CHAPTER 2

HARDWARE AND SOFTWARE PART OF SMARTPHONE FOR DEVELOPMENT OF DIFFERENT SENSING PLATFORM

This chapter discusses the different embedded sensors of the smartphone and other functional components that have been used to develop a reliable and affordable sensing system. The functionality of CMOS imaging sensor and ALS of the smartphone have been used as detector for the development sensing platforms in the present thesis work have been discussed in detail. In addition, the chapter covers the description of the software platforms that have been used to transform the smartphone sensing tool into a user-friendly standalone data analysis platform.

2.1 Introduction

With the rapid advancements in technology, smartphone technology has evolved into the most useful and important tool for human activities today. Nowadays, a modern smartphone serves as a platform for the integration of different consumer-oriented intelligent sensors and other functional components due to the rapid advancement of the technology. Due to the technological achievements, miniaturizations of integrated chips and as a result of falling prices, this technology has penetrated to the far remoted place on the earth. According to reports, there are more than six billion smartphone users globally till 2022, with a penetration rate of 66.21 % [1]. The penetration of mobile phones in developing as well as under developed countries is now promoting many developmental initiatives by various governmental and non-governmental organizations [2]. The embedded sensors can monitor a range of mechanical parameters, including motion and tilt, as well as environmental factors, including ambient lighting, temperature, pressure, and humidity [3]. Apart from the hardware, a modern smartphone is a perfect platform for the development of need-based computation or smart apps that can be used to accurately and precisely extract the raw sensor data. The major operating systems (OS) that are used in current smartphones are Android from Google, Inc., iOS from Apple, Inc., and Windows from Microsoft, Inc. Each of the OS gives the smartphone a unique design and set of features. With a market share of 70% worldwide, Android dominates the smartphone industry [4]. The high market share of Android OS over its counterpart is attributed to the availability of numerous open source application development framework that encourages the creation of more android-based applications. The most popular platform for developing applications is Google's Android Studio, which is a free software platform [5]. Other open source drag and drop cloud-based platforms, such as "MIT App inventor" and "Thunkable," are frequently used platform to develop a variety of applications in addition to Android Studio, which demands rigorous programming skills [6]. The Android sensor framework allows access to the sensor data in devices running the Android operating system. Numerous practical applications can be made of the sensor data [7]. The sensing tools developed in this thesis work are developed on Android powered smartphones due to the wide availability of these devices and the comparatively simple and free application development environment. The details of the embedded sensors, functional components, and computing platform that are utilized to design the different smartphone sensing systems are covered in this chapter.

2.2 Integrated smartphone sensors and their functionalities

Modern day smartphones are equipped with many smart sensors to upgrade their ease-of-use, capability, and management. A sensor is a device that measures physical input and transforms it into data that can be understood by either a human or decoded by a machine. The thermometer is an example of a conventional sensor that measures the temperature of any physical system and shows the result in terms of a number that can be easily understood by the user. Nowadays, most smartphones are provided with various sensors, including proximity sensors, accelerometer, temperature sensors, ambient light sensors, GPS, gyroscope, etc. These built-in sensors can measure motion, orientation, and various environmental conditions. The embedded sensors in smartphones can be classified based their working ability as motion sensors, environmental sensors, and position sensors. Each category of sensors is capable of sensing different parameters and is selected and arranged based on its application. Motion sensors are referred to sensors which attain information about movement and orientation of a device along the three axes. Almost all smartphones are equipped with motion sensors such as accelerometers, gravity sensors, gyroscopes, and rotational vector sensors. The environmental sensor monitors numerous parameters like temperature and pressure, illumination, and humidity of our surroundings. This type of sensor includes barometers, photometers, and thermometers. The position sensors provide information on the physical location of a device. Examples of this category of sensors are magnetometers, GPS, and orientation sensors [7]. The description of some standard smartphone sensors is given in Table 2.1.

In the current thesis work, the embedded ALS and CMOS sensor of smartphone have been used as detector for the purpose of developing various optical sensing platforms. The micro USB connection has been utilized to charge external LEDs from the smartphone battery using the USB-OTG protocol. In the following subsection, the technical specifications of the utilized sensors and the functional components in the development of the sensing tools are covered.

2.2.1 Use of integrated sensors and optical source of the smartphone for the development of different sensing systems

The embedded CMOS sensor of the smartphone has been widely used as an imaging sensor for a variety of applications, including microscopy, spectroscopy, and colorimetry [8–10]. From phone to phone, the optical design of the inbuilt camera module may differ. As shown in figure 2.1, it can be viewed simply as an assembly comprising a focusing lens and CMOS sensor. The smartphone camera module is primarily created for consumer application like photography, hence its response is only available in the visible field of view. The phone camera sensor response is sensitive in the wavelength range 400 nm to 700 nm wavelength range due to the involvement of an infrared (IR) filter in the sensor chip. All smartphones of the current generation have Bayer image sensor, which is a pixel array with red, green, and blue filters organized in a Bayer pattern [11]. The digital color picture formation in accordance with the Bayer pattern generation schematic is shown in figure 2.2 for the smartphone's CMOS image sensor. The data from each pixel can only partially identify each of the red, green, and blue values since each pixel is filled to record only one of three colors. Different binarization methods can be used to interpolate a set of complete red, green, and blue values for each pixel in order to produce a full-color image. To estimate the values for a specific pixel, these methods use the adjacent pixels of the respective colors. An imaging sensor's photodiodes records the intensity

Table 2.1: Standard smartphone sensors.

Sensors	**Type**	**Description**	**Applications**
Accelerometer	Hardware	Measures the acceleration force in m/s^2 that is applied to a device on all three physical axes (x, y, and z)	Detects motion and changes in the device's direction
Ambient temperature sensor	Hardware	Measures the ambient room temperature in degrees Celsius (°C)	Monitors temperature of air
Gyroscope	Hardware	Measures rate of rotation of a device in rad/s around each of the three physical axes (x, y, and z)	Detects spin or turn of a device
Light sensor	Hardware	Measures the ambient light (illumination) in lx	Adjust the screen brightness
Magnetometer	Hardware	Measures strength of the magnetic field around the phone for all three physical axes (x, y, z)	Works as a compass
Proximity sensor	Hardware	Measures the distance of an object in cm relative to the view screen of a device	Detects position of the Phone during a call
Barometer	Hardware	Measures the surrounding air pressure in hPa or mbar	Monitors changes in air pressure
Humidity sensor	Hardware	Measures the relative humidity of surrounding medium in percent	Monitors dew point, absolute, and relative humidity
Global Positioning System	software	Measures the latitude and longitude of the current location of the device	Uses a user's location to show the nearby information
Audio sensor (microphone)	Hadware	Measures sound in air into an electrical signal	Records voices

values in shades of grey using an 8-bit integer (0 to 255 levels). These numbers can be changed within the smartphone system to reconstruct the color image and display it on the phone's screen. Using specially designed smartphone applications, the images can be examined to determine pixel intensity or can be used in other image processing applications, such as microscopy, spectrophotometry, and colorimetry.

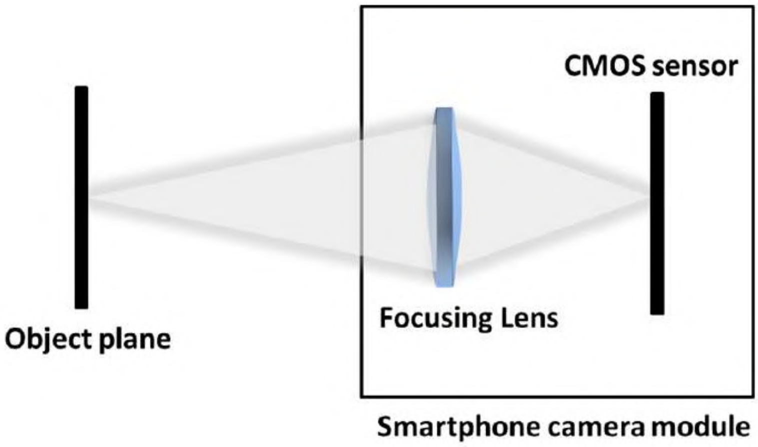

Figure 2.1: A smartphone camera's optical setup.

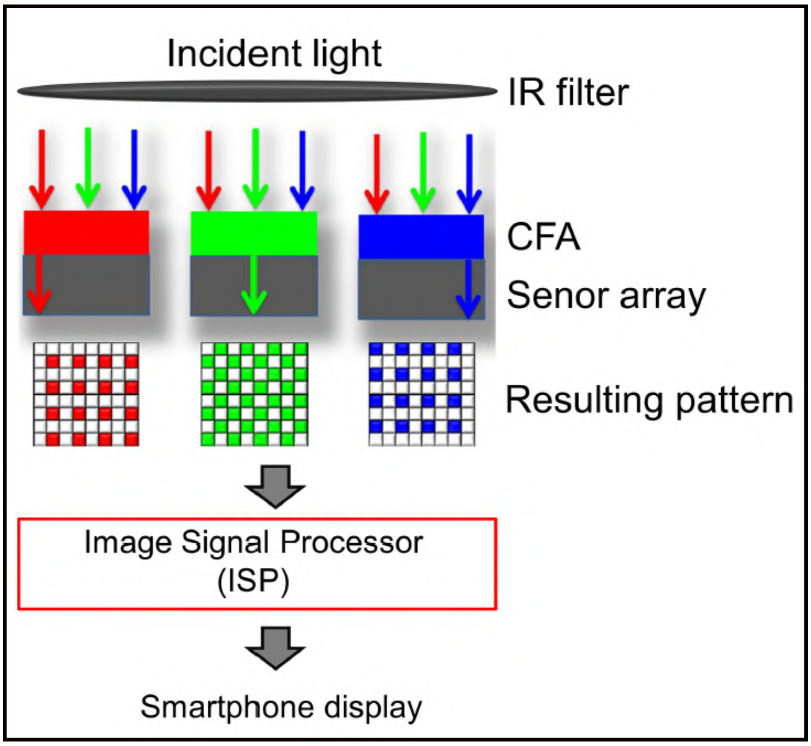

Figure 2.2: Schematic diagram of Bayer pattern production and digital colour image detection of a smartphone's CMOS sensor.

The ALS is embedded into the front panel of the smartphone and is designed to optimize the power consumption by automatically adjusting the display brightness in accordance with the ambient light conditions. Avago APDS-9930 or ams

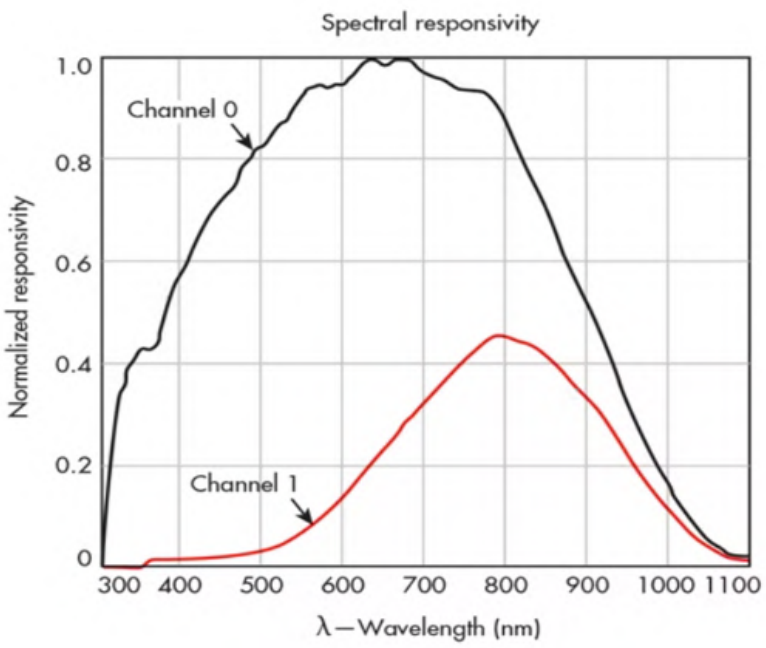

Figure 2.3: Response characteristic of the photodiode channels in Avago APDS-9930 sensor chip as adopted from the datasheet [12].

AG(TAOS) TMD2771 ambient light and proximity sensor chips are mostly used in almost all branded smartphones [12, 13] The Avago APDS-9930 sensor chip contains two photodiode channels 0, 1 and an IR LED as shown in figure 2.3.

The peak wavelength response of the channel 1 photodiode channel is in the wavelength range of 700 nm to 900 nm while the channel 0 photodiode channel is sensitive in the wavelength range of 350 nm to 1000 nm. Figure 2.4 shows the functional block diagram of Avago APDS-9930 sensor chip. This sensor chip provides on chip integrating amplifiers, ADCs, accumulators, clocks, comparators, a state machine and an I2C interface needed for device functioning. Upon detecting any light signal by the photodiode channels 0 and 1, the amplified photodiode current is converted to 16 bit digital values by the ADC unit. The converted digital values are then transferred to the channel 0 and channel 1 data registers from where the digital output can be read by a microprocessor for further processing where illuminance of the ambient light level can be read in terms of Lux units. From the microprocessor, the signal data can be communicated to the central smartphone processor through a fast two-wire Inter-Integrated Circuit or I^2C serial bus. Now, from the Android Sensor manager module, the ALS data can be accessed by user designed smartphone applications. The smartphone ALS serves as an excellent alternative over laboratory grade photodetector which may find its usability in many optical sensing applications. In some parts of the thesis work, the usability of the ALS has been explored to develop various optical platforms.

The micro USB port of the smartphone is used to charge the battery. The micro

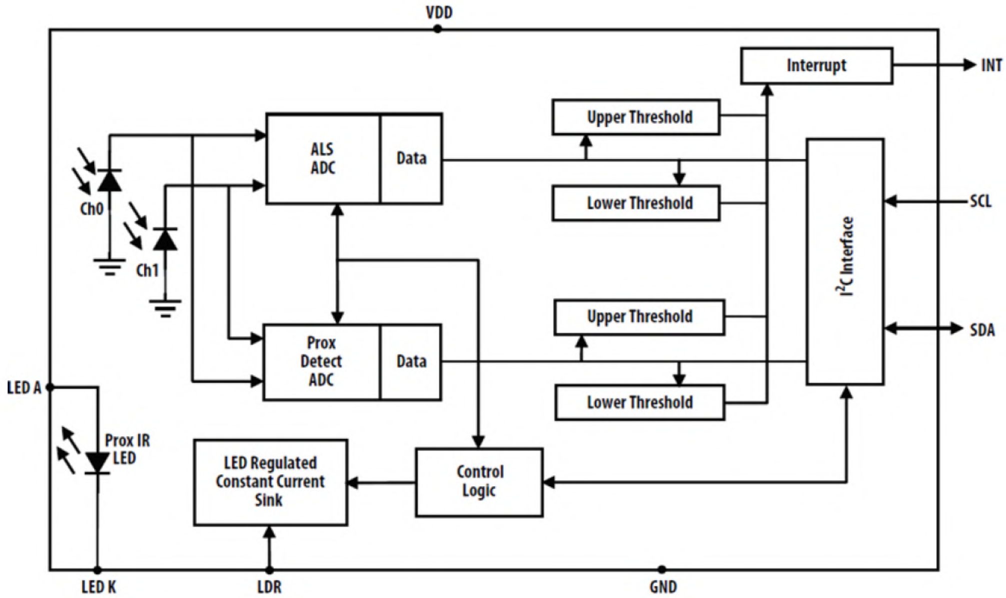

Figure 2.4: Functional block diagram of Avago APDS-9930 sensor chip as adopted from the datasheet [12].

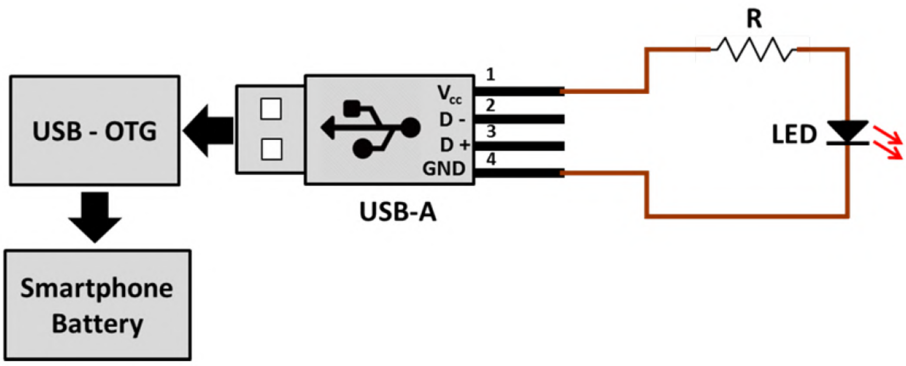

Figure 2.5: Circuit diagram for powering an external LED by the smartphone battery.

USB port can be used to interact with peripheral devices such as flash drives through USB On-The-Go (USB-OTG) protocol which is a communication specification port to provide access and storing of data to the host device [14]. The USB-OTG cable can also be used to power an external LEDs or any other optical source. Figure 2.5 shows the circuit diagram for connecting an external LED to the micro USB port of the smartphone. The output current rating of the smartphone micro USB port at 5V is 500 mA respectively. A resistor of value (250 Ω) is used in the present work to limit the current for illuminating an external LED.

2.3 Software platforms for development of the sensing tool

To develop a fully user-friendly, standalone, and handheld sensing system, software/applications plays a critical role for enabling the sensing system to be operated by a common citizen. The incredible processing power of modern smartphones allows for the onboard computation of sophisticated algorithms. The Android sensor manager module allows access to the sensing information of the embedded sensors. The flow diagram for the Android sensor subsystem is shown in figure 2.6. The sensing information from the CMOS sensor and ALS can be extracted by developing customized user-friendly smartphone applications. The ”MIT App inventor” platform has been utilized to create the mobile applications for the present thesis work. This is a cloud-based open source software platform created by Google and is now being maintained by Massachusetts Institute of Technology (MIT) [6].The block codes, which are drag-and-droppable blocks of code, are used in this platform to create the apps. This platform requires users to log in using a Google account. The platform offers two websites: Designer and Blocks editor, both of which have every feature needed to create an Android application.

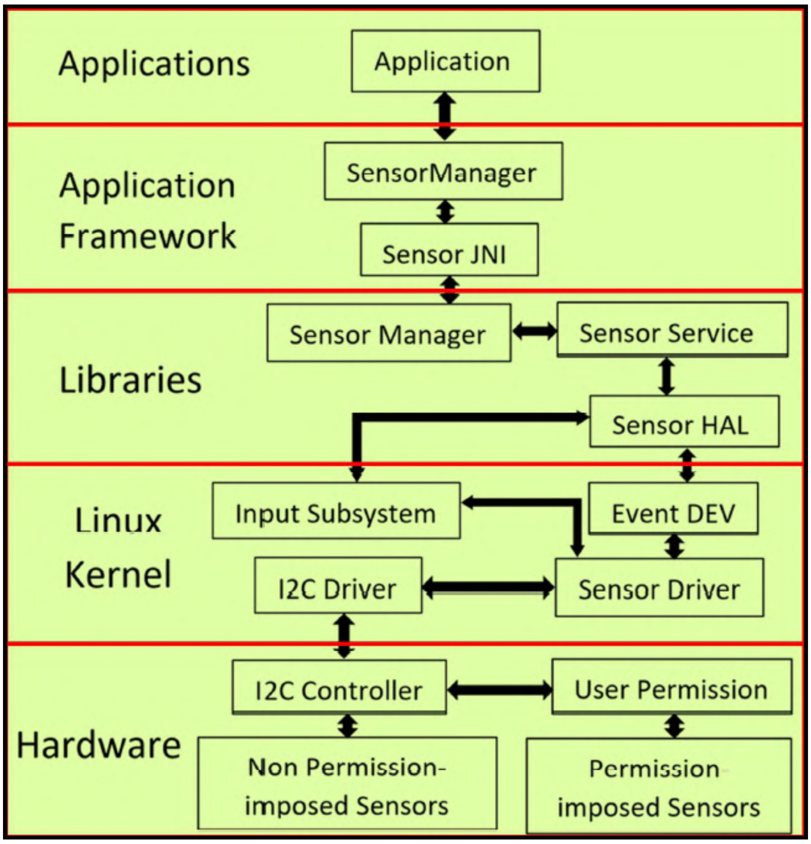

Figure 2.6: Functional block diagram of Avago APDS-9930 sensor chip as adopted from the datasheet [12].

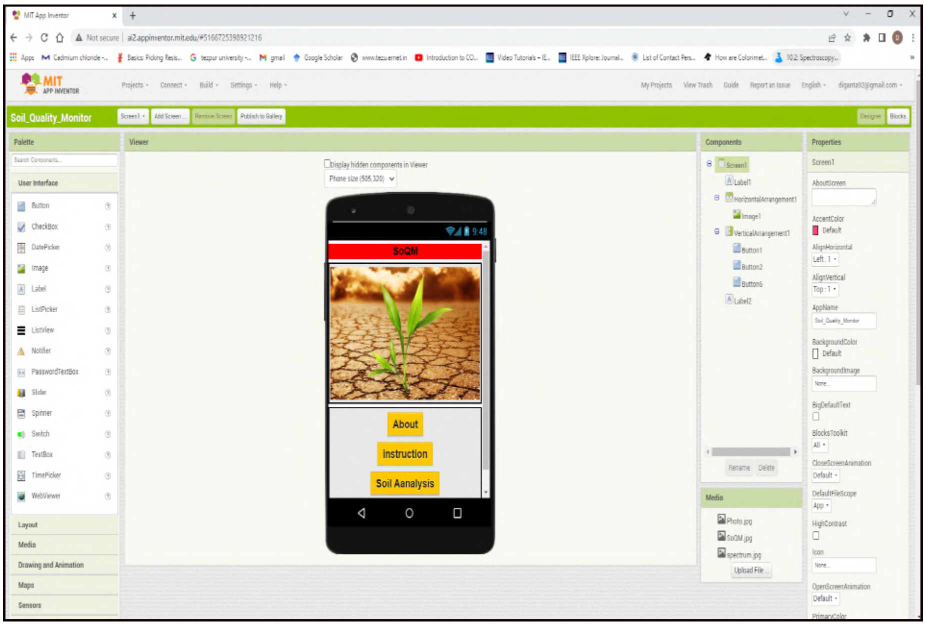

Figure 2.7: MIT App inventor Designer webpage.

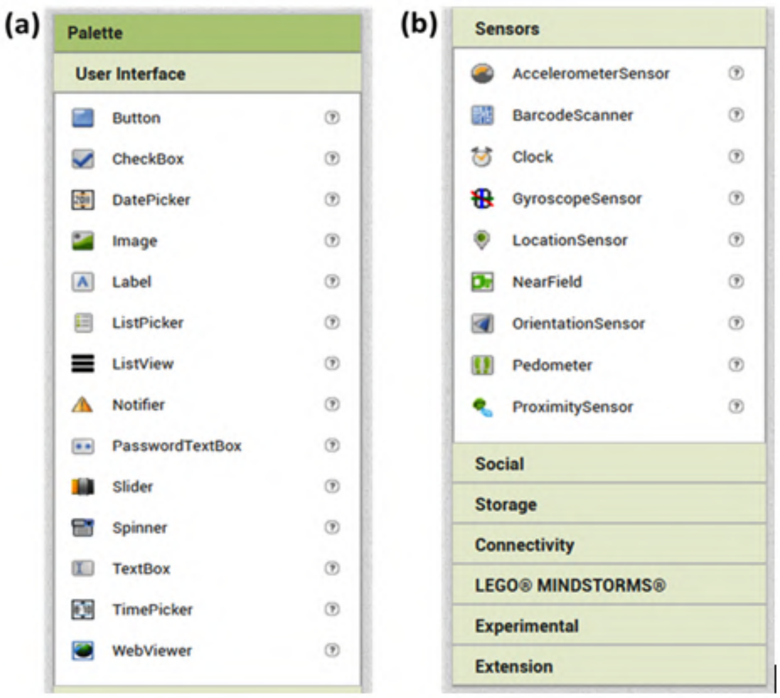

Figure 2.8: Components in Designer webpage for designing user interface of the application.

Figure 2.7 depicts the designer webpage, and the four red-marked sections inside represent the various functionalities it provides. The "Palette" in Region 1 has every part needed for designing a smartphone application, including buttons, sensors, and extensions. Upon clicking on "User Interface," as shown in figure 2.8(a), the user can access all the elements needed to create the application's user interface. Similarly, by clicking the "Sensors" button in figure 2.8(b), one may access all of the sensor components. Region 2 displays the ”Viewer,” where the user can drag and drop the necessary parts from the ”Palette” displayed in region 1 as needed. The various components required to create the user interface are displayed in region 3 of the web interface. These features of the components that are used to create the user interface in the ”Viewer” are displayed in Region 4. The component’s parameters and the user interface’s design can both be altered using this region.

2.4 Summary

In summary, different features of the sensors and other functional parts of a smartphone have been discussed in this chapter. The suitability of embedded CMOS sensor and ALS as an optical detector for various type of sensing studies has been naratted. Along with other components, the usage of the phone’s USB port as a power source has also been briefly narrated. The necessary application can be created for extracting data from the built-in sensors and using the same application the data can be processed within the phone itself. By using freely available software platforms like MIT App Inventor custom designed application can be developed to enable the designed sensor to be used by common citizen. Information on creating analytical applications using this platform has been included at the end of this chapter.

References

[1] Union, I. I.t. union, ict facts and figures 2022, 2022. URL http://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx./. Accessed on: 2022-09-20.

[2] Hutchings, M. T., Dev, A., Palaniappan, M., Srinivasan, V., Ramanathan, N., Taylor, J., Ross, N., and Luu, P. mwash: mobile phone applications for the water, sanitation, and hygiene sector. *Report for Nexleaf Analytics & the Pacific Institute*, pages 1–115, 2012.

[3] Khan, W. Z., Xiang, Y., Aalsalem, M. Y., and Arshad, Q. Mobile phone sensing systems: A survey. *IEEE Communications Surveys & Tutorials*, 15(1):402–427, 2012.

[4] Curry, D. Android statistics. 2021. *Business of apps (June 3, 2021). URL: https://www. businessofapps. com/data/androidstatistics/(visited on 10/21/2021)*, 2021.

[5] Android. Android studio, 2022. URL https://developer.android.com/studio. Accessed on: 2022-09-22.

[6] Massachusetts Institute of Technology, M. Mit app inventor, 2016-2021. URL https://appinventor.mit.edu/. Accessed on: 2022-03-15.

[7] Android. Sensors overview, 2022. URL https://developer.android.com/guide/topics/sensors/sensors_overview. Accessed on: 2022-03-15.

[8] Hussain, I. and Bowden, A. K. Smartphone-based optical spectroscopic platforms for biomedical applications: a review. *Biomedical Optics Express*, 12(4): 1974–1998, 2021.

[9] Chen, W., Yao, Y., Chen, T., Shen, W., Tang, S., and Lee, H. K. Application of smartphone-based spectroscopy to biosample analysis: A review. *Biosensors and Bioelectronics*, 172:112788, 2021.

[10] Contreras-Naranjo, J. C., Wei, Q., and Ozcan, A. Mobile phone-based microscopy, sensing, and diagnostics. *IEEE Journal of Selected Topics in Quantum Electronics*, 22(3):1–14, 2015.

[11] Jia, M.-Y., Wu, Q.-S., Li, H., Zhang, Y., Guan, Y.-F., and Feng, L. The calibration of cellphone camera-based colorimetric sensor array and its application in the determination of glucose in urine. *Biosensors and Bioelectronics*, 74: 1029–1037, 2015.

[12] Broadcom. A. apds-9930., digital ambient light and proximity sensor, 2022. URL http://www.avagotech.com/products/optical-sensors/integratedambient-light-proximity-sensors/apds-9930. Accessed on: 2022-03-15.

[13] AMS. A. ag, ag.digital ambient light and proximity sensor, 2022. URL http://ams.com/eng/Products/Light-Sensors. Accessed on: 2022-03-15.

[14] USBIF. Usbif product search, 2022. URL ttp://www.usb.org/developers/onthego. Accessed on: 2022-03-15.