North Carolina Agricultural and Technical State University

Integration of Machine Learning in Autonomous Devices

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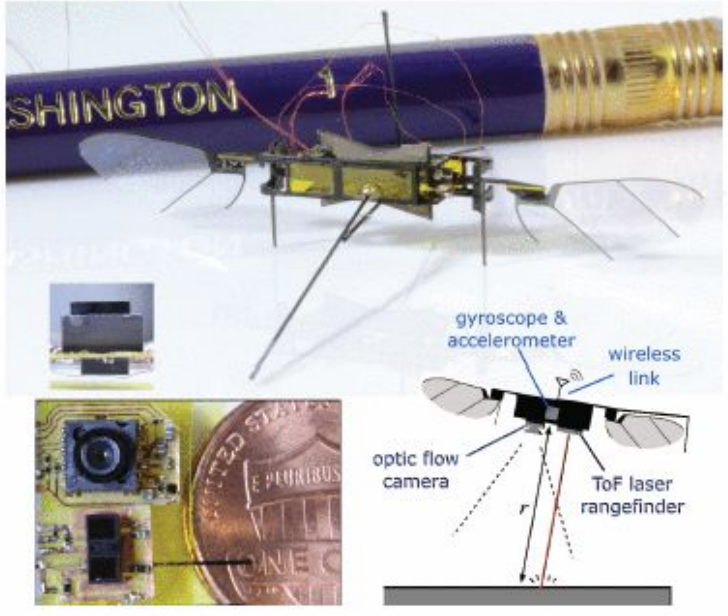
Mentor: Dr. Daniel Limbrick

AGGIES DO

Introduction

Small Scale Autonomy

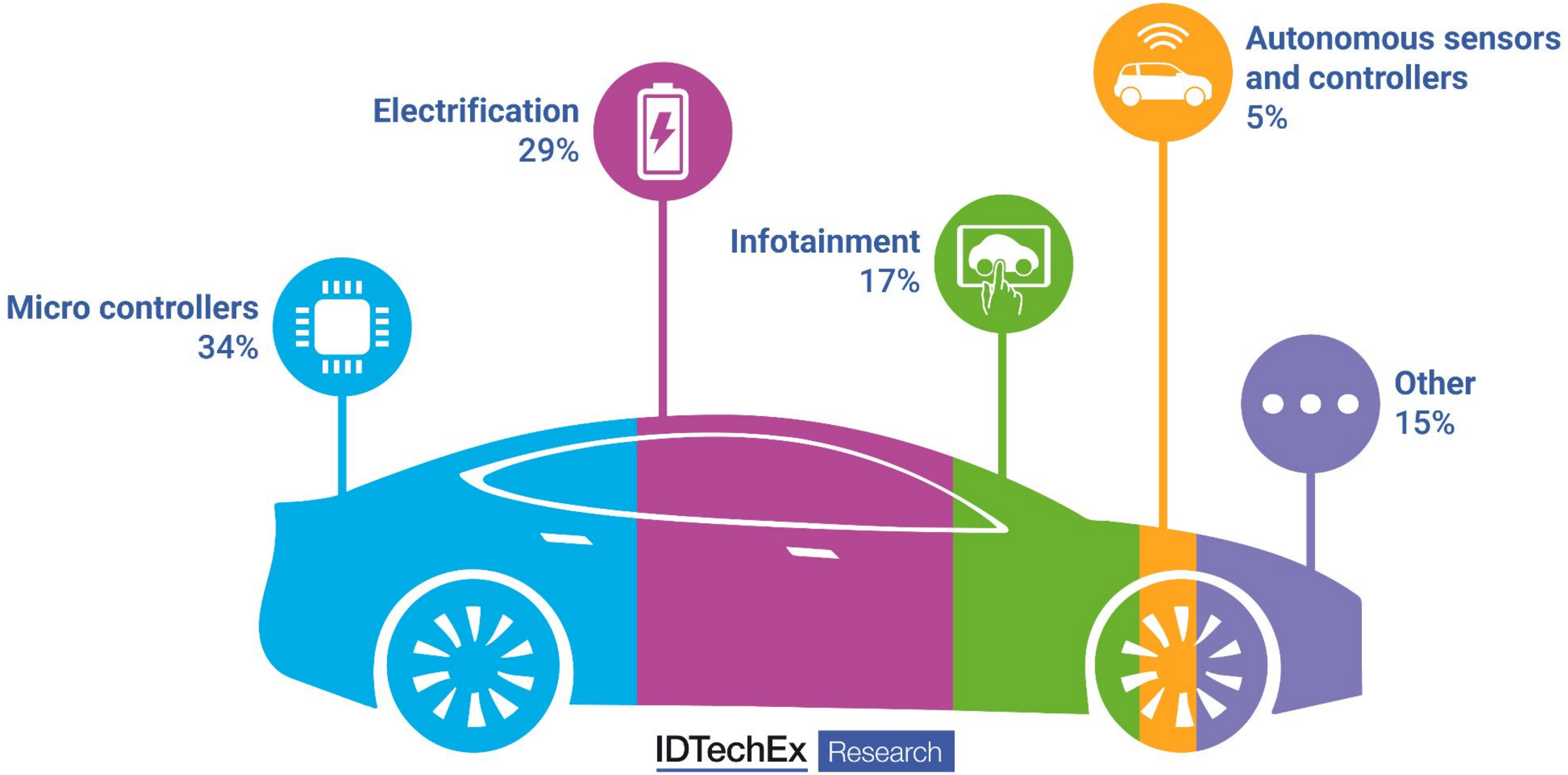


[1] Marshall, A. (2019, October 5). These small cars can help drive the Autonomous Future. Wired. https://www.wired.com/story/small-cars-help-drive-autonomous-future/

[2] Sidhartha. (2016, December 8). Different applications of Microcontroller. VLSIFacts. https://www.vlsifacts.com/different-applications-microcontroller/

[3] Y. P. Talwekar, A. Adie, V. Iyer and S. B. Fuller, "Towards Sensor Autonomy in Sub-Gram Flying Insect Robots: A Lightweight and Power-Efficient Avionics System," 2022 International Conference on Robotics and Automation (ICRA), Philadelphia, PA, USA, 2022, pp. 9675-9681, doi: 10.1109/ICRA46639.2022.9811918.

Semiconductor Distribution in a Tesla like Vehicle



Dipert, B. (2023, May 11). The importance of Tesla's full transition to in-house controller design. Edge AI and Vision Alliance. https://www.edge-ai-vision.com/2023/05/the-importance-of-teslas-full-transition-to-in-house-controller-design/

Motivation

- Cost-effective and accessible platform for autonomous vehicular experimentation
- Low power consumption of microcontrollers
- Utilization of machine learning and deep learning
- Testing for faults on microcontrollers with fault injection studies
- Desire for a search and rescue (SAR) robot

Minority Report (2002) Spider Robots

Starship Autonomous Delivery Robot

Summer Research Objectives

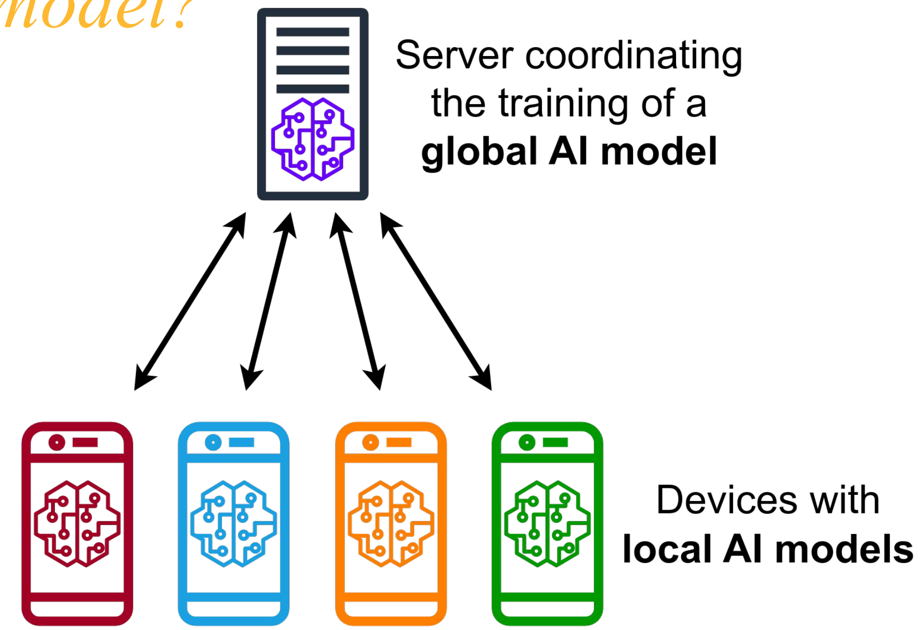
- Create a prototype highlighting each major area of interest
  - Federated Learning
  - Autonomous Motion
  - Object Recognition
- Create foundational proof of concept for a SAR robot
- Learn from collected data to form reasonable solutions

Federated Learning

Federated Learning

How will Federated Learning benefit our model?

- What is Federated Learning?
- Modern examples
  - Face recognition
  - Voice recognition
  - Word prediction
- Centralized vs. decentralized Models
- Advantages and disadvantages



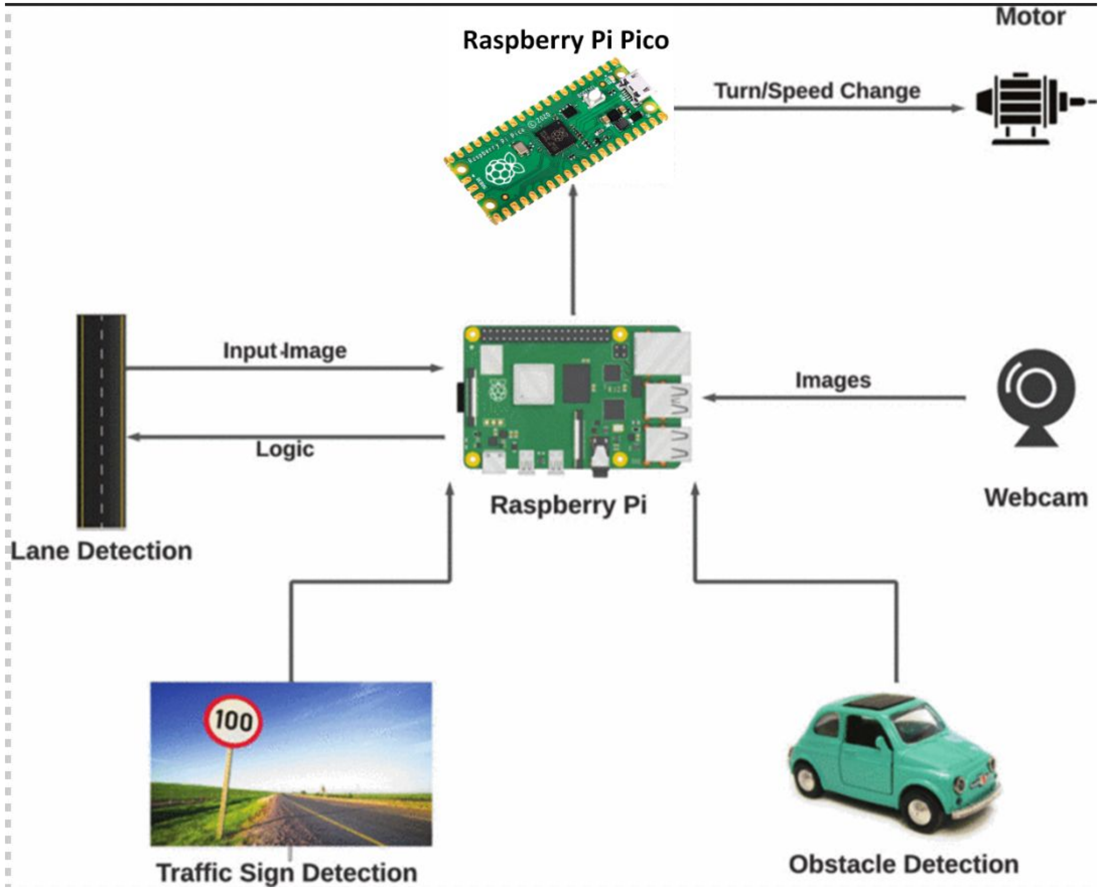
Model Deployment in SAR Prototype

Communication within and between SAR bots

- Centralized Aspect
  - Host server will be in charge of coordinating training
  - Pico will send real time data to the server (Multiple)
  - Model will be created by server and sent back to Pico devices
- Decentralized Aspect
  - Each individual SAR robot will communicate with each other
  - Data will be molded by the individual bots themselves
  - Provides unique form of communication

Training Methods

- Using the RPi 4 as the host server
- Using the Pico as the client/controller
- Federated Learning
  - A model is trained on the Pico and that model will be sent to the RPi 4



Modified from [A Self-Driving Car Platform Using Raspberry Pi and Arduino](#) [1]

[1] V. Shahane, H. Jadhav, M. Sansare and P. Gunjgur, "A Self-Driving Car Platform Using Raspberry Pi and Arduino," *2022 6th International Conference On Computing, Communication, Control And Automation (ICCUBEA*, Pune, India, 2022, pp. 1-6

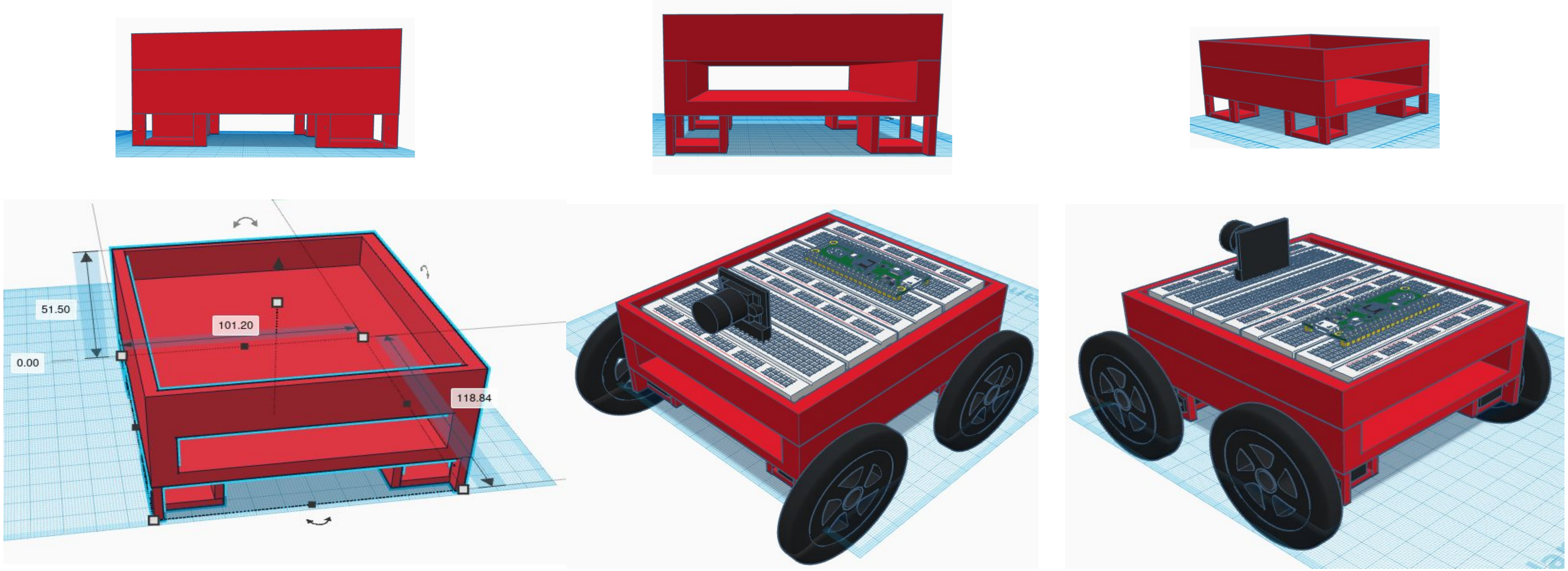
Autonomous Motion / Self-Driving

Implementation of the Pico

Usefulness within small-scale car and beyond

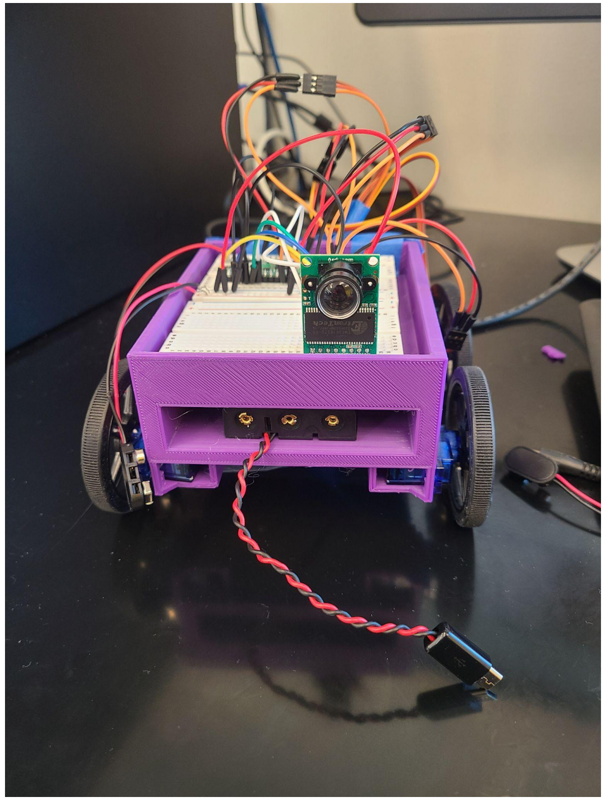
- Explore the accessibility of the Raspberry Pi Pico
- Allow Pico device to efficiently maneuver in various situations
  - Difficult terrain
  - Foreign Objects
  - Groups of People
- Feasibility of microcontrollers
- How does this relate to a SAR robot?

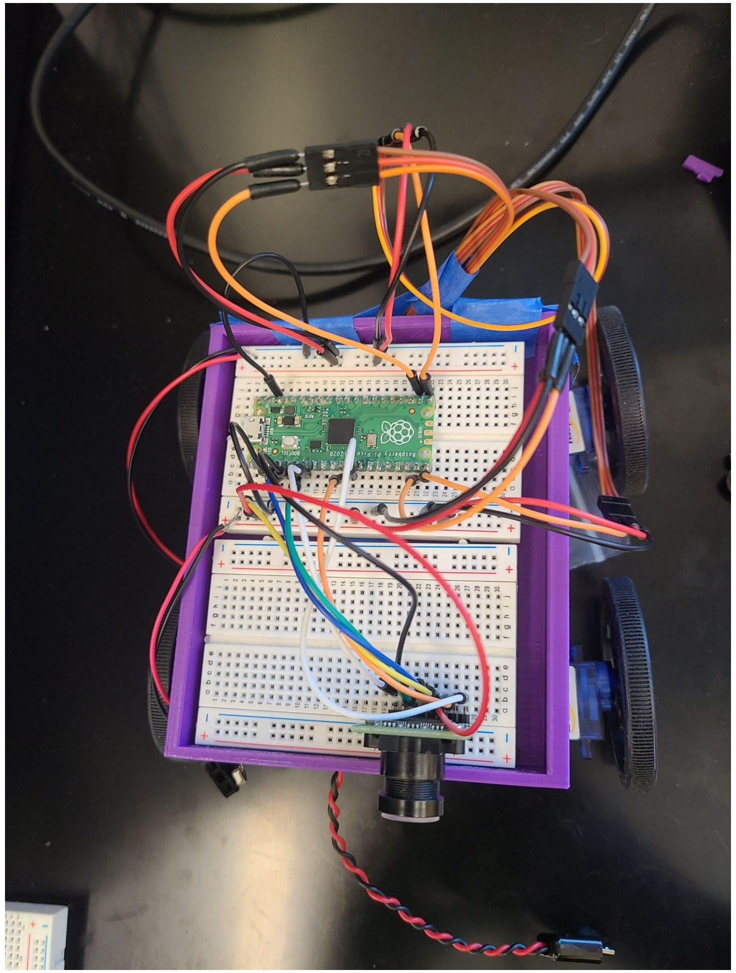
Motion/Self-Driving

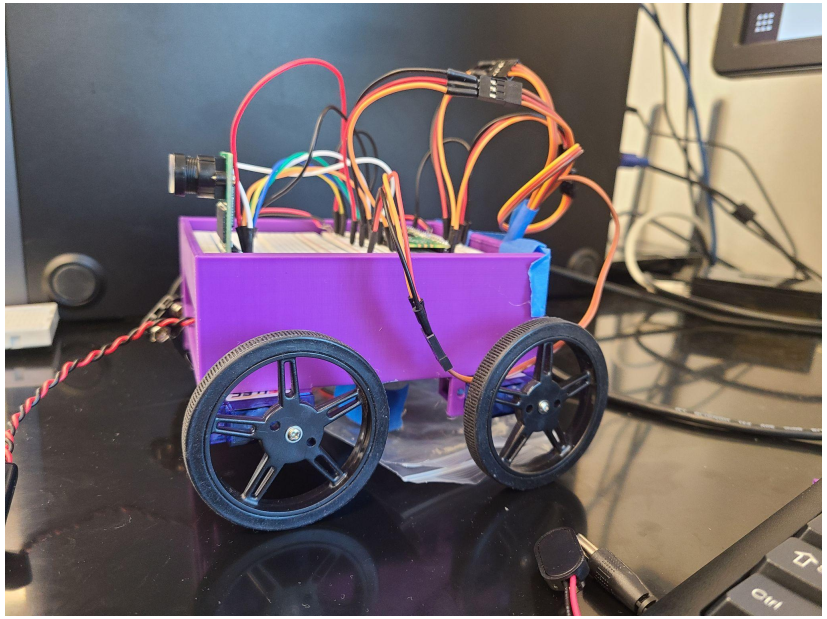


Screenshots created and obtained from TinkerCAD

Motion/Self-Driving







Front, Top, and Side views of Model

Materials

- Raspberry Pi Pico & Raspberry Pi Pico W
- Arducam Mini 2MP
- USB to TTL Adapter
- 4 FS90R Continuous Servo Motors
- 4 Wheels
- 2 Breadboards
- 2 9V Batteries
- 3 AA Battery Holder with Micro USB Connector

Part	Raspberry Pi 4	Raspberry Pi Pico
CPU	BCM2837 4x Cortex-A72@1.5GHz	RP2040 2x Cortex-M0+@133MHz
Memory	48BK(I)/32KB(D) L1 cache 1MB L2 (16-way) L2 cache 4GB LPDDR4	264KB SRAM
Storage	8GB+ micro-SD	2MB Flash
Power	3A	<100mA

Figure from DeepPicarMicro: Applying TinyML to Autonomous Cyber Physical Systems [1]

[1] M. Bechtel, Q. Weng and H. Yun, "DeepPicarMicro: Applying TinyML to Autonomous Cyber Physical Systems," 2022 IEEE 28th International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA), Taipei, Taiwan, 2022, pp. 120-127, doi: 10.1109/RTCSA55878.2022.00019.

Motion Moving Forward

Autonomous Application

- Key Challenges to improve upon
  - Power consumption/ performance
  - Consistency of wheel rotation
- Making machine learning the focal point of directional maneuverability
- How will this help in a search and rescue environment?

Object Recognition with Camera Module

Introduce Object Rec. here

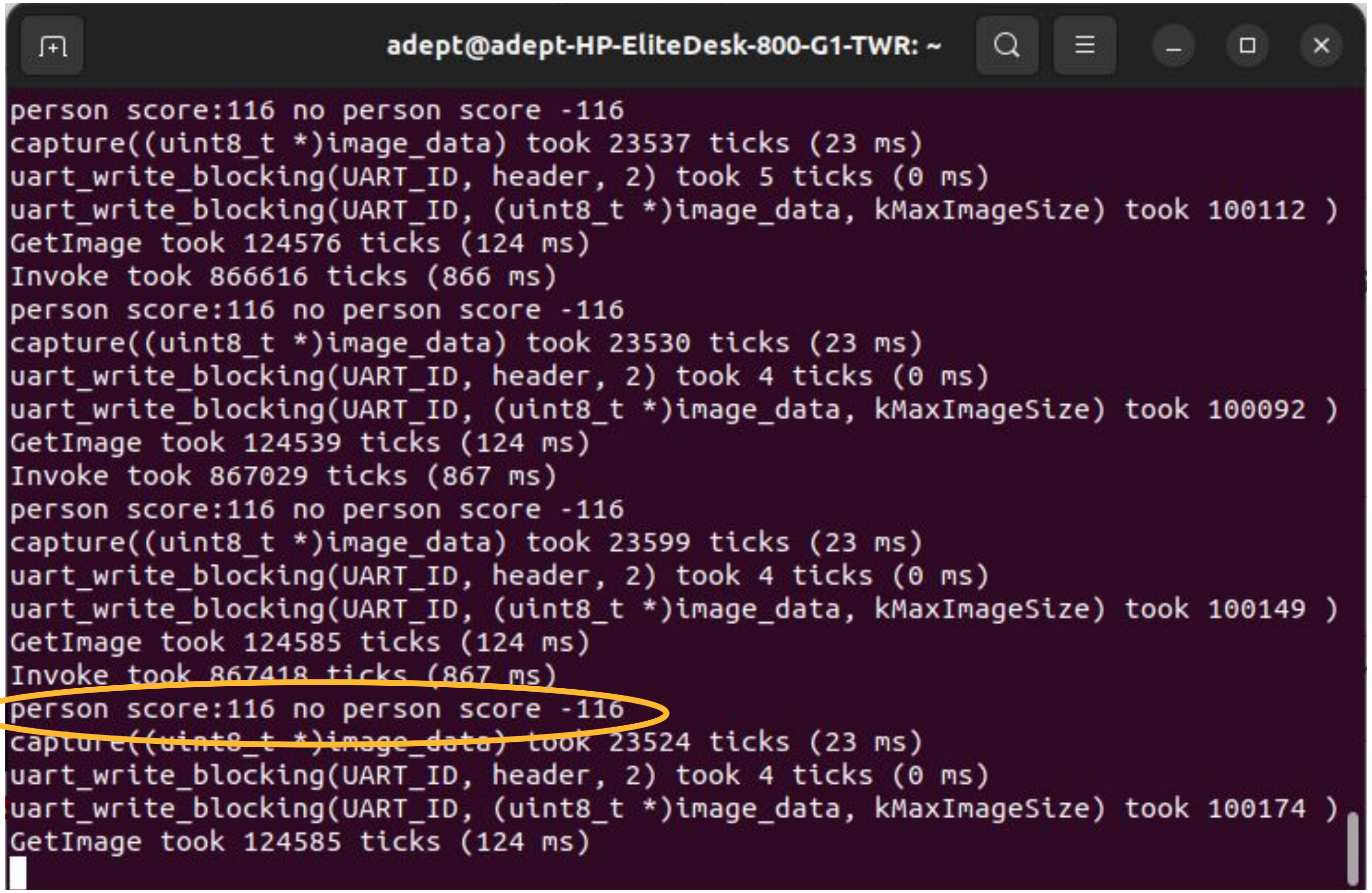
- Goal of this particular topic
- What we want our prototype to be able to do
- Specific deliverables and needs for the detection

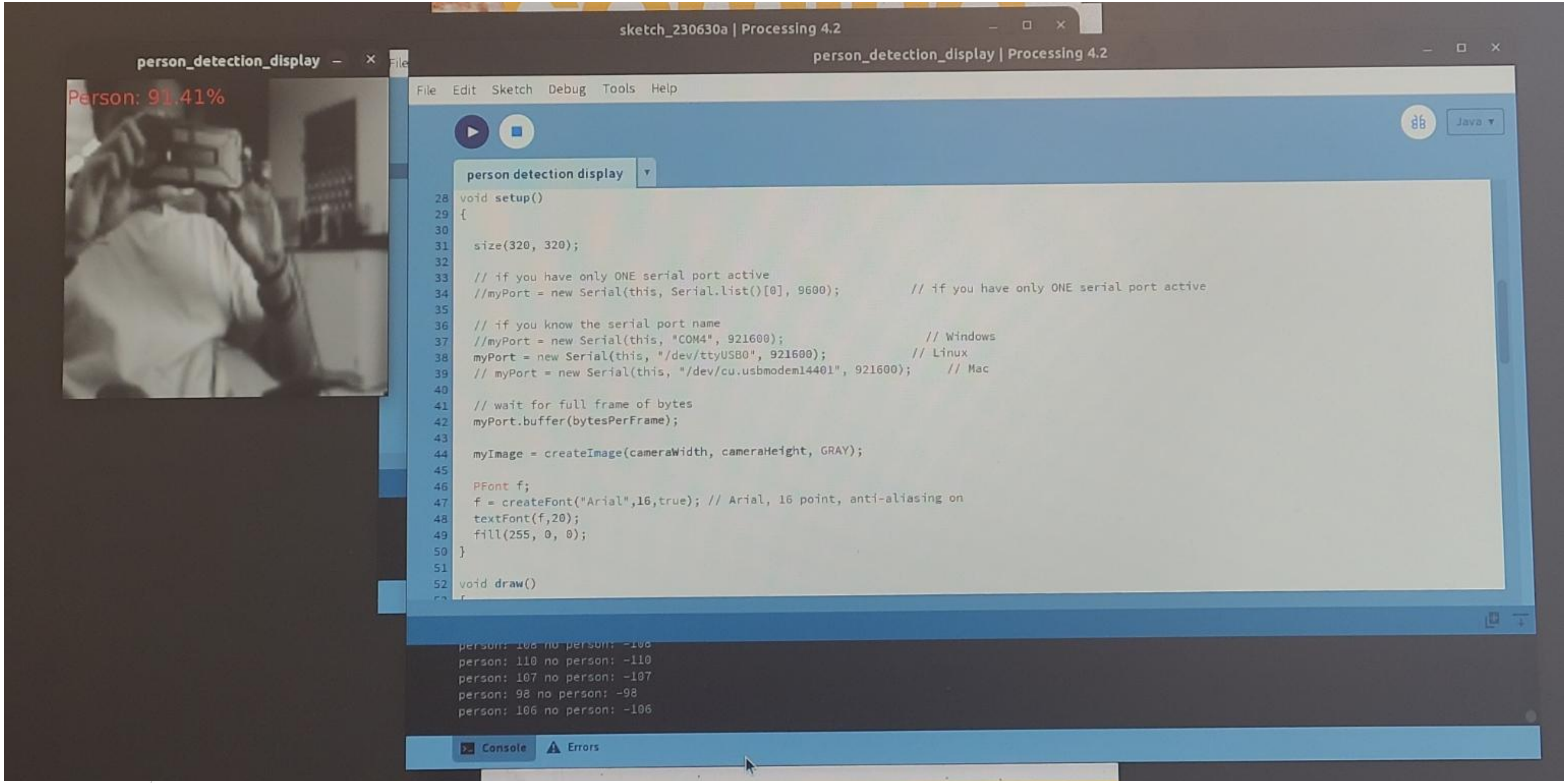
Object Recognition

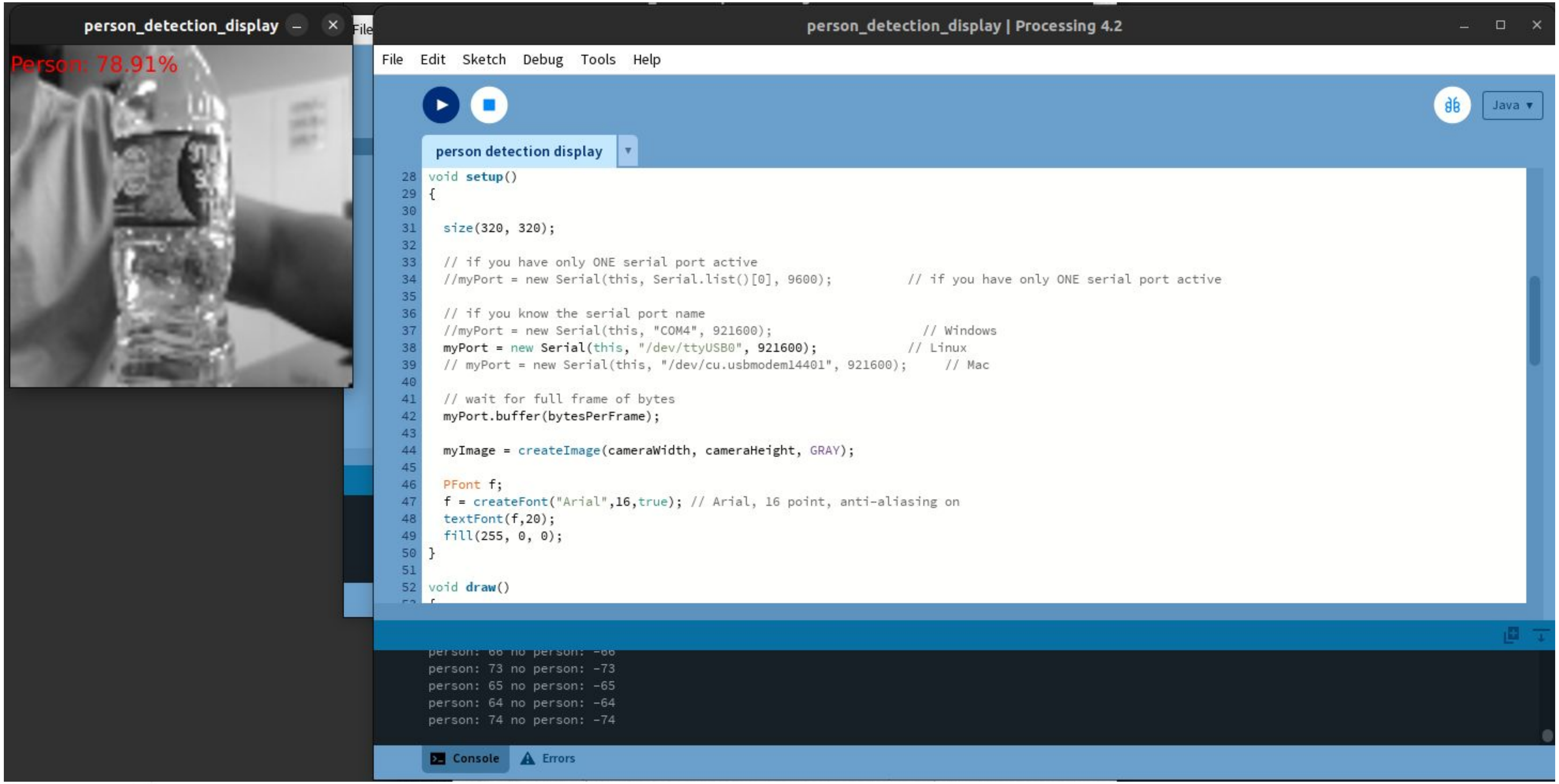
- Goal - achieve maneuverability around objects in the same way that an ultrasonic sensor would
- What do we want our prototype to be able to do?
- Deliverables
  - Camera Module (ArduCAM Mini 2MP)
  - Object Detection Model (TensorFlow Micro Lite)
  - Code

Object Recognition

- OpenCV
- TensorFlow Lite Micro
- PyTorch




sketch_230630a | Processing 4.2
person_detection_display
Person: 91.41%
person_detection_display | Processing 4.2
File Edit Sketch Debug Tools Help
Java
person detection display
void setup()
{
size(320, 320);
// if you have only ONE serial port active
//myPort = new Serial(this, Serial.list()[0], 9600); // if you have only ONE serial port active
// if you know the serial port name
//myPort = new Serial(this, "COM4", 921600); // Windows
myPort = new Serial(this, "/dev/ttyUSB0", 921600); // Linux
// myPort = new Serial(this, "/dev/cu.usbmodem14401", 921600); // Mac
// wait for full frame of bytes
myPort.buffer(bytesPerFrame);
myImage = createImage(cameraWidth, cameraHeight, GRAY);
PFont f;
f = createFont("Arial",16,true); // Arial, 16 point, anti-aliasing on
textFont(f,20);
fill(255, 0, 0);
}
void draw()
person: 110 no person: -110
person: 107 no person: -107
person: 98 no person: -98
person: 106 no person: -106
Console
Errors


person_detection_display
Person: 78.91%
person_detection_display | Processing 4.2
File Edit Sketch Debug Tools Help
Java
person detection display
void setup()
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size(320, 320);
// if you have only ONE serial port active
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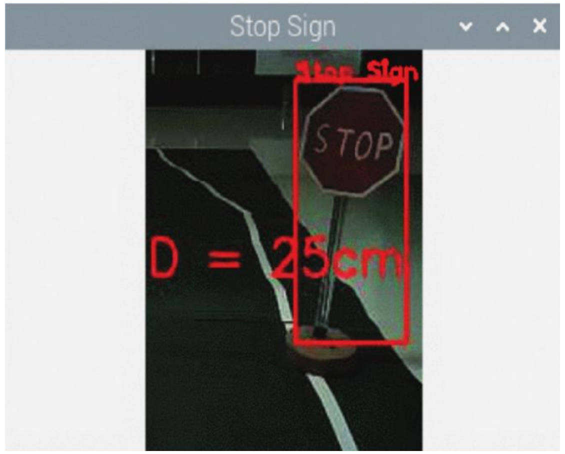
textFont(f,20);
fill(255, 0, 0);
}
void draw()
person: 73 no person: -73
person: 65 no person: -65
person: 64 no person: -64
person: 74 no person: -74
Console
Errors

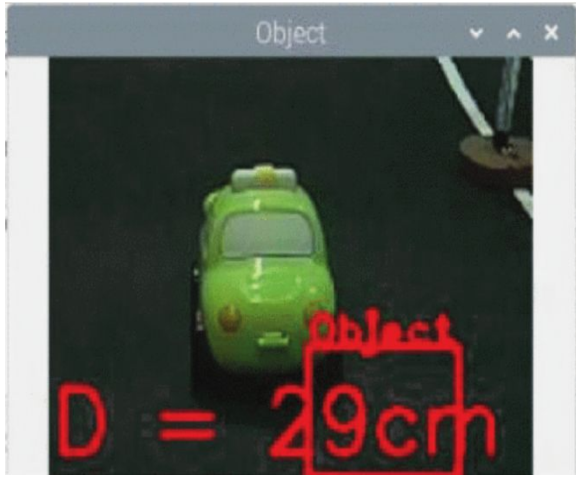
Traffic Sign Detection

- Method would allow the vehicle to come to a stop at a stop sign
- CNN - PilotNet

Obstacle Detection

- Detects any obstruction in front of the vehicle and the vehicle will take appropriate action to evade that obstruction
- The system detects the distance between the vehicle and an object
- HAAR Cascade





Figures from [A Self-Driving Car Platform Using Raspberry Pi and Arduino](#) [3]

[3] V. Shahane, H. Jadhav, M. Sansare and P. Gunjgur, "A Self-Driving Car Platform Using Raspberry Pi and Arduino," *2022 6th International Conference On Computing, Communication, Control And Automation (ICCUBEA*, Pune, India, 2022, pp. 1-6

imagenet/mobilenet_v3_large_075_224/classification/5/metadata

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Drag/click to upload image

Results Latency: 47ms

Type	Score
street sign	12.216
traffic light	7.385
cinema	6.568
parking meter	6.406

Embed

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Results Latency: 881ms

Type	Score
street sign	9.181
traffic light	5.273
chainlink fence	5.001
birdhouse	4.253

Embed

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Results Latency: 43ms

Type	Score
pomegranate	7.889
buckeye	6.386
bell pepper	4.868
fig	3.936

Embed

imagenet/mobilenet_v3_large_075_224/classification/5/metadata

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Results Latency: 32ms

Type	Score
hand blower	10.198
microphone	7.022
spotlight	6.204
power drill	5.882

Embed

Input Image

Model Predictions

street sign

street sign	86%
traffic light	3%
cab	2%
barbershop	1%

Grad-CAM

Input Image

Model Predictions

street sign

street sign	86%
traffic light	0%
mailbox	0%
chainlink fence	0%

Grad-CAM

Image

Model

tf_efficientnet_b0

Clear

Submit

output

street sign

street sign	93%
traffic light	1%
mailbox	0%

Image

Model

tf_efficientnet_b0

Clear

Submit

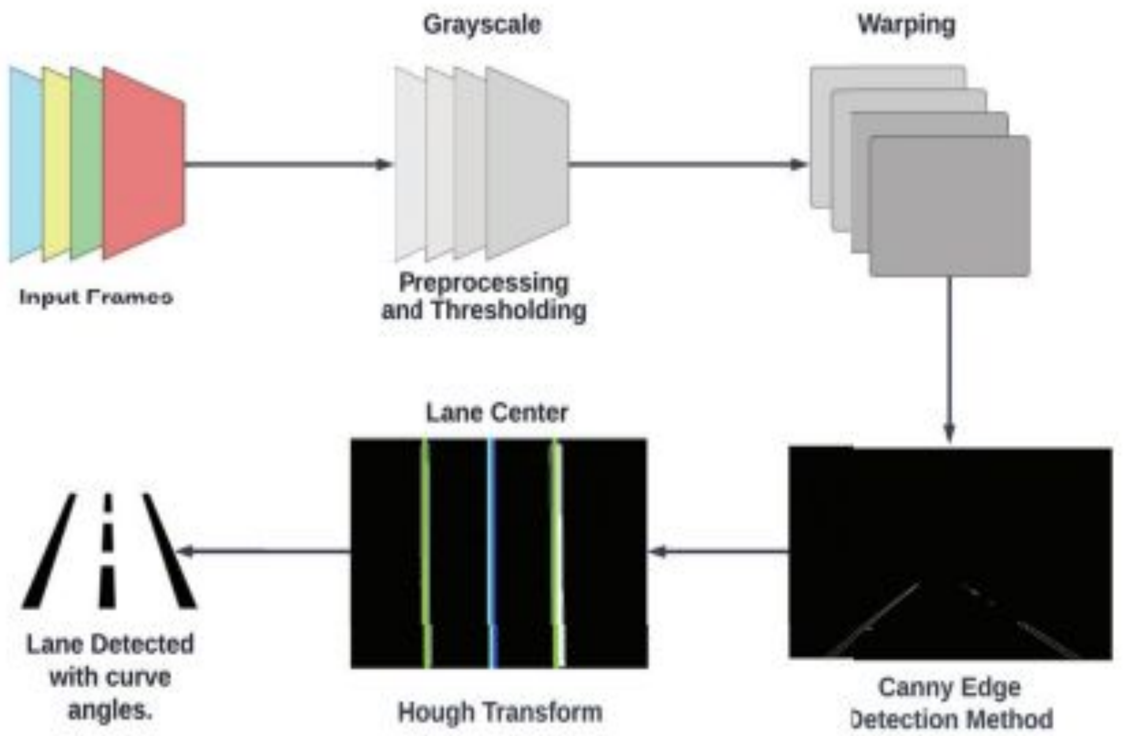
output

street sign

street sign	89%
traffic light	3%
library	1%

Lane Detection

- Input from camera module
- Grayscaling and warping images to isolate lanes
- Hough transform to differentiate outer and inner lanes



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Having the self-driving car stop when the camera module detects a stop sign

Must get images of environment, i.e. printed traffic signs, random obstructions, or random objects in the room

Combining the details of TSD, OR, LD, etc…

- Take the info from traffic sign detection, lane detection, and object recognition and combine it over the next few slides to support the idea of having a small device that can seek out objects
- Ex.
  - Use the Hough transform from lane detection to explain how a device could differentiate the colors of pixels to isolate different objects
  - Use CNN- PilotNet to explain why the device would come to a stop when it finds its desired target or destination
  - Use HAAR Cascade to explain how the device could maneuver around objects in it’s way

Conclusion

Next Steps

- Currently implementing Raspberry Pi 4 as host server
- Goal of training exclusively on Raspberry Pi Pico W
- Making a second model of the autonomous car model for federated learning
- Creating a miniature city for the car model to maneuver and navigate through