IoT Lab 0: Intro to IoT Devices

Preliminary Due Date (subject to change): end of 1st week of class

Tasks You Will Perform In This Lab

- **Overview and Background [No submission required]**
  Get familiar with the IoT Devices that you will be working on.
- **What to Purchase [Submission required]**
  Purchase necessary hardware for future Lab assignments. (Start early! Some parts may take more than 1 week to arrive.)
- **Group Formation [Submission required]**
  Form a team with up to 4 people. Working in a team is not required but strongly encouraged.

Lab Overview

Modern cars are no longer just engines and tires. Inside of them are highly sophisticated computer networks, controlling and monitoring an array of sensors, machine learning and computer vision algorithms, performing mathematical computations to keep you and your passengers maximally safe in every contingency and danger that arises.

In this class, we will guide you to gain experience with Internet of Things devices. You will do this by implementing a 2023 Tesla Model S. In particular, you will be implementing a vehicular network, navigation systems, and computer vision infrastructure comparable to a simplified version of the 2023 Tesla Model S. To save on costs, we won't be building a life-sized car, we'll build something smaller (and simpler!). But don't be fooled though - your infrastructure will share several key capabilities with real car platforms, performing real-time communications within the automobile to perform life-saving features such as obstacle avoidance and lane departure mitigation. Doing this will give you experience in programming IoT components, as well as teach you about vehicular networks, an emerging powerful use case for IoT.

Background on Self-Driving Cars

To help provide some context for our work, and to teach you more about vehicular IoT in general, in this section, we give some background on autonomous vehicle design. We start out by giving a functional overview of the internals of an autonomous vehicle.

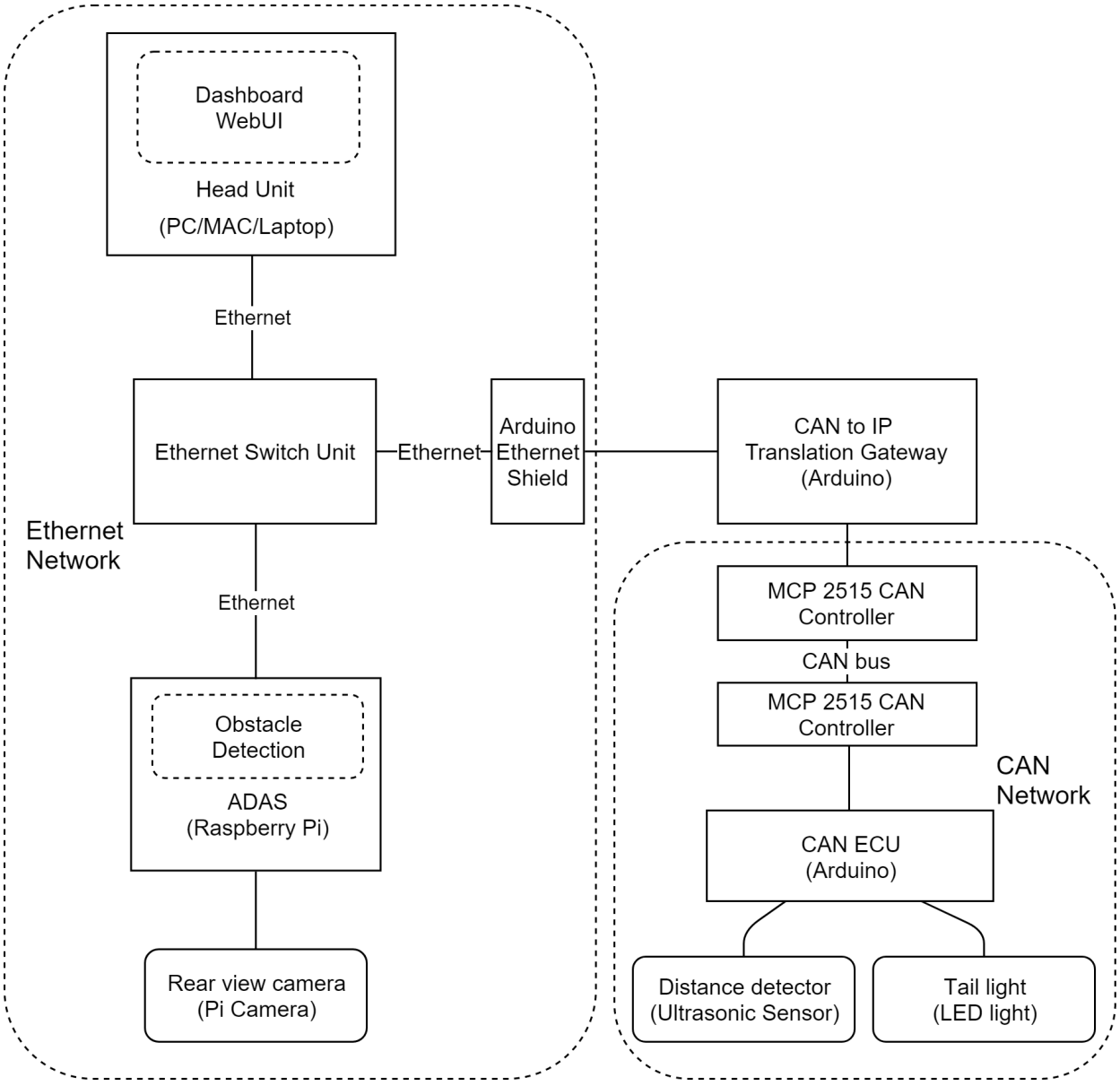

Figure 1: Overview of how intra-vehicular networks are built in real cars (you'll be building a simplified version of this in the next section -- keep reading). The parenthetical marks denote comparable IoT components that could be used to emulate the corresponding

components (real cars don't use Raspberry Pis and such, but they do use microcontrollers/processors and such that provide similar functions).

A typical vehicular network (shown above) consists of a Head Unit, an Ethernet Switch Unit (ESU), an Advanced Driver-Assistance System (ADAS), Engine Control Units (ECU), Sensors (Like Ultrasonic sensors and Lidars), an Ethernet Network and a CAN[1] (Controller Area Network). A CAN is a network within the car, providing a means of communication between the various sensors and microcontrollers in a distributed fashion without the need for a dedicated head computer. The Head Unit allows the vehicle to communicate with the Internet via 5G or Wi-Fi, while displaying media and driving assistance information to the driver. The ADAS is responsible for taking input from all the sensors to perform driver assistance like lane departure mitigation and obstacle avoidance. Although the recent trend of Vehicular Networks is to leverage Ethernet, most cars still have a CAN bus for inter ECU communications, as well as providing diagnostic information via the OBDII port[2].

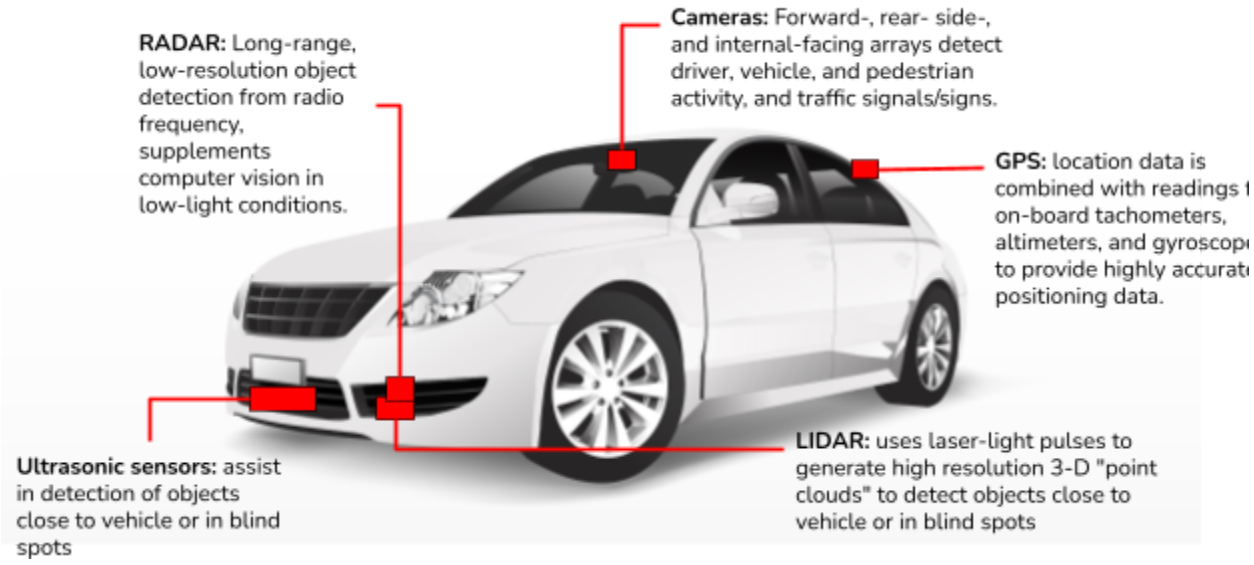

Figure 2: External on-board sensor deployment

[1] For more background on CAN networks see this youtube link, or this wikipedia page.
[2] If you would like to build projects that interface with your own car, this is where you plug in. Please always exercise caution when connecting with some sort of object that you care about. This video may be of assistance in locating the OBDII port in your car: https://www.youtube.com/watch?v=dKvNft0dLBU .

What to Purchase

Working with real components and assembling them yourself is both important and necessary to give you a more complete, hands-on experience. Since you purchase these components yourself, they are yours to keep, and the thing we construct will be something that you can keep and continue to use (show your friends!). Moreover, many of these components are general-purpose widely used to build IoT devices - if you like, you can later reassemble them into many other amazing IoT projects.

Here is what you will need to purchase for this project. We suggest you purchase exactly these items where possible - variants of these components will probably work but there is some chance you may end up with something incompatible. If you are not sure what you're doing, just try to purchase exactly what we have on this list.

[WARNING - some prices of these items may have increased substantially since the pandemic and resulting chip shortages. I encourage you to shop around, consider using Google Shopping, Amazon, Walmart, etc., to try to find the lowest possible prices.[3]]

What you need to purchase:

1. **Raspberry Pi[4] 4B (4 GB RAM) (Link) (Alternative Link - select 4GB or 8GB) (Alternative Link - full kit with additional items):** A Raspberry Pi is like a small computer. We will be using it to run various programs to control the car.
    a. Purchasing a Raspberry Pi 5 should work as well.
2. **64 microSD card (Link):** (32GB, 128GB should also be fine)
    a. If your computer doesn't have an **SD/microSD card reader**, you need to purchase one as you'll need to load data using your PC - (Something like this)
3. **Raspberry Pi Camera (Link):** This camera will be used to give your car the gift of vision! Your camera will be able to see and recognize objects in its environment.

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[3] Also when you receive them, please test them out immediately, occasionally parts will arrive that are DOA -- if it happens please contact the vendor and they should ship you a free replacement (if they do not or if they give you other problems please let me know so I can remove their link from this document and stop recommending them)

[4] If you were building a real car, having strong guarantees of timing would be critical ("brakes must close within 1ms of camera detecting pedestrian") so real cars make use of what are called Real Time Operating systems, where the programming interfaces are similar to what we will explore in this lab, but are built using schedulers that provide guarantees on the time it takes to complete various sorts of operations. Popular real time operating systems include VXWorks (used in the Mars Rover!), QNX (built by Blackberry, runs in hundreds of millions of cars!), and FreeRTOS (open source and free for commercial and noncommercial use!). Since real time operating systems are not needed for most IoT applications we'll use Raspberry Pi OS as that's a much more common platform you'll encounter in practice.

4. **Car Chassis Kit (Link) (Alternative link 1) [5]:** This will be the physical housing of the car, including the wheels, steering mechanism, and rest of the chassis.
    a. If you would like to do something different, you can complete this lab using an alternative kit, for example a robot dog (link), spider (link), tank (link) - however, note not all kits are compatible with this lab, so you're on your own if you choose one of these.
    b. We would like to also let you know that students have successfully done this lab with these cars as well: (Link 1 - if you choose to buy this one then you will need to work with Freenove library rather than Pycar library for the following labs) (Link 2 - this one also works but you'll have to manually mount the sensor atop the camera, which can be a bit of a pain)
5. **18650 Batteries (Link) (Alternative links 1 2 3 4 5):** These batteries will be used to provide power to the car and Raspberry Pi. A 4-pack of 18650 batteries should be sufficient if you can find other links. Make sure you get a set with a charger (or if you get something like these that don't come with a charger make sure you get the charger (Alternative link) separately as well). The standard battery should be 3.7V.
6. **Optional items:**
    a. **Video display cable:** Note the Raspberry Pi 4 has MicroHDMI output, so you'll need a MicroHDMI to HDMI cable if you plan on using an HDMI monitor with your Pi (Link).
        i. You can alternatively use a VNC (Virtual Network Computing) server to stream the Pi's GUI to a remote machine. Use this link to set up VNC. There are also other alternatives like VSCode.
    b. **USB keyboard and mouse (Link):** Similarly, it can be helpful to have a USB keyboard and mouse to plug into the Raspberry Pi. If you already have a USB keyboard and mouse you can probably just use those.
    c. **USB Type-C cable and charger (Link)**: This is useful to power the Pi instead of using the batteries while the device is stationary (Warning: DO NOT run the motors when solely powered by the cable as the Pi can not handle the amount of current which can cause it to burn out). If you happen to have a powerful enough charger already you can just get a USB-C cable **(Link)**. **3D printed components:** You can 3D print these components, may make it easier to attach the camera to your car

[5] If you search around you'll see many other car kits online (e.g., Link, Alternative link, Alternative link 2), and even things like tanks (Link) and walking spiders (Link) this lab is doable with these other platforms, but we recommend going with the SunFoundry PiCar for this lab as other platforms may have different wrapper libraries, and so you might not be able to leverage the sample code we provide. But after you do this lab you might want to go back and try some of those other platforms, for fun.

(https://www.thingiverse.com/thing:5207872) or focus the ultrasonic sensor (https://www.thingiverse.com/thing:5214602).

d. **Digital multimeter (Link):** A multimeter is a handy way for people to debug electronic circuits. You can take the probes and touch them to different parts of your circuit to see if electricity is flowing (e.g. to see if a pin is receiving current, touch one probe to the pin and the other to ground).
e. **An external computer monitor:** An external monitor to plug into the Raspberry Pi isn't required but will make some steps of this lab easier. Any computer monitor you have lying around will do, but you can also buy something specifically designed for the Pi such as (Link). You can use a tablet but it is not recommended.
f. **Breadboard**: This can be helpful for testing out various wiring configurations and practicing making smaller circuits. These are widely available and come in many forms but here is an example that comes with some wires and other components you can use to create other various things (may be useful for class project): (Link).

Group Formation

You are allowed to form a team with up to 4 people. Working in a team is not required but strongly encouraged. Group formations are not final. In the condition that the members of your group change, please submit another form.

Please submit your group formation at this link (only one submission is needed for each group):
https://forms.gle/TPhd8xUEKrBVByZZA

Lab 0 Submission and Grading

Your final submission should have 2 parts: 1) **report** in PDF format. 2) submit a group formation form**.**
The report must contain:

1) A list of purchased items. Each item should include a screenshot of the receipt (include the approx. date of arrival if provided). Please number your list to align with the **What to Purchase** section.
    a) If you already have required items and don't need to purchase new ones, please include pictures of them.
2) Submit name(s) and NetID(s) of your group through google form.

The rubric for grading that you should follow is provided here:

Report (10 pts)	
Full list of items	
Receipts are provided for purchased items. Pictures are provided for owned items. All required items are included. (There are 5 items required, not including the optional items.)	10
1-2 items are missing/not purchased	7
More than 2 items are missing/not purchased	0
Group Formation (10 pts)	
Form submission	
Form submitted on time	10
Form not submitted by due date	0

Category	**Points**
Purchase Receipt	10
Group Formation	10
Total	**20**