Introduction to System-on-Chip and its Applications

Group Final Project Report

Advanced Dashcam Assistance System

Teammates

110064533 陳劭珩

111061537 洪子晴

111062574 徐瑞憫

111064537 林亭君

111065515 鄭皓姿

Instructor: 邱瀞德 教授 (Prof. Ching Te Chiu)

January 2023

Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1. Motivation and Target Applications

Self-driving technology has seen significant advancement in recent years, with various levels of automation identified. Level 0 represents a lack of Advanced Driver Assistance Systems (ADAS), while Level 1 includes basic ADAS features. At the highest level, Level 5, the vehicle is capable of fully autonomous driving without the need for a steering wheel. Currently, most self-driving systems on the road are at Level 2 or 3, which denotes the presence of advanced ADAS capabilities such as real-time road condition detection, collision prevention, and lane deviation prevention. The ultimate goal of ADAS technology is to progress towards fully autonomous driving. Currently, TESLA is widely recognized as the leader in this industry.

While TESLA is a well-known and strong company in the self-driving car industry, its products can be expensive. In an effort to provide a more accessible alternative, our company has developed a dash camera with automatic driving assistance system capabilities that can be used with a variety of more affordable and common car models. This dash camera offers advanced ADAS features such as real-time road condition detection, collision prevention, and lane deviation prevention, which can be enjoyed by simply purchasing and installing the camera in one's car - no need to purchase a TESLA vehicle. In addition to these standard ADAS features, our dash camera also includes drunk driving detection and driver mental state monitoring to enhance safety for both drivers and passengers. Overall, our design aims to provide a cost-effective solution for those looking to incorporate self-driving assistance technology into their vehicles.

1.2. Application Scenario

Figure 1, Our ADAS prototype, image source: https://comma.ai/shop/comma-three

1.2.1. Taxi Systems

Taxi systems should be installed to provide passengers with safe and comfortable services. There are taxi services around the world, which is very convenient and practical. However, accidents caused by taxi drivers are also emerging one after another, and the safety of passengers will be threatened if the car driven by a driver who is mentally ill, so if it is stipulated that the cars of all taxi-related system companies, such as Car rental company and Uber, must be equipped with our designed products, it will It will greatly improve the service quality of global taxis, thereby increasing the passenger capacity. It is the best choice for both parties to receive profits.

1.2.2. Personal Cars

Personal car is also the best choice to install this product because traffic accidents frequently occur in modern society, including drunk driving and fatigue driving. In particular, fatalities and injuries caused by drunk driving are a serious problem in Taiwan. With our product, we can continuously monitor the condition of the driver and take corresponding countermeasures to avoid unfortunate traffic accidents.

Chapter 2 System

1.1 Features

Our ADAS is mainly a focus reminder system, it divides into inner and outer focus subsystem. The former detects the vital sign of passengers and drivers to ensure their safety and prevent from fatigue drivers, while the latter offers driving assistance for drivers.

The inner subsystem has three following functions: first, a pressure sensor on the steering wheel to assure whether drivers' hands are placed on the wheel or not. If drivers distract attention and leave their hands from the steering wheel, the pressure sensor will send a request to dashcam and the dashcam will have a voice prompt. Besides, if there are car accidents that make drivers' hands leave the steering wheel, the pressure sensor will also send requests to ECU and the ECU will report to the police. Second, a gas sensor can detect the C_2H_5OH and CO gas concentration and to prevent from drunk driving and fatigue driving. In addition, It can also detects harmful gas for trunk drivers who sometimes work in a construction site or factory. Once the gas sensor detects high gas concentration, it will send requests to dashcam to inform drivers to open the door or leave the car. Third, an inner camera and radar to detect drivers' and passengers' behavior.

On the other hand, the outer subsystem has two main functions: a camera for object detection and lane detection, and a radar for object detection that provide range and doppler estimation. They will detect abnormal driving condition and inform the drivers to pay attention. The outer subsystem will ensure driving safety.

1.2 System Diagram

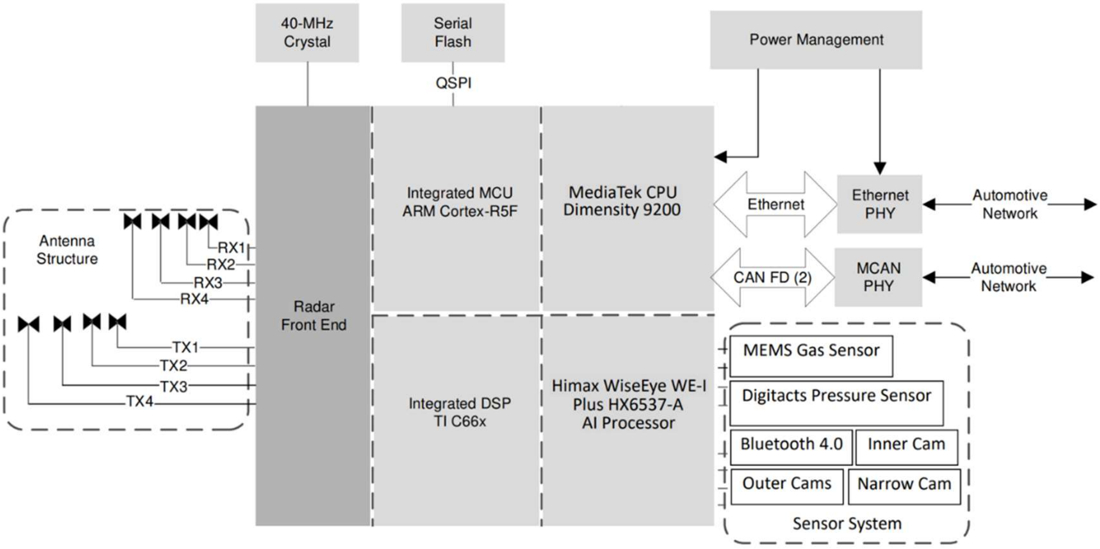


Figure 2, our ADAS System Diagram

Our ADAS has a main chip. The SoC consists of a radar processor, a DSP, a CPU, and an AI Processor on the dashcam. The radar processor and the DSP process the radar information. The AI processor process object detection and lane detection according to image and radar information. The CPU make driving decision according to input information. Besides, it has radar antenna to receive radar information, while using cable to transmit camera image input. It use Bluetooth4.0 to transmit the information of the gas sensor and pressure sensor.

1.3 Data Flow Diagram

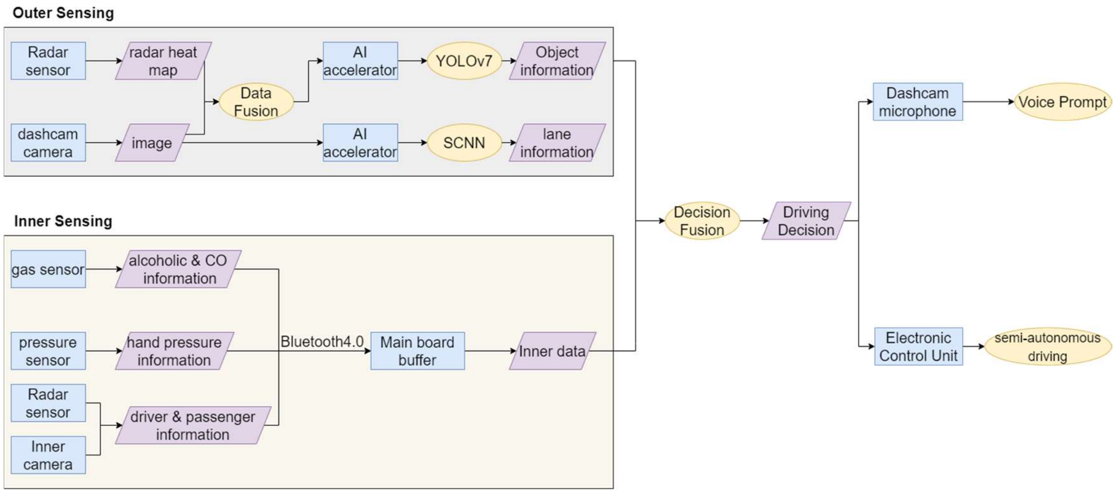


Figure 3, Our ADAS Dataflow Diagram

Figure 3 shows the dataflow diagram of ADAS. For the outer sensing part, the outer radar sensor will create radar heat map, while dashcam camera will get image. These inputs will process data fusion, then transmit to AI processor to training and predict object and lane information. For the inner sensing part, inner sensors will transmit information by Bluetooth or cable and get inner information.

The outer an inner information will process decision fusion and create a driving decision. Finally, the decision will send to dashcam microphone or to EUC to semi-autonomous driving.

1.4 System Specification

Component	**Spec**
Main Processor	• MediaTek Dimensity 9200
Radar Processor	• ARM Cortex-R5F • TI DSP C66x
Camera	• Three 1080p cameras w/ 120 dB of dynamic range: dual-cam 360° vision • One narrow camera to see far-away objects
Storage	• 32 GB built-in storage • 1TB Samsung 980 NVMe SSD

Connectivity	• Cellular Technologies
	  • FR1: Sub-6GHz
	  • FR2: mmWave
	  • LTE, GSM
	• Wi-Fi
	• Bluetooth
	• High-Precision GNSS
	  • GPS
	  • BeiDou
	  • Glonass

Night Vision	• IR LEDs for interior night-vision monitoring • Radar Sensor

Table 1, ADAS Specifications

Chapter 3 Technology

3.1. Sensor

3.1.1. Radar Sensor —— TI AWR 2944

As autonomous driving technology advances from the demonstration phase to the implementation phase, it demands higher levels of perception capability. The most widely used autonomous driving systems rely on combining cameras and LiDARs for perception. While millimeter wave radar has been commonly utilized in mass-produced vehicles for active safety functions like automatic emergency braking (AEB) and forward collision warning (FCW), it has not been a popular choice for autonomous driving.

Next-generation 4D radar has an angular resolution of about 1° in both horizontal and vertical views, allowing it to accurately classify static objects. Radar can also measure Doppler velocity and radar cross-section, which can aid in classifying road users. In addition, 4D radar has a long detection range of up to 300 m, can operate in all weather conditions, has low power consumption, and is cost-effective. Therefore, we believe that radar is a valuable complement to LiDAR and vision, and the fusion of these sensors allows for all-weather, long-range environment perception. We are looking forward to seeing the use of radar sensors in Tesla's Autopilot system.

Overview

The AWR2944 evaluation module (EVM) is an easy-to-use platform for evaluating the AWR2944 millimeter-wave system-on-chip (SoC) radar sensor, which has direct connectivity to the DCA1000EVM (sold separately).

The AWR2944EVM kit contains everything required to start developing software for the on-chip C66x digital signal processor (DSP), Arm Cortex-R5F controller, and hardware accelerator (HWA 2.0).

Also included is onboard emulation for programming and debugging, as well as onboard buttons and LEDs for quick integration of a simple user interface.

Features

1. 76-GHz to 81-GHz millimeter-wave radar sensor.
2. Onboard four-transmit four-receive (4TX/4RX) antenna.
3. On-chip C66x DSP core and Arm Cortex-R5F controller.
4. On-chip hardware accelerator (HWA 2.0) for FFT calculations.
5. Direct interface with DCA1000EVM.

System Specifications

The AWR2944 is a single-chip, millimeter-wave sensor consisting of a Frequency-Modulated Continuous-Wave (FMCW) transceiver operating in the 76-81 GHz band, radar data processing elements, and peripherals for in-vehicle networking. The device's parameters are listed below.

Number of receivers	4
Number of transmitters	4
ADC sampling rate (Max) (MSPS)	37.5
Interface type	2 CAN-FD, Ethernet, I2C
DSP	C66x DSP 360MHz
Hardware accelerators	Radar hardware accelerator
Rating	Automotive
Operating temperature range (C)	-40 to 140
Power supply solution	LP87745-Q1
Security	Cryptographic acceleration, Device identity/keys, Secure boot, Secure software update, Software IP protection, Trusted execution environment

Table 2, TI AWR 2944 System Specifications

System Block Diagram

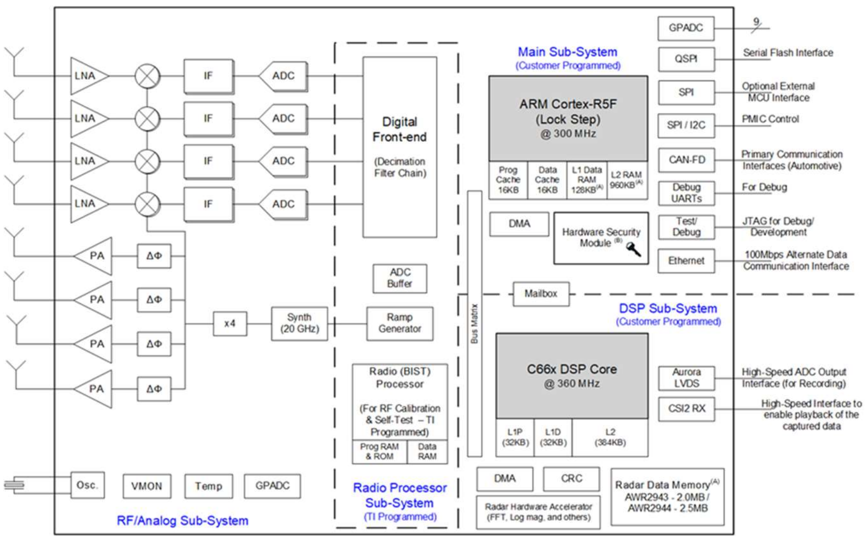


Figure 4, Block Diagram of TI AWR 2944

, image source: https://www.ti.com/product/AWR2944

3.1.2. Gas Sensor —— Gravity: MEMS Gas Sensor

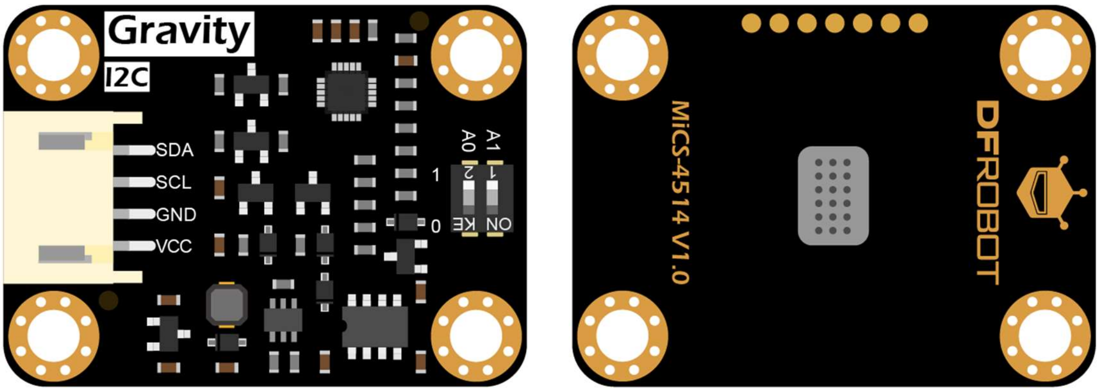


Figure 5, MEMS Gas Sensor Board Review

, image source https://www.dfrobot.com/product-2417.html

MEMS Gas Sensor is a gas concentration sensor from DFRobot. It supports the detection of six kinds of gas concentrations: Carbon monoxide (CO), Ethanol (C2H5OH, Alcohol), Nitrogen dioxide (NO2), Hydrogen (H2), Ammonia (NH3), Methane (CH4). Besides, it is compatible with Arduino, Raspberry Pi, ESP32 and other mainstream controllers due to I2C output and 3.3 ~ 5.5V wide voltage input.

System Features

1. Low power consumption
2. Support the detection of various gas
3. I2C digital output and compatible with 3.3~ 5.5V master controller

System Specifications

Operating Voltage (V)	Operating Voltage (V)
3.3 ~ 5.5 (DC)	3.3 ~ 5.5 (DC)
Power Dissipation (W)	Power Dissipation (W)
0.45 (5V)	0.45 (5V)
Output Signal	Output Signal
I2C (0 ~ 3V)	I2C (0 ~ 3V)
Operating Temperature (°C)	Operating Temperature (°C)
-30 to 85	-30 to 85
Operating Humidity	Operating Humidity

Table 3, MEMS Gas Sensor System Specifications

System Block Diagram

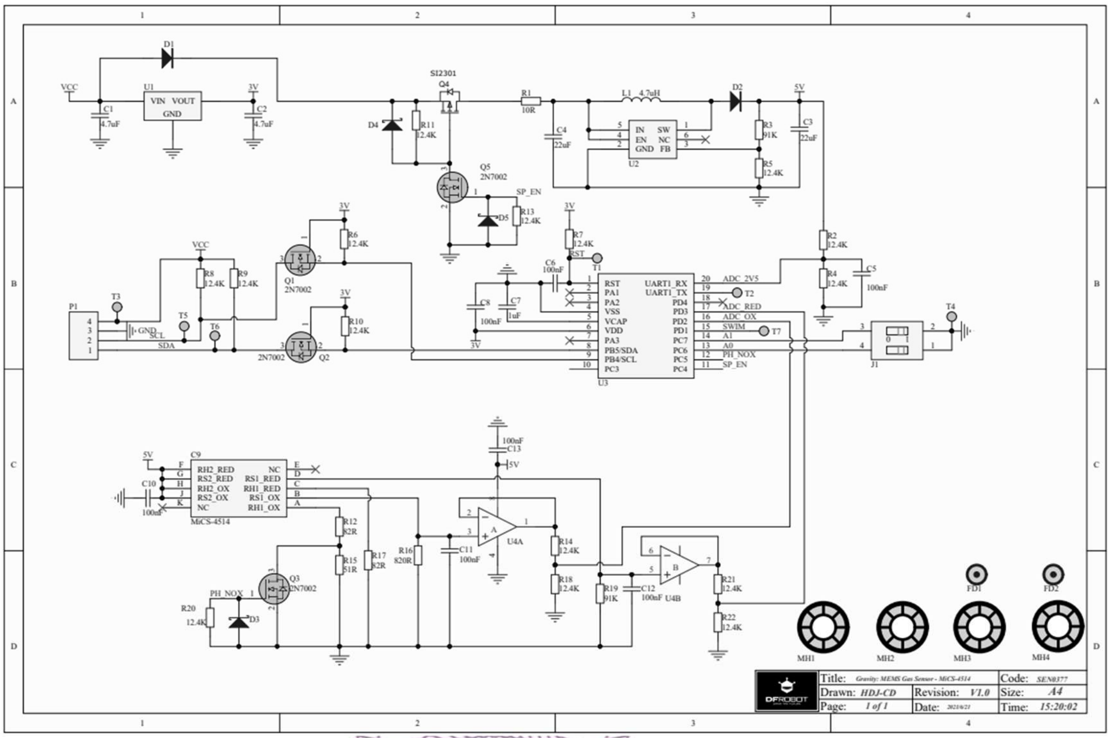


Figure 6, Block Diagram of MECS-4515

, image source: https://img.dfro-bot.com.cn/wiki/5b973267c87e6f19943ab3ad/ec7dd3a55ba1d58fcbd5830ee08c0e7f.pdf

Measuring Range

- 1 – 1000 (ppm) (Carbon monoxide CO)
- 10 – 500 (ppm) (Ethanol C_2H_5OH)
- 0.05 – 10 (ppm) (Nitrogen dioxide NO_2)
- 1 – 1000 (ppm) (Hydrogen H_2)
- 1 – 500 (ppm) (Ammonia NH_3)
- >1000 (ppm) (Methane CH_4)

3.1.3.Pressure Sensor —— Digitacts

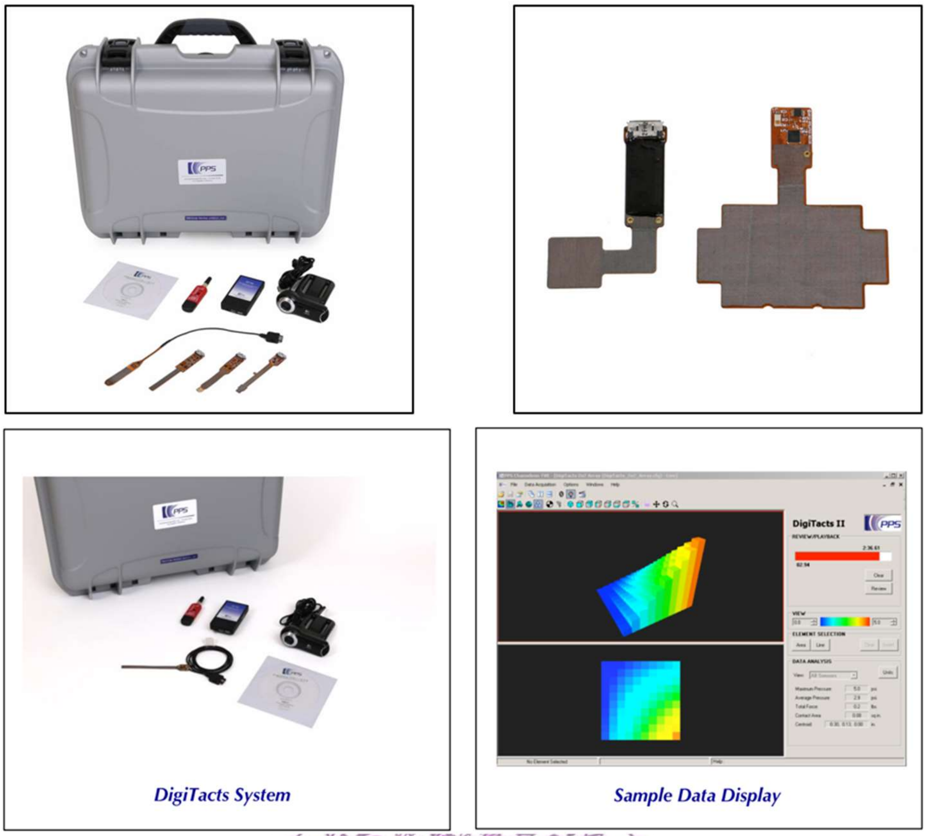


Figure 7, Digitacts Sensor Illustration

, image source: https://pressureprofile.com/sensors/digitacts

Digitacts system is a system that has high performance embedded tactile sensors from Pressure Profile Systems (PPS). The system provides the "sense of touch" for products in different fields such as medical devices, robotics, automotive, and so on. The system includes Digitacts sensors which are composed of multiple sensing pads with 12-24 sensing elements on each pad. These sensors can be placed on any location with the choice in sensor active area.

System Features and Benefits

1. Sensitive tactile sensors can be used on almost any geometry surface, with stable and
2. repeatable sensor output.
3. Capable of measuring a wide range of pressures on various applications.
4. Bluetooth wireless technology and SPI or I2C serial digital output.
5. High performance capacitive sensing technology
6. Easy to use, high-quality visualization software —— Chameleon Visualization Software

System Component

1. DigiTacts sensor of chosen design (includes one additional spare sensor)
2. Rechargeable D710 electronics interface module with Bluetooth connectivity
3. Chameleon Visualization and Data Acquisition Software
4. Remote Installation and Training

System Specification

1. Sensor

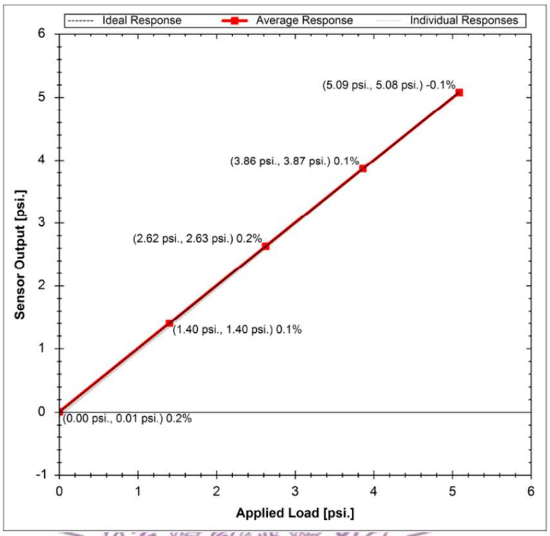


Figure 8, Pressure Sensor Chart, image source: https://cdn2.hubspot.net/hubfs/5361756/Spec%20Sheets/Spec%20Sheet_DigiTacts%20System.pdf

Pressure Range (psi)	5, 20, 40
Pressure Sensitivity	0.2%
Linearity	99.7%
Signal to Noise Ratio (SNR)	700
Contact Surface Material	Cloth and Polyimide
Sensor Thickness (mm)	0.5
Cable Length(m)	1.5
Operating Temperature (°C)	-20 to 100

Table 4, Digitacts Sensor System Specifications

2. Electronics

Sampling Rate (Hz)	30-100
Computer Interface	Bluetooth
Input Voltage	5V
Input Power	2.5W
ADC Resolution	16 bits
Enclosure Size (cm)	75x40x12.8
Weight (g)	55

Table 5, Digitacts Electronics System Specifications

3.2. Main Chip

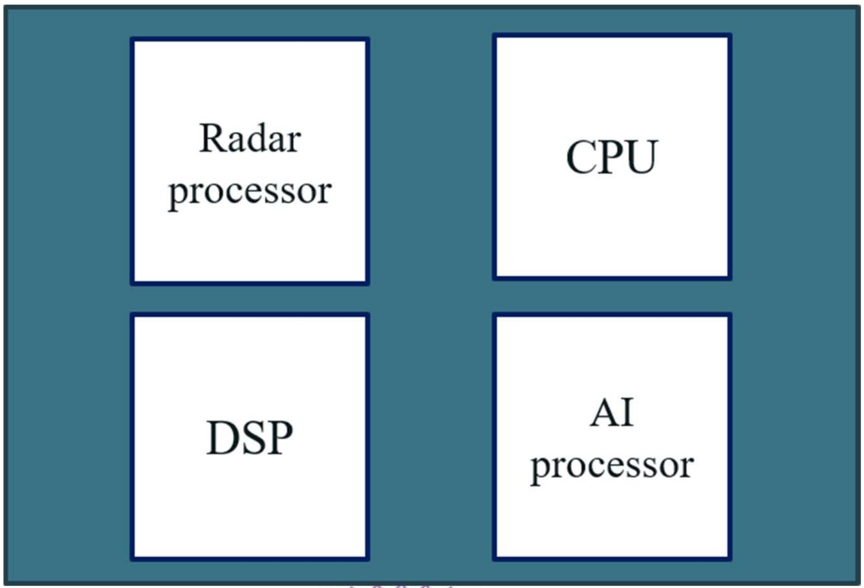


Figure 9, Main Chip Block Diagram

In order to accelerate the computing process and decrease the area of the chip, we combine a radar processor, a DSP, a CUP, and an AI processor in the SoC. Since the main sensing component is radar, we added a radar processor and its DSP in the main chip. The other main function is machine learning for object detection and lane detection, so we add an AI processor in it.

System Specifications

Components	Specifications
Radar Processor	ARM Cortex-R5F
DSP	TI DSP C66x
CPU	MediaTek Dimensity 9200
AI Processor	Himax WiseEye WE-I Plus HX6537-A

Table 6, ADAS SoC System Specifications

3.2.1.CPU —— MediaTek Dimensity 9200

The MediaTek Dimensity 9200 is a mobile processor that was announced in 2021. It is part of MediaTek's Dimensity series of processors, which are designed for use in smartphones and other mobile devices. The Dimensity 9200 is built using a 5nm manufacturing process and features a octa-core CPU with a maximum clock speed of 3.0 GHz. It also has a 6-core GPU and supports 5G connectivity. Other features of the Dimensity 9200 include support for artificial intelligence (AI) and machine learning (ML), as well as support for high-resolution displays and camera systems. It is intended to be a high-performance processor for use in premium smartphones.

System Specifications

Components	Specifications
Processor (8 - core)	• 1x Arm Cortex-X3 at 3.05GHz • 3x Arm Cortex-A715 up to 2.85GHz • 4x Arm Cortex-A510 up to 1.8GHz
Memory and Storage	• Memory Type: LPDDR5x • Storage Type: Universal Flash Storage (UFS) 4, Multi-Circular Queue (MCQ)
Camera	• Max Camera Sensor Supported: 320MP • Max Video Capture Resolution: 8K30 (7690 x 4320) ,4K60 (3840 x 2160)
Graphics	• GPU Type: Arm Immortalis-G715 • Video Encoding: H.264, HEVC • Video Playback: H.264, HEVC, VP-9, AV1

Connectivity	• Cellular Technologies
	  • Sub-6GHz (FR1)
	  • mmWave (FR2)
	  • 2G-5G Multi-Mode
	  • 5G-CA, 4G-CA
	  • 5G FDD / TDD, 4G FDD / TDD
	  • TD-SCDMA, WDCDMA
	  • EDGE, GSM
	• GNSS
	  • GPS L1CA+L5
	  • BeiDou B1I+ B2a + B1C + B2b
	  • Glonass L1OF
	  • Galileo E1 + E5a +E5b
	  • QZSS L1CA+ L5
	  • NavIC L5
	• Wi-Fi
	  • Wi-Fi 7 (a/b/g/n/ac/ax/be) ready
	  • Wi-Fi Antenna: 2T2R
	• Bluetooth: 5.3
	• Display:
	  • Max Refresh Rate
	  • Full HD+ up to 240Hz
	  • WQHD up to 144Hz
	• AI Processing Unit: APU 690 (MDLA+MVPU+SME+DMA)

Table 7, MediaTek Dimensity 9200 System Specifications

Universal Flash Storage (UFS) 4 is a next-generation flash memory standard that is expected to be used in smartphones, tablets, and other consumer electronics devices. It is designed to offer faster data transfer speeds, lower power consumption, and improved performance compared to previous versions of UFS.

UFS 4 is based on the JEDEC UFS 3.1 specification and is expected to offer data transfer speeds of up to 5 GB/s, which is significantly faster than the maximum data transfer speed of UFS 3.1 (2.9 GB/s). It is also expected to support low-power modes that will allow devices to use less power when idle, which could help improve battery life.

Other features of UFS 4 include support for more advanced error correction techniques and improved reliability, as well as support for the NVMe protocol, which is commonly used in high-performance solid-state drives (SSDs). In our case, we have a 1TB Samsung 980 NVMe SSD.

5G-CA (5G Carrier Aggregation) is a feature of 5G technology that enables carriers to combine multiple frequency bands to provide a wider channel and higher data rates. This can be used to improve the coverage and capacity of a 5G network. By aggregating several smaller channels, carriers can increase the amount of data that can be transmitted over the network, leading to faster download and upload speeds for users. 5G-CA can also be used to improve the reliability of the network by allowing devices to switch between frequency bands if one becomes congested or unavailable.

System Block Diagram

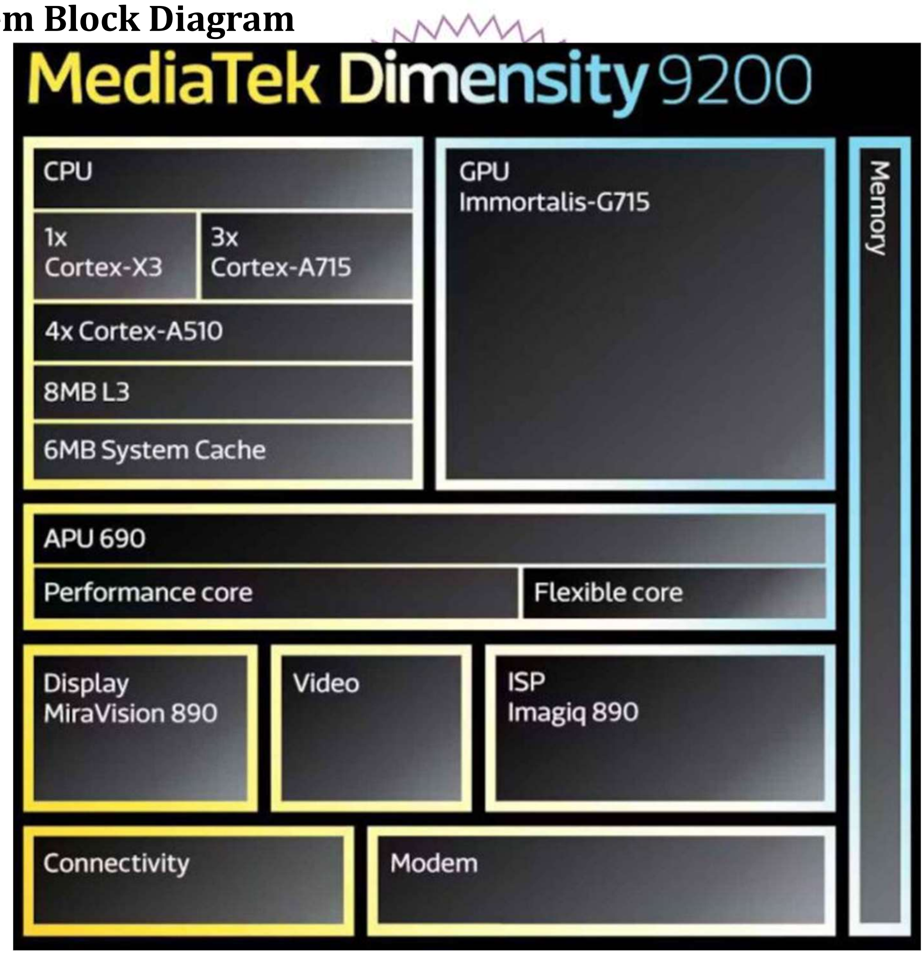


Figure 10, MediaTek Dimensity 9200 System Block Diagram

, image source: https://www.sammobile.com/news/mediatek-dimensity-9200-launched-specifications-performance/

3.2.2.AI Accelerator —— WiseEye WE-I Plus HX6537-A

AI accelerator is a class of specialized hardware accelerator or computer system designed to accelerate artificial intelligence and machine learning applications. We need an AI accelerator to accelerate applications such as object detection and lane detection. Since the accelerator will be embedded on our intelligence dashcam, the power consumption, board size, and performance may take into consideration. Therefore, we select WiseEye WE-I Plus HX6537-A as our AI accelerator.

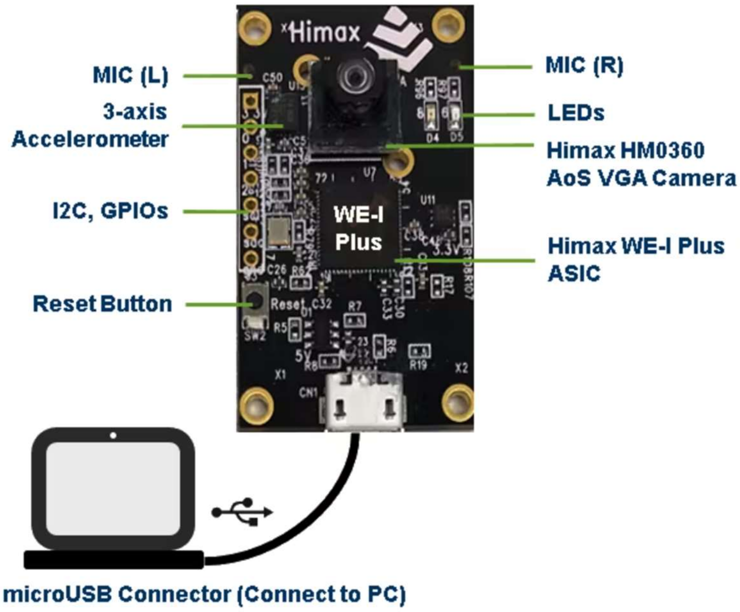


Figure 11, WiseEye WE-I Plus HX6537-A Board Review

, image source: https://cdn.sparkfun.com/assets/1/b/b/2/1/WE-I_Plus_EVB_Technical_Document_v03.pdf

Features

1. Ultra low power and high-performance AI processor
2. Support Google TensorFlow Lite for Microcontrollers
3. Comprehensive WiseEye Computer Vision solution with Himax AoS Sensor.

WiseEye WE-I Plus HX6537-A was launched by Himax Technologies in 2022/06/30. Himax collaborated with Google to design a processor supporting Google's TensorFlow Lite for Microcontrollers. Himax is providing the HX6537-A processor with neural network (NN) based Software Development Kit (SDK) for developers to generate deep learning inferences running on TensorFlow Lite for Microcontrollers kernel to boost overall system AI performance. The Himax

WiseEye solution is composed of the Himax HX6537-A processor and Himax AoS (Always on Sensor) sensor.

System Specifications

Parts	compenents
WE-I Plus ASIC (HX6537-A)	• ARC 32-bit EM9D DSP with FPU • 400MHz clock frequency • 2MB SRAM • 2MB Flash
On board	• Himax HM0360 AoS TM ultra-low power VGA CCM • FTDI USB to SPI/I2C/UART bridge • LDO power supply (3.3/2.8/1.8/1.2V) • 3-asix accelerometer • 1x reset button • 2x microphones (L/R) • 2x user LEDs • microUSB connector
Expansion header	• 1x I2C master • 3x GPIOs • Power/Ground

Table 8, WiseEye WE-I Plus HX6537-A System Specifications

Its main chip: WE-I Plus ASIC accelerates deep learning processes. It consists of ARC 32-bit EM9D DSP with FPU, a clock with 400MHz frequency, a 2MB SRAM, and a 2MB Flash. As for the On board chips, Himax HM0360 AoS TM ultra-low power VGA CCM offers vision inputs. The sensor supports up to VGA@60fps image input and fast wake-up for speedy sensor image capture. Additionally, average Himax AoS sensor power consumption can be less than 1mW.

3.3. Network Protocol

3.3.1. Bluetooth Low Energy 4.0

Bluetooth Low Energy is a bluetooth protocol, which is created in a low energy consumption mode by Nokia. The feature of Bluetooth Low Energy 4.0 is (1) Low power (2) Use GATT protocol (3) 2.4GHz for bandwidth. There are various applications of Bluetooth Low Energy, like Blood Pressure Profile, Health Thermometer Profile, Glucose Profile, UDS or HID connection, and all of the application is based on GATT profile.

System Specifications

Specifications	*Classic Bluetooth*	*Bluetooth Low Energy*
Range	100 m	Greater than 100 m
Data rate	1–3 Mbps	125 kbitps – 1 Mbps – 2 Mbps
Application throughput	0.7–2.1 Mbps	0.27 Mbps
Active slaves	7	Not defined
Frequency	2.4 GHz	2.4 GHz
Security	56/128-bit	128-bit AES with Counter Mode CBC-MAC
Robustness	Adaptive fast frequency hopping, FEC, fast ACK	24-bit CRC, 32-bit Message Integrity Check
Latency	100 ms	6 ms
Time Lag	100 ms	3 ms
Voice capable	Yes	No
Network topology	Star	Star
Power consumption	1 W	0.01 - 0.50 W
Peak current consumption	less than 30mA	less than 15mA

Figure 12, Bluetooth Low Energy 4.0 System Specifications
, image source: https://www.researchgate.net/figure/3-Comparison-of-Classic-Bluetooth-and-Bluetooth-Low-Energy-BLE-46_tbl3_341913410

The figure above shows the specifications of Bluetooth Low Energy and Classic Bluetooth. The reason why we choose Bluetooth Low Energy is the lower power consumption and lower latency. Because of the importance of ensuring security during the driving period, we should choose the one which has higher usage time and is more continuous on data transmission. In addition to the reason above, the less wire for transmitting data is another reason why we choose Bluetooth Low Energy.

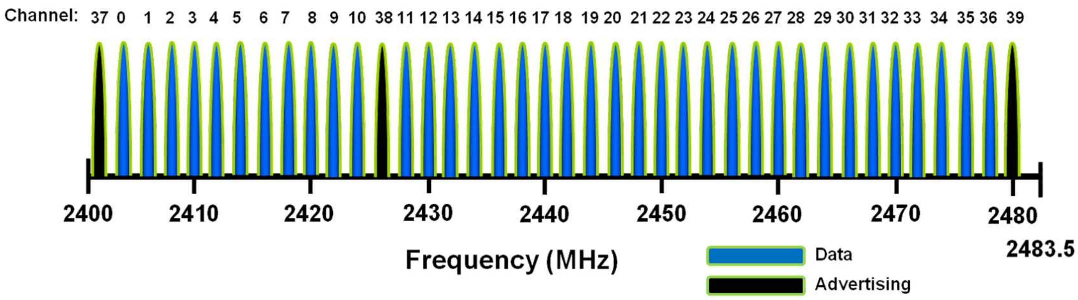


Figure 13, Bluetooth 4.0 Bandwidth

, image source: https://microchipdeveloper.com/wireless:ble-phy-layer

In Bluetooth Low Energy, the frequency is divided into 40 channels with 2GHz, and the way to spread spectrum is use the Frequency-Hopping Spread Spectrum (FHSS) technology.

GATT (Generic Attribute Profile)

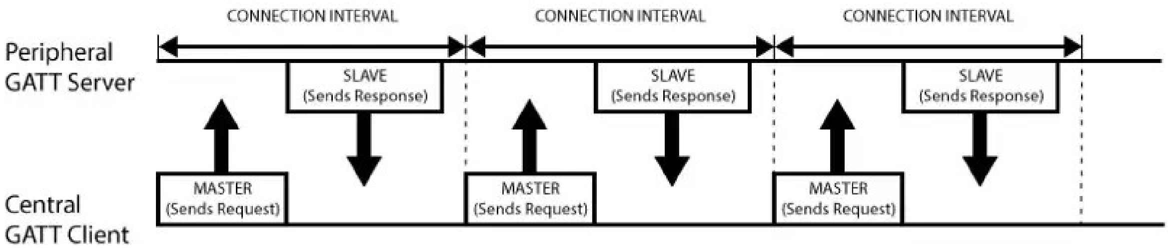


Figure 14, Connection of GATT

, image source: https://microchipdeveloper.com/wireless:ble-phy-layer

The framework of GATT is ATT protocol (Attribute Protocol), and it defined the two mayer characteristics, GATT Server and the GATT Client, the Client usually means the mobile device of communication. The Figure 14 shows the architecture of GATT. We can realize that the GATT Client usually sends the request to the GATT Server, and waits for the request from the Server, if there is no connection between them, the Server will broadcast its location, until the connection occurs. In the GATT, if the GATT Server wants to request data for a GATT Client, the Client should request the attribute(16 bits of 128 bits digital) to the Server, which includes the Properties(ex. write, read, no connection and so on) and the Descriptors(ex.extended properties, user description and so on).

HID (Human Interface Devices)

The GATT profile we use in our report is HID connect, which provides the wireless connection with longer usage time, like wireless mouse, wireless keyboard and so on. The HID provides users with a computer, and the device should be maintained by the USB slot. The figure below shows the architecture of HID.

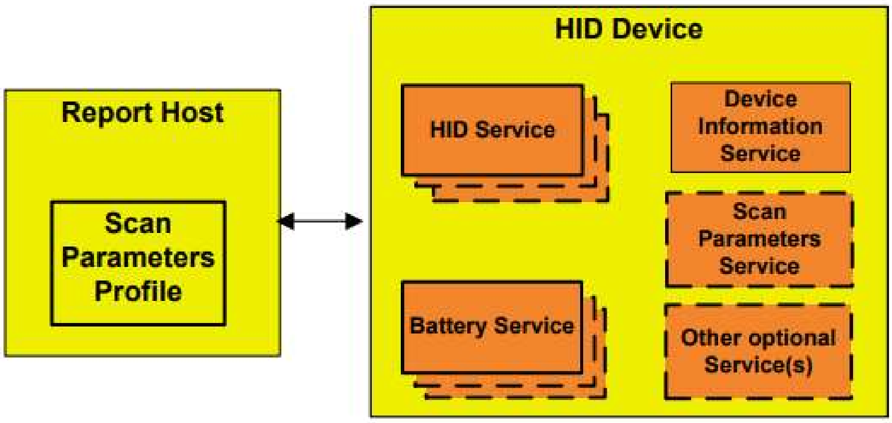
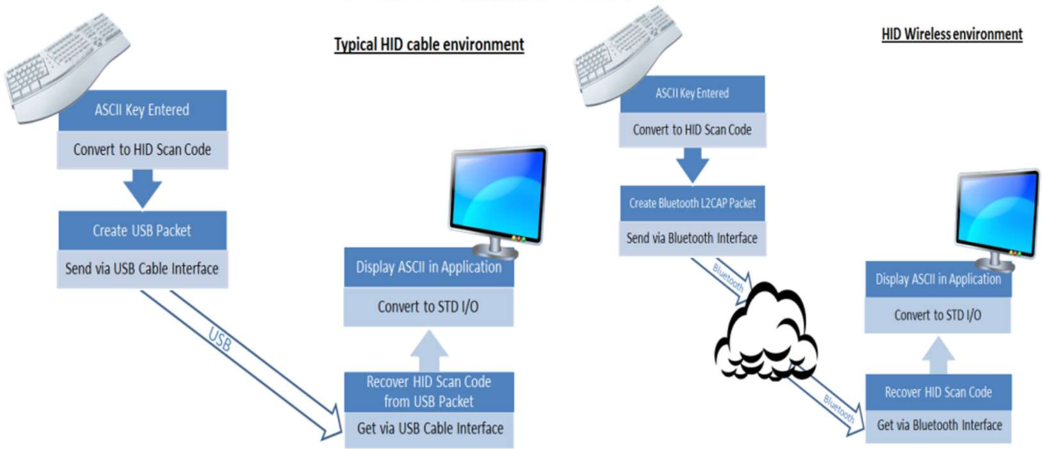


Figure 15, The architecture of HID

In Figure 15, if a computer receives HID data, it becomes the HID Host, and the HID Server means the GATT Server, in the same way, the HID Client means the GATT Client,which sends input data to the computer device. In the communication structure, the Client is allowed to connect one Server at the same time. For example, in the situation of using a wireless keyboard, the keyboard which transmits the data to the computer is defined as the HID Device, and the laptops are defined as the HID Host, and the keyboard cannot connect to two laptops at the same time. The profile of HID use is called HOGP, the target of HOGP is to eliminate the need for wires or a physical connection in the HID.



The type of HID device, such as a keyboard, mouse, or joystick, is defined by the HID descriptor in the raw HID report.

Figure 16, The typical environment of HID

, image source: https://cdn.sparkfun.com/datasheets/Wireless/Bluetooth/RN-HID-User-Guide-v1.0r.pdf

The figure above shows the typical environment of HID, the ASCII Key entered can be transmitted to the display application by a virtual Bluetooth interface, which means there is no need to connect another cable to transmit the data.

3.4. Detection Algorithm

3.4.1. YOLOv7 for Object Detection

YOLOv7 was developed by YOLO. To realize the concept of YOLOv7, we need to understand the basic method of YOLO. You only look once (YOLO) is a state-of-the-art, real-time object detection system. It's a one-stage detector that processes object detection and object classification in one go. The advantage of one-stage detection is that it can speed up the detection process for embedding systems, which have limited memory and hardware specification.

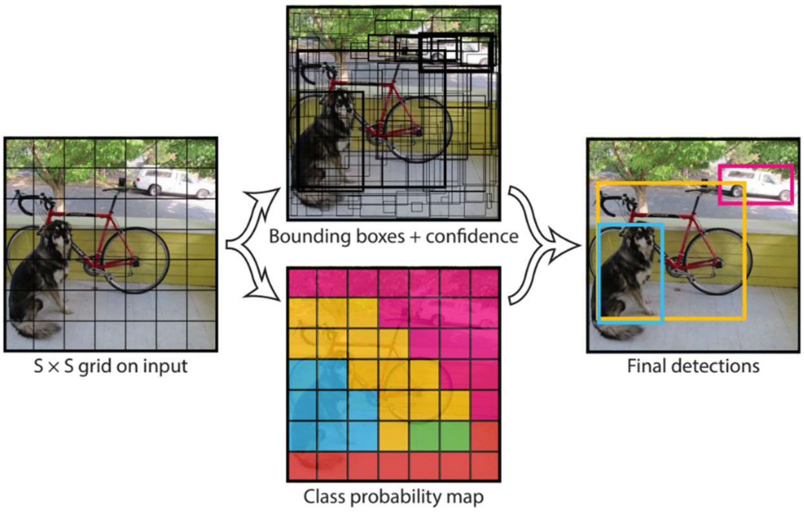


Figure 17, The YOLO Detection System

, image source: https://arxiv.org/pdf/1506.02640v5.pdf

YOLO has three processes: resizing images to 448448, running Convolutional Neural Network (CNN), and running Non-Maximum Suppression (NMS). YOLO has the following steps for detection: first is splitting an image into an $S \times S$ grid, the particular grid cell will be responsible for detection as long as the center of an object falls into that cell. Second, each grid cell predicts B bounding boxes and confidence scores. Each bounding box will have five values: center position (x, y), size (w, h), and a confidence score. The confidence score was evaluate by the function: $\Pr(\text{Object}) * \text{IOU}(\text{truth}, \text{predict})$. If it is background, the output will be 0, while the output will be 1 when it is an object. Next, using NMS to eliminate redundant bounding boxes and find the best ones. Finally, YOLO will compute the conditional class probability for each cell. The probability function is $\Pr(\text{Class}|\ \text{Object})$. The probability will be part of the loss function. The overall predictions are encoded as an $S \times S \times (B * 5 + C)$ tensor.

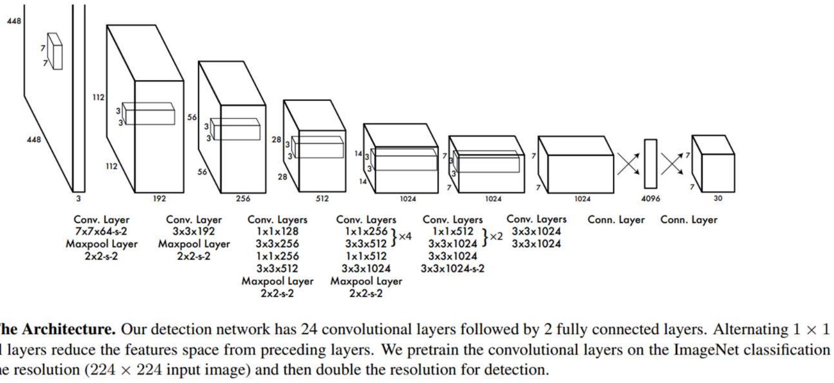


Figure 18, The architecture of YOLO, image source: https://arxiv.org/pdf/1506.02640v5.pdf

The CNN architecture is based on the GoogleNet model, it has 24 convolutional layers and 2 fully connected layers. YOLO pretrains these layers on the ImageNet classifications task.

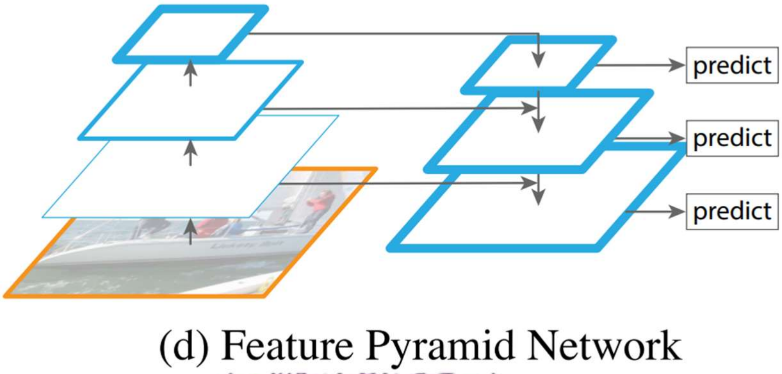


Figure 19, FPN, image source: https://arxiv.org/pdf/1612.03144.pdf

YOLOv2 modified the predict method. It predicts B bounding boxes and confidence scores for each bounding box instead of a grid cell. Moreover, The overall predictions are encoded as an S SB5+C tensor. YOLOv3 adds Feature Pyramid Network (FPN). The core concept is that it downsample to 3 types of size, then predicts bounding boxes. At the last step, it upsample.

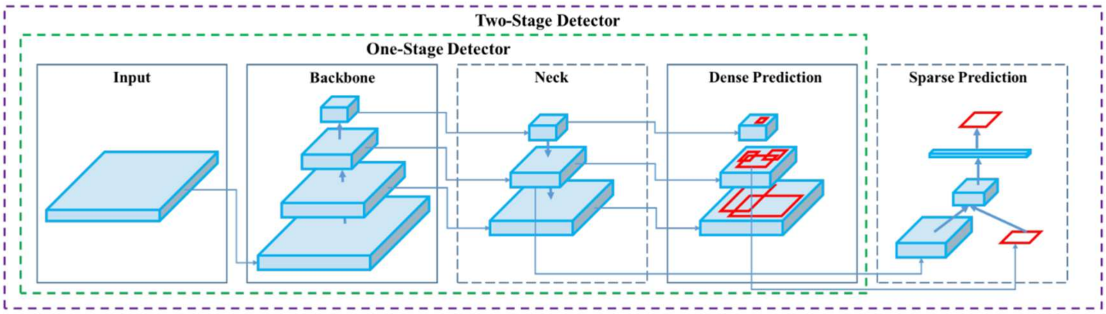


Figure 20, two-stage detector, image source: https://arxiv.org/pdf/2004.10934.pdf

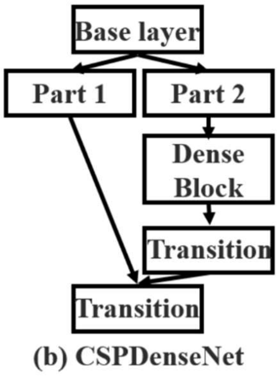


Figure 21, CSPDenseNet, image source: https://arxiv.org/pdf/1911.11929.pdf

The YOLOv4 development team describes that the architecture of the object detector is composed of a backbone, a neck, a head, a dense prediction, and a sparse prediction. The one-stage detector includes the first three parts. The backbone is the pretrain CNN model, and is responsible for capturing features. YOLOV4 combines its ResNet50 and Darknet53 with Cross Stage Partial Network (CSPNet). The neck part is to extract features from different pooling layers, whereas the head part predicts bounding boxes according to the features.

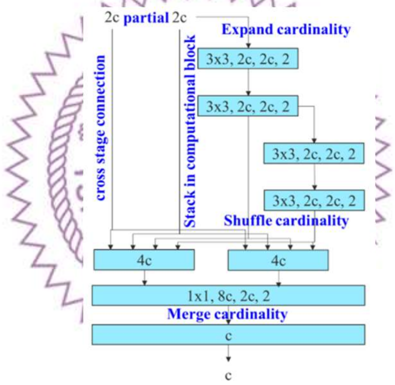


Figure 22, The architecture of YOLOv7, image source: https://arxiv.org/pdf/2207.02696.pdf

As for YOLOv7, they introduce a new architecture called Extended efficient layer aggregation networks (E-ELAN). The E-ELAN does not change the gradient transmission path of the original architecture at all, but uses group convolution to increase the cardinality of the added features, and combine the features of different groups in a shuffle and merge cardinality manner. This way of operation can enhance the features learned by different feature maps and improve the use of parameters and calculations.

3.4.2.SCNN for lane detection

Convolutional neural networks (CNNs) are usually built by stacking convolutional operations layer-by-layer. Although CNN has shown strong capability to extract semantics from raw pixels, it's not good at capturing spatial relationships from raw pixels. Sparse CNN (SCNN) generalizes slice-by-slices convolutions within feature maps, thus enabling message passings between pixels across rows and columns in a layer. SCNN is particularly suitable for long continuous shape structures such as lane markings or poles.

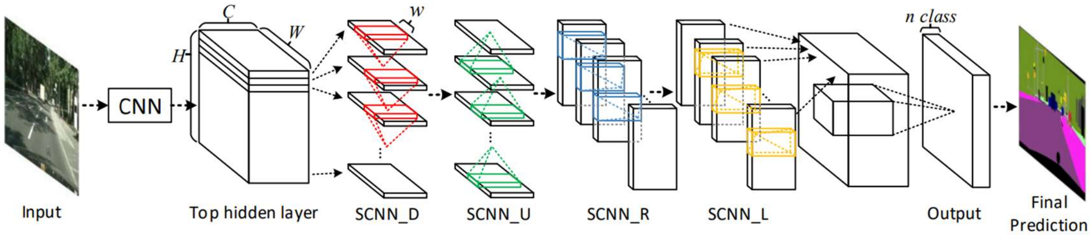


Figure 23, the architecture of SCNN, image source: https://arxiv.org/pdf/1712.06080.pdf

The SCNN views rows or columns of feature maps as layers. SCNN has a 3D tensor of size CHN, where C, H, and W denote the number of channels, rows, and columns respectively. The tensor will be split into slices and sent into convolution layers with C kernels. The SCNN will do the similar processes four times. It will convolute downward, upward, rightward, and leftward respectively. By this way, SCNN message passing can be realized in a sequential propagation scheme. Thus, it makes computation more efficient.

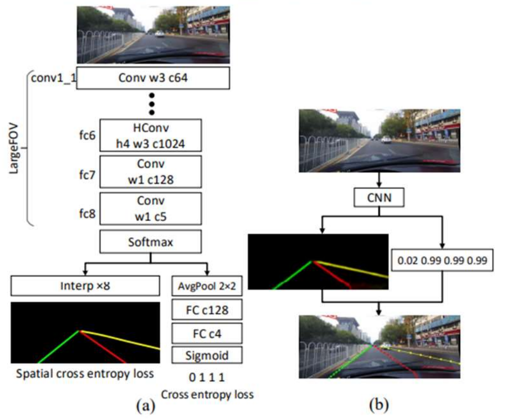


Figure 5: (a) Training model, (b) Lane prediction process. 'Conv','HConv', and 'FC' denotes convolution layer, atrous convolution layer (Chen et al. 2017), and fully connected layer respectively. 'c', 'w', and 'h' denotes number of output channels, kernel width, and 'rate' for atrous convolution.

Figure 24, the training and prediction process, image source:

https://arxiv.org/pdf/1712.06080.pdf

Unlike common object detection tasks that only require bounding boxes, lane detection requires precise prediction of curves. Instead of viewing different lane markings as one class, SCNN views different lanes as different lane markings. It is more robust to ordinary detection models.

Chapter 4 Global Market Analysis

4.1 Market Forecast

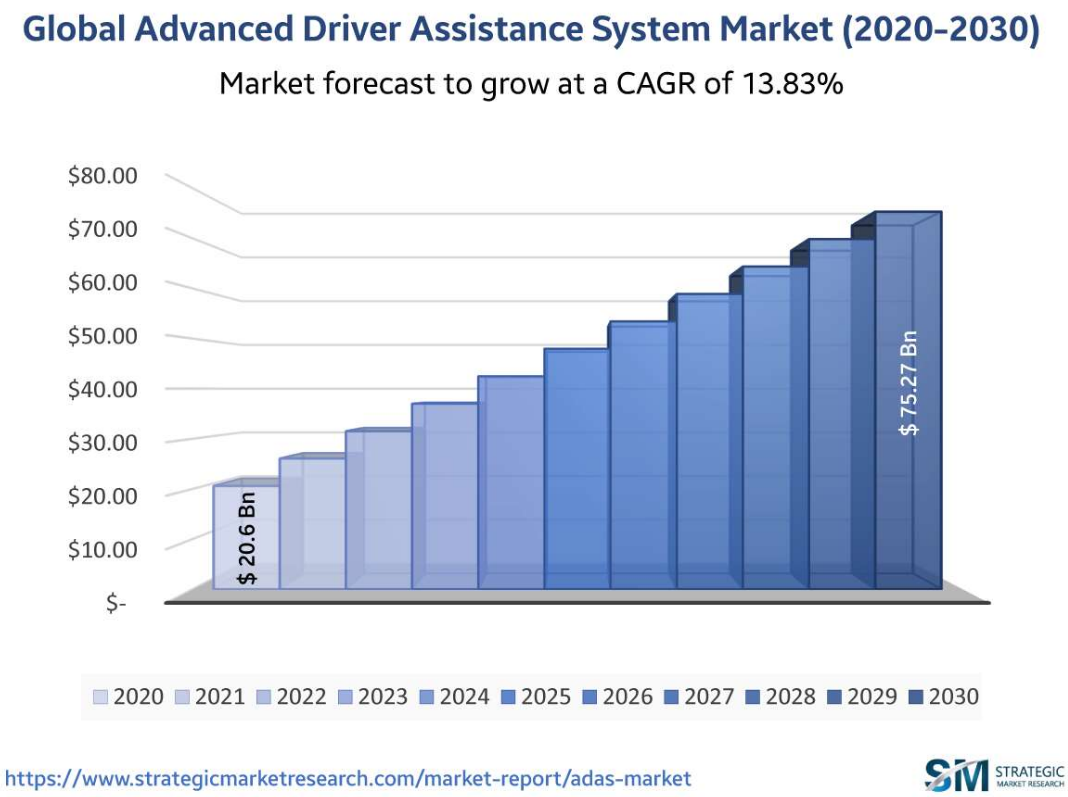


Figure 25, Global ADAS Market, image source: [https://www.strategicmarket-research.com/market-report/adas-market](https://www.strategicmarketresearch.com/market-report/adas-market)

According to a strategic market research report, the Advanced Driver Assistance Systems (ADAS) market was valued at $23.44 billion in 2021, and is expected to reach a value of $75.27 billion by 2030 due to a compound annual growth rate (CAGR) of 13.83%.

There are two key factors contributing to the strong growth of the Advanced Driver Assistance Systems (ADAS) market. The first is the increase in disposable income levels among consumers, and the second is the stricter enforcement of transportation regulations by authorities around the world.

One factor contributing to the growth of the Advanced Driver Assistance Systems (ADAS) market is the increase in disposable income among consumers. According to a study by the US Bureau of Economic Analysis, the average disposable income per individual in the US was $55,671. In Europe, the figure was €15,055, while in China, disposable income increased by 8.1% to approximately ¥35,000 in 2021. While certain components of ADAS systems may be considered premium features due to the precision machining and coding involved, the rising income levels of consumers allow for more widespread adoption of these systems without considering them a luxury.

The second factor contributing to the growth of the Advanced Driver Assistance Systems (ADAS) market is the stricter enforcement of transportation regulations by authorities around the world. The main purpose of ADAS is to prevent vehicular accidents and resulting loss of life. According to the US Department of Transportation's Fatality Analysis Reporting System (FARS), there were over 35,000 fatal vehicle crashes and more than 38,000 deaths in 2020. Similarly, European Commission statistics show that there were over 18,000 road accident deaths in Europe in 2020, and in China, there were over 67,000 fatalities due to road vehicle accidents in 2021. In an effort to make vehicles safer and reduce the number of accidents and fatalities, transport authorities have begun implementing national legislation mandating the use of advanced safety measures such as ADAS. For example, the European Commission introduced the updated General Safety Regulation (GSR) in 2019, and in the US, legislation was introduced in Congress in 2020 to require the use of lane-assist technology and automatic emergency braking in commercial trucks within two years of the act's passing. Therefore, the implementation of laws by national and global transport authorities will drive the growth of the ADAS market in the future.

4.2 SWOT Analysis

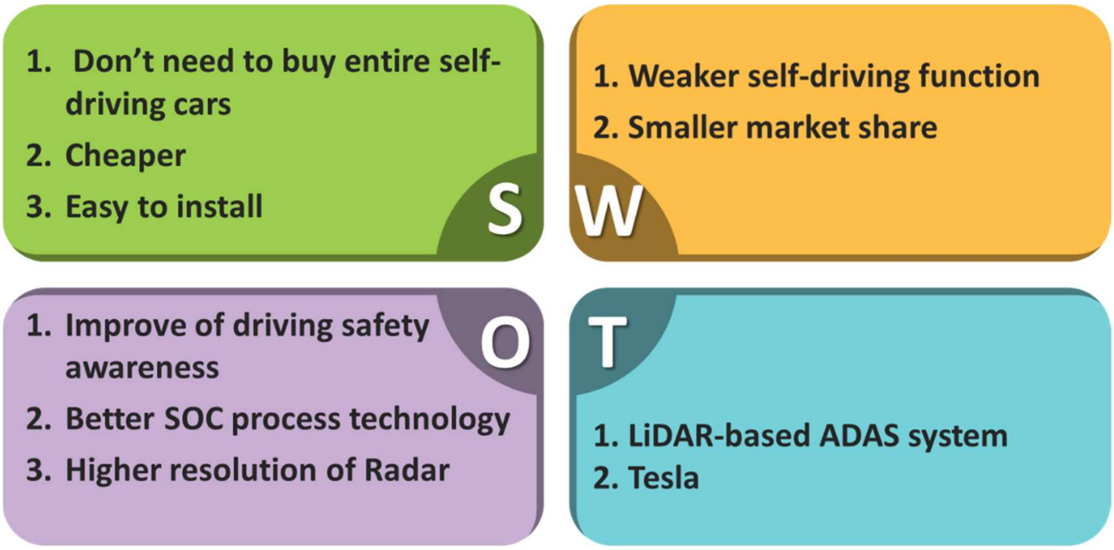


Figure 26, SWOT Analysis

Strength

- Product is cheap
- Convenience to install
- Don't need to buy entire self-driving car

Weakness

- Lack of self-driving function
- Smaller market share

Opportunity

- Development of a chip car and taxi market
- Improve of driving safety awareness
- Better SoC process technology
- Higher resolution of camera

Threat

- Many companies are more mature in this regard, such as Tesla
- Normal Dashcam

4.3 Porter's 5 Forces Analysis

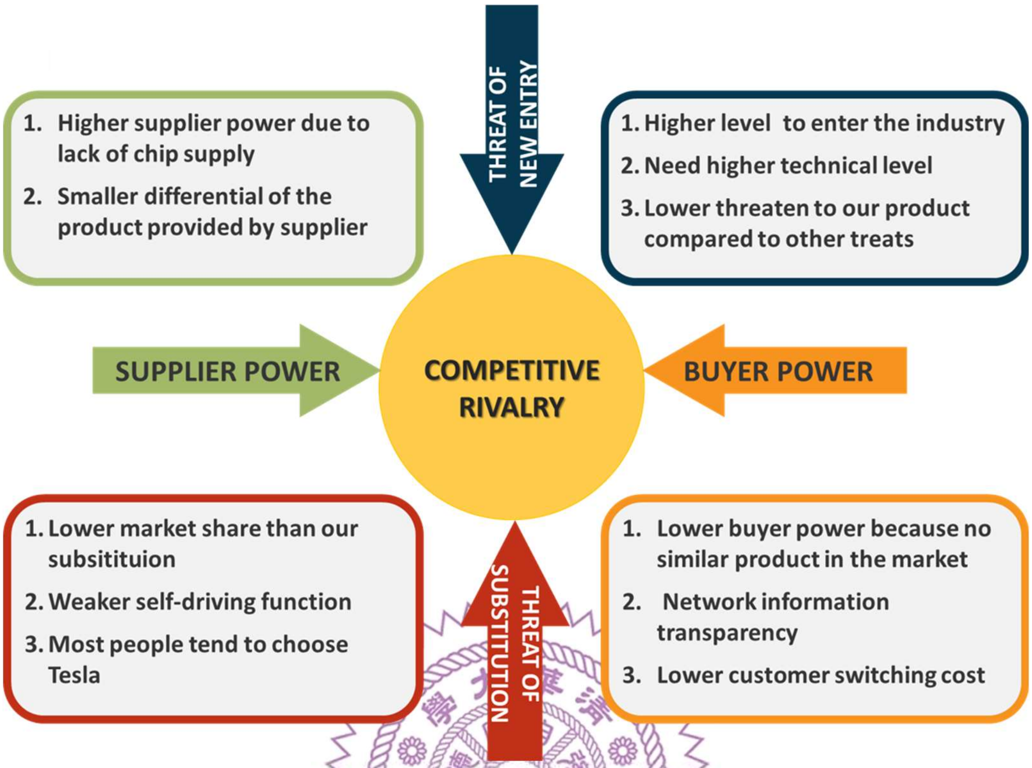


Figure 27, Porter's 5 Forces Analysis

Threat of new entry

- Higher level to enter the industry
- Need higher technical level
- Lower threaten to our product compared to other treats

Buyer power

- Lower buyer power because no similar product in the market
- Network information transparency
- Lower customer switching cost

Threat of substitution

- Lower market share than our substitution
- Weaker self-driving function
- Most people tend to choose Tesla

Supplier power

- Higher supplier power due to lack of chip supply
- Smaller differential of the product provided by supplier

Competitive revalry

- no competitors in the market

Reference

Radar Sensor —— TI AWR 2944

[1] https://pressureprofile.com/sensors/digitacts

[2] https://cdn2.hubspot.net/hubfs/5361756/Spec%20Sheets/Spec%20Sheet_Digi-Tacts%20Sys-tem.pdf?__hstc=57482165.7b47cad7ed79f0c6c059ea4d87fe50ad.1672817794233.1672817794233.1672820140562.2&__hssc=57482165.1.1672938130050&__hsfp=2977007349&hsCtaTracking=4427830a-a50d-4af1-b425-660de65748d0%7Cd684d85b-195b-4d34-a900-a1b2273652b7

Gas sensor —— Gravity: MEMS Gas Sensor

[3] https://www.dfrobot.com/product-2417.html

[4] https://img.dfro-bot.com.cn/wiki/5b973267c87e6f19943ab3ad/ec7dd3a55ba1d58fcbd5830ee08c0e7f.pdf

[5] https://img.dfro-bot.com.cn/wiki/5b973267c87e6f19943ab3ad/b5b08fe2ea631f0becdfa0c15db88c4a.pdf

Pressure SensorDigitacts

[6] https://pressureprofile.com/sensors/digitacts

[7] https://cdn2.hubspot.net/hubfs/5361756/Spec%20Sheets/Spec%20Sheet_Digi-Tacts%20Sys-tem.pdf?__hstc=57482165.7b47cad7ed79f0c6c059ea4d87fe50ad.1672817794233.1672817794233.1672820140562.2&__hssc=57482165.1.1672938130050&__hsfp=2977007349&hsCtaTracking=4427830a-a50d-4af1-b425-660de65748d0%7Cd684d85b-195b-4d34-a900-a1b2273652b7

AI Accelerator: WiseEye WE-I Plus HX6537-A

[8] https://www.himax.com.tw/wp-content/uploads/2020/06/Himax-Launches-WiseEye-WE-I-Plus-HX6537-A-to-Support-AI-Deep-Learning-with-TensorFlow-Lite-for-Microcontroller_-final.pdf

[9] https://cdn.sparkfun.com/assets/1/b/b/2/1/WE-I_Plus_EVB_Technical_Document_v03.pdf

[10] https://en.wikipedia.org/wiki/AI_accelerator

YOLOv7 for Object Detection

[11] https://arxiv.org/pdf/1506.02640v5.pdf

[12] https://chih-sheng-huang821.medium.com/%E6%A9%9F%E5%99%A8-%E6%B7%B1%E5%BA%A6%E5%AD%B8%E7%BF%92-%E7%89%A9%E4%BB%B6%E5%81%B5%E6%B8%AC-non-maximum-suppression-nms-aa70c45adffa

[13] https://arxiv.org/pdf/1804.02767.pdf

[14] https://arxiv.org/pdf/2207.02696.pdf

[15] https://arxiv.org/pdf/1612.03144.pdf

[16] https://arxiv.org/pdf/1612.03144.pdf

[17] https://arxiv.org/pdf/2004.10934.pdf

[18] https://arxiv.org/pdf/1911.11929.pdf

SCNN for lan detection

[19] https://arxiv.org/pdf/1712.06080.pdf

Bluetooth Low Energy 4.0

[20] https://hackmd.io/@ShenTengTu/SkPltNmiE?type=view

[21] https://medium.com/@nalydadad/%E6%A6%82%E8%BF%B0-gatt-%E8%97%8D%E8%8A%BD%E5%82%B3%E8%BC%B8-9fa218ce6022

[22] https://ithelp.ithome.com.tw/articles/10224000

[23] https://www.ti.com.cn/cn/lit/an/swra715/swra715.pdf?ts=1656944702493

[24] https://www.2cm.com.tw/2cm/zh-tw/market/B1C12F26DAD442478C0CACF162E9D44D

[25] https://www.researchgate.net/figure/3-Comparison-of-Classic-Bluetooth-and-Bluetooth-Low-Energy-BLE-46_tbl3_341913410

[26] https://microchipdeveloper.com/wireless:ble-phy-layer

[27] https://wifivitae.com/2020/05/01/ble-overview/

[28] https://cdn.sparkfun.com/datasheets/Wireless/Bluetooth/RN-HID-User-Guide-v1.0r.pdf

Market analysis

[29] https://www.globenewswire.com/en/news-release/2022/07/20/2482868/0/en/Advanced-Driver-Assistance-Systems-ADAS-Market-Worth-USD-75-27-Billion-by-2030-With-a-CAGR-of-13-83.html

Team Member Task Partition

Our work has been divided into the following tasks. Great thanks to 瑞憫 for organizing the work, to 皓姿 for the great presentation, and to 子晴 for handling the difficult task of working with the special sensors.

陳劭珩：**CPU, DSP, Radar**

洪子晴：**Presure Sensor, Gas Sensor**

徐瑞憫：**AI accelerator, YOLOv7, SCNN**

林亭君：**Introduction, Memory**

鄭皓姿：**Bluetooth LN 4.0 HID**