensorFlow libraries.
- Recognize someone with or without a mask in under 2 seconds.
- Must be able to detect if multiple people are approaching the door and remain locked if one of them is not wearing a mask.

2 Design

2.1 Block Diagram

Our design consists of five different subsystems: Power, Control, User Interaction, Camera and Lock. The Power subsystem will take input from a 120V AC wall outlet and convert it to 12V DC to power the lock and using a DC/DC converter it converts the 12V DC to 5V DC to power the controller and camera subsystems. The system consists of a microcontroller to take in signals from the camera subsystem and outputs signals to control the lock subsystem. The accelerator module handles the data signals sent to the video interaction module. The lock subsystem consists of a solenoid lock that will lock an unlock based on input from the control subsystem. The camera subsystem will take in video using a camera and feed the footage into an acceleration module that will run our model for detecting faces with mask/no mask. It will then output to the controller. The user interaction subsystem will take input from the controller on whether someone without a mask is present in front of the door. If such an individual is detected the video controller module will load a small video to be displayed on a LCD screen. This entire process is outlined visually in Figure 2.

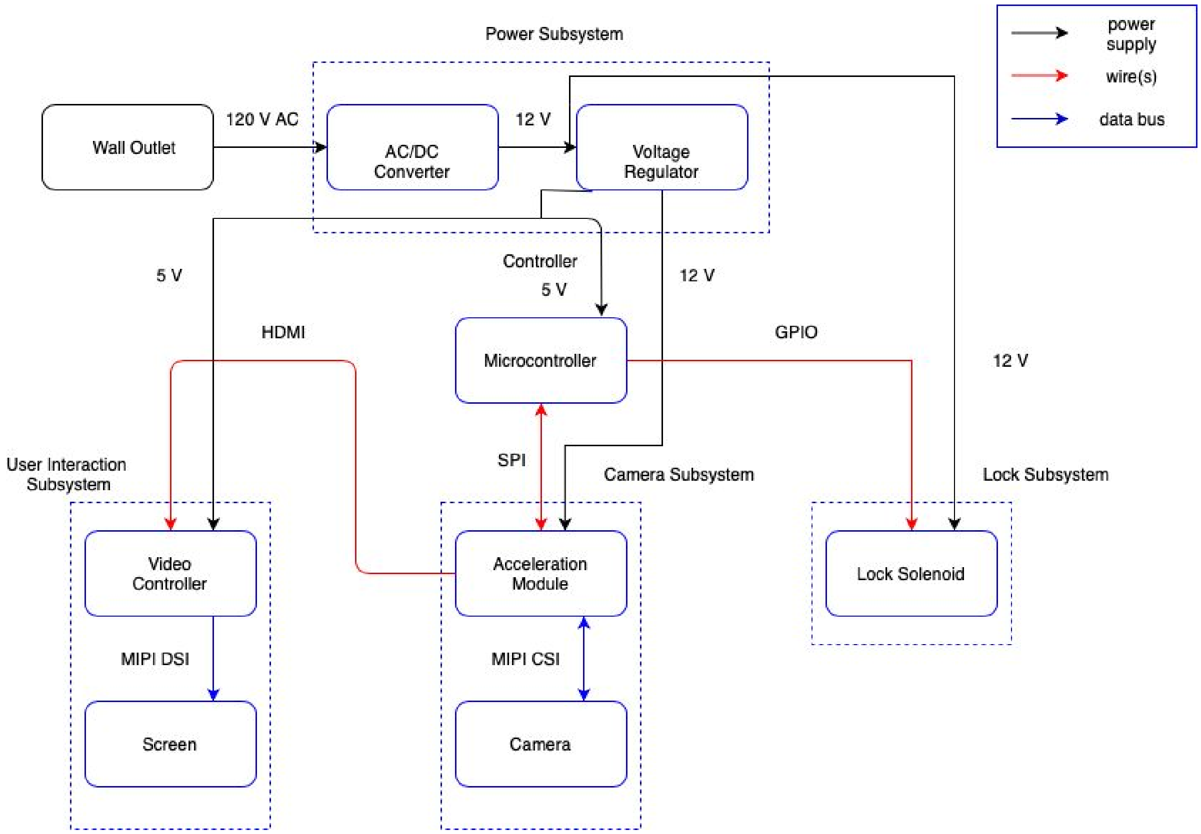

Figure 2. Block Diagram

2.2 Power Subsystem

The power subsystem is required to power all the other components in the system: Control, User Interaction Camera and Lock. The power supply will take in a 120V AC power supply from a wall outlet and use that to generate both a 5V DC and 12V DC power source for the systems.

2.2.1 AC/DC Converter

This AC/DC Convertor will plug into a 120V AC wall outlet and generate 12V DC current as output. The converter will connect to the wall using a NEMA 1-15 wall plug and will give a 12V output using a 2.1mm x 5.0 mm plug.

Requirement	Verification
1. Generate 12+/-0.5V DC voltage from a 120V wall outlet.	1. Check the output of the AC/DC converter on the PCB using a multimeter on test pads.
2. Must be able to power all devices with a current output of 2A.	2. Will use a multimeter to check input to each of the peripheral devices being powered.

2.2.2 Voltage Regulator

We will most likely be using a RECOM DC/DC converter that will take in a 12V DC input and output 5V DC current in return. This will allow us to power the camera subsystem as well as the controller subunit.

Requirement	Verification
1. Must be able to provide 5+/-0.5V with above 600mA from the output of AC/DC converter.	1. Will use a multimeter to test the output voltage based on test pins. We will also use the same multimeter to check incoming current to the camera and control subsystems.

2.3 Camera Subsystem

This subsystem will use a camera to feed live video footage to an acceleration module to be able to detect whether or not they are wearing a mask. This information will then be sent to our microcontroller.

2.3.1 Accelerator Module

This component will run the neural network necessary for detecting whether or not someone is wearing a mask as well as relay this information back to the microcontroller. Our software will first use a Haar feature-based cascade to detect each portion of the footage that possesses a face and draw a bounding box around it. We plan on using the OpenCV library in python and taking advantage of some pretrained models for this task. Using these bounding boxes we will run a convolutional neural network on each of the faces and see if they are wearing a mask or not. We are currently considering taking advantage of pretrained models to complete this task. We are currently thinking of using VGG19 and using transfer learning to retrain it to detect whether or not someone is wearing a mask. Will use the TensorFlow Lite framework for this portion of our software. If we detect faces that are all wearing masks we will signal to the microcontroller to unlock the door. We are considering using a Google Coral mini-dev board for this and taking advantage of the onboard Tensor Processing Unit (TPU) for our project. A TPU is an ASIC optimized for the inferencing stage of machine learning. To train our models we will use a dataset of roughly 12,000 images of masked faces to train our model [5]. For the training phase we will take 80% of our data as a training dataset and another 10% as a validation set. We will train the model on the training set and tune the parameters of our model using the test set. After maximizing our performance on the validation set, we will then test if on the remaining 10% to determine our test accuracy.

Requirement	Verification
1. Be able to detect people within 5 feet of the door.	1. We will have to manually test this ourselves. We will mark spaces that are at distances of 5 feet from our camera.
2. Have a testing accuracy of >80%.	2. We will hold a portion of our data ~10% and then train our model on the other 90% on data. Then we will check how accurate our model is on this held out data.
3. Recognize mask/no mask in under 2 seconds.	3. We will modify our code to show that we can track how long it takes our neural network to classify a prediction. We will also test this manually with several time trials where we wear masks and see how long it takes to detect whether a person is with or without a mask.

2.3.2 Camera

This is a camera that will be used to look at the surroundings and provide real time footage to the accelerator module.

Requirement	Verification
1. Must have sufficient resolution and angle to detect persons approaching the door.	1. We will manually check this on a laptop to see if we can make out persons with our camera.

2.4 User Interaction Subsystem

This subsystem will play a small GIF showing how to wear a mask when the user is not wearing one.

2.4.1 Video Controller

This module is part of the Coral Dev Board Mini that handles the video storage on the dev board and video playback on the LCD Display via a Breakout Board that handles HDMI to MIPI DSI signal conversion.

Requirement	Verification
1. The display's MIPI DSI interface is compatible with the HDMI interface of the Coral Dev Board.	1. Connect the Coral Dev Board Mini to a breakout board which then connects to the 50-pin 4-lane MIPI DSI display

	and ensures that data flow from host and data received by slave traffic is the same.
2. Be able to receive video or GIF and transfer data to display.	2. Store video data in flash memory and check if data shows up on display.

2.4.2 Screen

A display that will take in input from the video controller and play the GIF.

Requirement	Verification
1. The 5 inch TFT LCD display is visible from at most 5 feet of distance.	1. Run a test image on the screen, check the viewing angle at a radius of 5 feet from the display and measure the region for clear visibility for the user.

2.5 Controller Subsystem/Microcontroller

This is the subsystem that will coordinate the other subsystems taking in state signals from the camera subsystem through SPI and controlling the state of the lock solenoid in the lock subsystem through GPIO.

Requirement	Verification
1. Need to be able to take a 2-bit signal using the SPI interface from the acceleration module and send data to the microcontroller.	1. Connect a debugging circuit with 2 LEDs on a breadboard corresponding to the range of values that can be represented by the 2-bit values and check output states.

2.6 Lock/ Solenoid

This subsystem will use a motor to engage and disengage the locking mechanism. It will consist of a solenoid lock. We want this lock to be placed on a single-wing exterior door similar to the door in figure 1. We will drive the lock solenoid with the microcontroller using a diode and a resistor as shown in Figure 3.

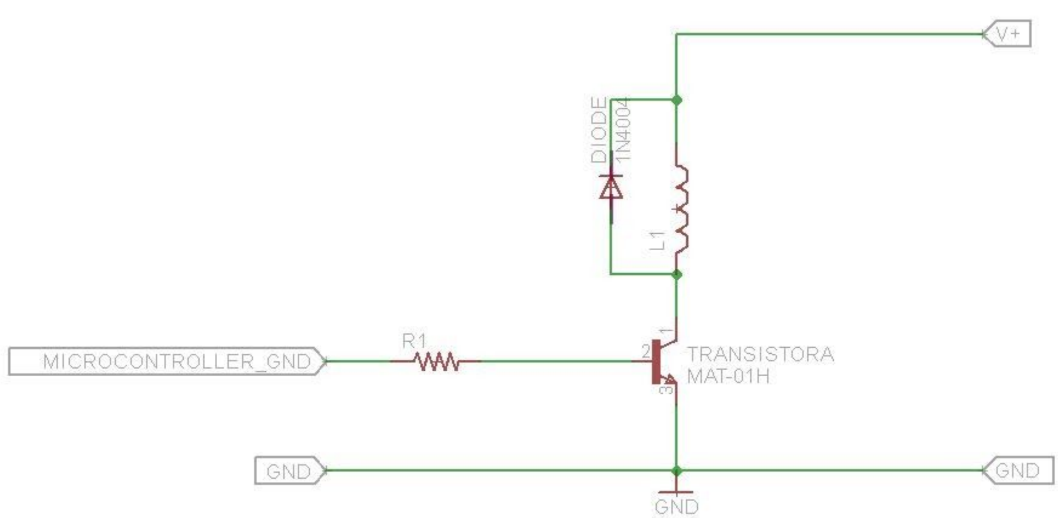

Figure 3. Lock Solenoid Schematic

Requirement	Verification
1. Must have the ability to be switched on and off based on input from the microcontroller.	1. Manually probe using a digital signal from an oscilloscope to see if we can turn the lock on and off.
2. The lock must be compatible with home exterior doors that are one wing.	2. Verify if our lock is compatible with a home exterior door in a building by placing it in a locked state and seeing if it is compatible with the home exterior doors that we have in our vicinity.

2.7 Tolerance Analysis

An important subsystem that requires tolerance analysis is the power subsystem. Our device will be powered by a wall outlet. An adapter will be used to convert 120V AC input to a 12V DC output. The power subsystem will get power from the adapter and distribute it to lock, microcontroller, user interaction and camera subsystems. According to specifications of the adapter, it is able to supply 12+/-0.5V DC [6]. The solenoid valve we will be using requires an input voltage in the range of 9-12 V DC which is within the range of adapter output voltage [7]. Also, the same solenoid lock requires 650 mA of rated current when activated. The specified adapter supplies 2A. Based on the specifications, it should be able to power the solenoid lock by itself. The microcontroller we are planning to use is ATmega 2560. It is a low power high performance microcontroller. It operates between 4.5V-5.5V [8]. Comparing the most power consuming mode, active mode, with the highest frequency, the microcontroller needs 20 mA at most [8]. The camera subsystem we are planning to use is Google Coral Dev Board Mini and Google Coral Camera. The camera is powered by the Coral dev board. Therefore, there is no need for an individual power line for the camera. The ideal operating voltage for the board is 4.5-5.5V [9]. Although it is noted that the power consumption changes according to the ML model being deployed, the maximum power consumption occurred at 3W in the testing phase of the board [9]. Using the power equation,

$$P = V \times I$$

maximum current required is 600mA at optimum input voltage of 5V DC. As a result, we need a back converter that can lower the input voltage of 12+/-0.5V DC to the DC voltage range of 4.5-5.5 V. Also, combining the maximum current from all subsystems (20 mA for microcontroller, 600 mA for camera subsystem), the buck converter should be able to supply at least 620mA. The buck converter we chose has an input voltage range of 9-24 V and output voltage range between 5-5.3V with rated current of 5A.

3 Cost and Schedule

3.1 Labor Cost

During the 2017-2018 academic year the average salary of a Computer Engineer was $93,000 and the average salary of a Electrical Engineer was $78,000 from the University of Illinois. Assuming a 40 hours work week and using the fact that there are 52 weeks in a year, we get an hourly rate of $44.70 and $37.50 for Computer Engineers and Electrical Engineers respectively [11]. We will assume that we work roughly 17 hours a week on the project in question meaning we will have worked 272 hours during the course. We get our labor cost as follows.

Labor Cost

Employee	Hourly Rate	Hours Worked	Labor Factor	Labor Cost
Teja Gupta	$44.70	272	2.5	$30,396
Kalpit Fulwariya	$44.70	272	2.5	$30,396
Faruk Toy	$37.50	272	2.5	$25,500

Part Cost

Part #	Description	Manufacturer	Quantity	Cost
12V2A0823	12V DC Power Adapter	XINKAITE	1	$9.99
732-5930-ND	Power Barrel Connector	Würth Elektronik	1	$0.96
R-78E5.0-0.5	DC/DC Converter	RECOM POWER	1	$2.66
G950-01455-01	Google Coral Dev Miniboard	Google LLC	1	$99.99
138915	USB-C to	Monoprice	1	$5.99

	USB-C			
105450-0101	USB-C Connector	MOLEX	1	$0.95
Sonewfxb8vt90mg	Lock Solenoid	Sonew	1	$10.99
CD4052BE	Analog Multiplexer	TEXAS INSTRUMENTS	1	$0.46
G840-00180-01	Google Coral Camera	Google LLC	1	$19.99
E45RA-MW307-N	LCD Screen	FOCUS LCDs	1	$31.49
KBB5050	50-Pin FPC Breakout Board	FOCUS LCDs	1	$9.00
ATMEGA2560-16AU	Microcontroller	Microchip Technologies	1	$12.44

The cost of parts comes out to $203.63. The cost of labor comes out to $86,292. This brings the total cost of the project to $86,487.51.

3.2 Schedule

Week	Teja	Kalpit	Faruk
3/1	Design Document, Order Google Coral	Design Document	Design Document
3/8	Order Google Coral and Camera. Figure out how to set it up and flash it. Will also need to learn TensorFlow Lite in this period.	Order Microcontroller, LCD Display and breakout board. Verify the MIPI DSI interface on the Display and HDMI compatibility.	Order power subsystem and lock subsystem elements (adapter, buck converter, solenoid lock etc.). Start designing the power subsystem PCB
3/15	Start looking at different datasets that we can use to train our models. Maybe even create our own data using members	Finalize PCB layout for First Round of PCB orders. Verify signal transfer requirements between	Finalize the power subsystem PCB layout for First Round of PCB orders. Verify the parts we received works well.

	of our group. Also start looking into pretrained models and similar projects that other people have done.	microcontroller and dev board.	
3/22	Begin the process of training our model and begin the model selection process	Finalize all verification for microcontroller and user interface subsystems	Solder received PCB and received parts to perform initial subsystem testing
3/29	Continue the model selection process. Start looking into how to relay the information from the board to the microcontroller. See if the board can help with the user interaction subsystem.	Begin integrating microcontroller and user interface subsystems with the other subsystems and perform unit testing	Integrate power subsystem and lock system and test compatibility. Perform tests with compatibility with other subsystem such as microcontroller, camera subsystem and user interaction subsystem
4/5	Investigate edge cases (hand covering mouth, etc.) in our model and tweak our model based on its response to these inputs. This set may require us to purchase additional PPE (face shields, different color masks, etc.)	Assist with testing subsystem integration and camera subsystem model training	Continue testing subsystem integration. Debug problems as they arise.
4/12	Test a fully integrated system and fix any issues that may occur.	Test a fully integrated system and fix any issues that may occur.	Test a fully integrated system and fix any issues that may occur.
4/19	Mock Demo	Mock Demo	Mock Demo
4/26	Final Demo	Final Demo	Final Demo

4 Ethics and Safety Issues

There are several ethical concerns that we need to address with this project. Since our system uses cameras to track individuals, there are many potential ethical concerns that may result from the use of our system.The first is the issue of privacy. Our system uses cameras to track the entrants to a building. This could place us into potential conflict with IEEE code of ethics #1: “protect the privacy of others…[12]”. If someone hacked the camera subsystem we could risk the privacy of our potential clients. To mitigate this risk we will refrain from using wireless protocols for our system. This prevents someone from listening in and possibly recording our users. We could also be placed into conflict with the ACM Code of ethics 1.6 which states, “Only the minimum amount of personal information necessary should be collected in a system. The retention and disposal periods for that information should be clearly defined, enforced, and communicated to data subjects [13]”. To combat this risk we refuse to record any of the participants entering a building and make sure any frames analyzed will only be stored temporarily. We will also ensure that no facial recognition is being run over the video data to prevent further privacy violations.

Another issue that we may run into is unintentional racial discrimination. Since a lot of the data we use to train the camera subsystem may be biased to people of a particular racial group, in this case East Asian people, our system may not work as well when detecting people of other races. This might place us into conflict with IEEE code of ethics #7: “ to treat all persons fairly and with respect, and to not engage in discrimination based on characteristics such as race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression [13]”. This same principle may also place into conflict with the people who may possess some sort of facial disfigurement or disability for the same reasons.

There are also several safety concerns that need to be considered as well. With the system we have in place we will not be able to detect people who are wearing masks incorrectly. For example, if people are not covering their nose, our system could potentially let them into the building, posing a risk to everyone that is inside. Another risk is if our system misidentifies people without a mask and lets them into a building. Both of these scenarios would be a violation of the IEEE code of ethics #9 “avoid injuring others [13]”. To prevent the first risk, there is a simulated dataset of people wearing masks incorrectly that we could potentially use. Since it is simulated, there is most likely a high rate of error when dealing with actual mask wearers. There is no easy way to prevent the second risk aside from doing everything to ensure our classifier has a low error rate on real-world samples.

Electrical hazards pose another issue. Since our product will be powered by 120 V AC wall electricity, we must exercise caution. We will implement our product so that it will satisfy all the safety standards put in place by OSHA [13]. Our device might be installed outside of a building. Therefore, weather plays a big role in our safety considerations. If there is a heavy rain outside, water can leak into the product and cause short circuits. This would not only damage the product, but also it can possibly create a fire in the building. To combat this risk, we will be using a water proof casing around our product.

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