Chapter 2

Smartphone as a hardware and software platform for optical device development

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This chapter gives an overview of different embedded sensors and functional components of smartphone which have been used to develop different optical sensing platforms. The usability of the smartphone ALS as an optical detector has been throughly discussed by comparing its performance with a standard laboratory grade photodetector. Moreover, a brief overview of the computational platform used to develop the smartphone applications (smart apps) which has been used from detection and data analysis throughout this thesis work has been discussed at the end of this chapter.

2.1 Introduction

With rapid technological advancement, now a days, a modern smartphone becomes a platform for integration of various consumer oriented miniaturized sensors and other functional components. The embedded sensors are capable for monitoring of various mechanical parameters such as motion and tilt and other parameters such as ambient illumination, temperature, pressure and humidity [1]. Besides hardware, a modern smartphone is an ideal platform for development of need based computation or smart apps which can be used to extract the raw sensor data with high precision and accuracy. Smartphones can be broadly categorized by their operating systems (OS) viz. Android from Google, Inc., iOS from Apple, Inc. and Windows from Microsoft, Inc. etc. are major OS used in modern smartphones, each of which provides different look and functionality to the smartphone. Till 2017 with 85% of market share, Android becomes the most widely used OS within smartphones [2]. The superiority of Android OS over others may be due to its open source application development framework which promotes the development of more and more android based application. Google's freely available software platform 'Android Studio' is the most commonly used for application development [3]. Besides Android Studio which requires rigorous programming skills, other open source drag and drop cloud based platforms such as 'MIT App inventor' and 'Thunkable' are commonly being used to develop various applications [4,5]. In Android OS based smartphones, the sensor data can be accessed trough the Android sensor framework. The sensor data can be used for many real life applications [6]. Due to vast availability of the Android powered smartphones and relatively easy and free application development framework, the sensing tools designed in the present thesis work are mainly developed on Android based smartphones. In this thesis chapter, the detail about the embedded sensors, functional components and the computational platform used to develop the required smartphone applications for reliable functioning of the designed optical platforms are discussed.

2.2 Embedded sensors and functional components in smartphone

The embedded sensors in an android OS based smartphone can be categorized in two types: hardware-based and software-based [6]. The hardware-based sensors are physical sensors which directly yields the sensoristic data of the physical parameters, on the other hand in software-based sensors virtual sensors that make use of one or more hardware-based sensors to derive the sensoristic data. Table 2.1 provides the details of various sensors embedded in the smartphone that are supported by the Android platform. Besides these sensors there are many other useful functional components such as GPS, wi-fi, LED flash and micro USB are embedded in all the smartphone. In the present thesis work, the embedded ALS has been exploited as a light intensity detector for development of different optical sensing tools. Besides ALS, the camera module has been used for designing of smartphone based interferometric platform. The functional components such as LED flash has been used as a light

Table 2.1: Sensor types supported by the different variant smartphones

Sensors	**Type**	**Description**	**common uses**
Accelerometer	Hard-ware	Measure acceleration along x, y, and z axis	Motion detection due to shaking or tilting
Ambient light	Hard-ware	Measure illumination in Lux	To control the brightness of screen
Barometer	Hard-ware	Measure the ambient pressure	To monitor change in air pressure
Camera	Hard-ware	CMOS sensor	Image capturing and video recording
Gravity	Software or Hard-ware	Measure force due to gravity along x,y, and z axis	Motion detection due to shaking or tilting
Gyroscope	Hard-ware	Measures the rate of rotation of the device along x, y, and z axis	Rotation detection due to spinning and turning
Magnetometer	Hard-ware	Measures geomagnetic field along x, y, and z axes	Serves as magnetic compass
Orientation	software	Make use of the gravity sensor and the geomagnetic field sensor to obtain the inclination matrix and rotation matrix of the device	To determine the device position
Proximity	Hard-ware	Detects whether any object is present at the proximity of the screen of the smartphone	Makes the phone's screen insensitive to external touches
Relative humidity	Hard-ware	Measure the relative humidity of the surrounding	To monitor dew point, absolute and relative humidity
Temperature	Hard-ware	Measures the temperature of the device in degrees Celsius	To monitor device temperature.

source and the micro USB port has been used to power an external LEDs from the smartphone battery through USB-OTG protocol. The technical details of these sensors and functional components are discussed in the subsection below.

2.2.1 Brief overview of smartphone embedded sensors used to develop different tools for the present work

The ALS embedded in the front panel of the smartphone is meant for optimizing battery power consumption of the phone by controlling brightness of the display panel automatically in accordance with the surrounding environment. Almost all branded smartphones contain Avago APDS-9930 or ams AG(TAOS) TMD2771

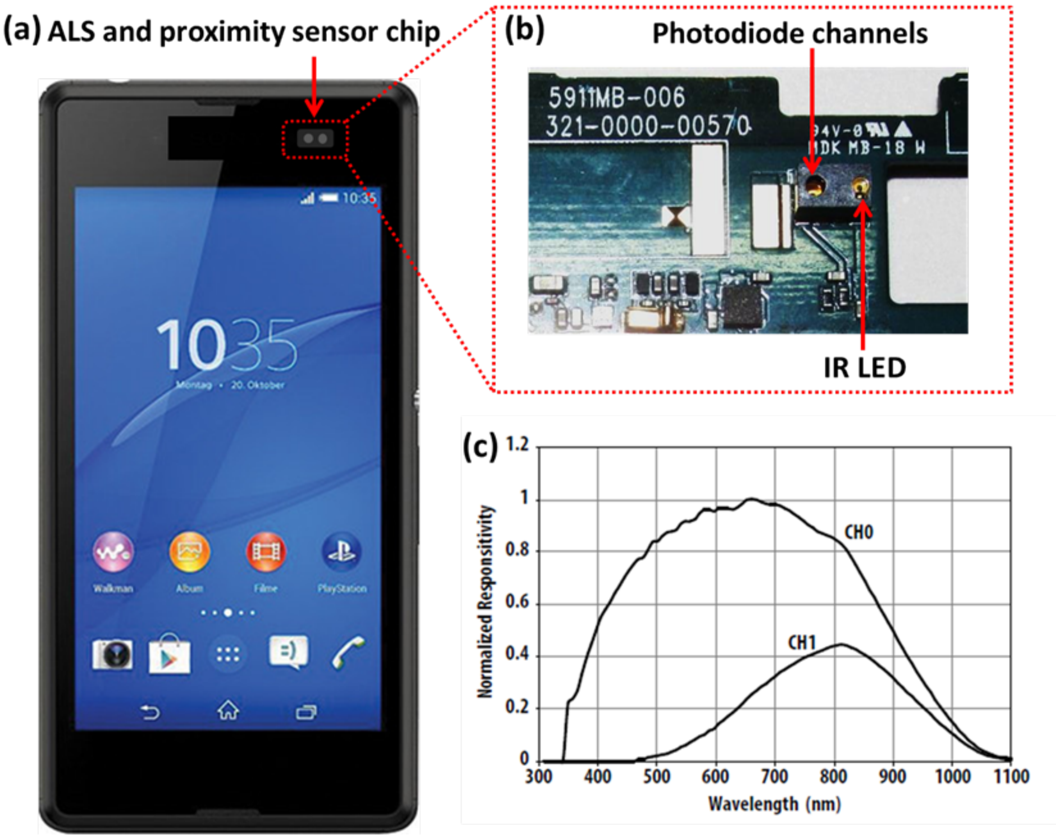

Figure 2.1: Embedded ALS in a Sony Xperia E3 smartphone: (a) position of the ALS, (b) photo image of integrated ambient light and proximity sensor chip, and (c) response characteristic of the photodiode channels in Avago APDS-9930 sensor chip as adopted from the datasheet [7].

ambient light and proximity sensor chip [7,8]. In the present thesis work,Sony Xperia E3 smartphone has been used for both detection and data analysis of the sensor signal. This smartphone is equipped with Avago APDS-9930 sensor chip [9]. The detailed specification of this smartphone has been provided in table 2.2. Figure 2.1 (a) shows the position of the integrated ambient light and proximity

Table 2.2: Detailed specifications of the Sony Xperia E3 smartphone

Body	Dimension	137.1 × 69.4 × 8.5 mm
	Weight	143.8 g
Display	Type	IPS LCD capacitive touchscreen
	Size	4.5 inches
	Resolution	480× 854 (218 ppi)
Platform	Operating system (OS)	Android 4.4.2 (KitKat) (Nougat)
	Central processing unit (CPU)	Quad-core 1.2 GHz Cortex-A7

sensor chip of the considered smartphone. Figure 2.1 (b) shows the in-built sensor module which contains two photodiode channels CHO, CH1 and an IR LED. As shown in figure 2.1 (c), the peak wavelength response of the CH1 photodiode channel is in the wavelength range of 700 nm to 900 nm while the CH0 photodiode channel has its responsivity in the wavelength range of 350 nm to 1000 nm which is used as the ALS in the smartphone. The embedded ALS of the smartphone has a signal intensity variation dynamic range of 0 Lux to 20000 Lux with resolution

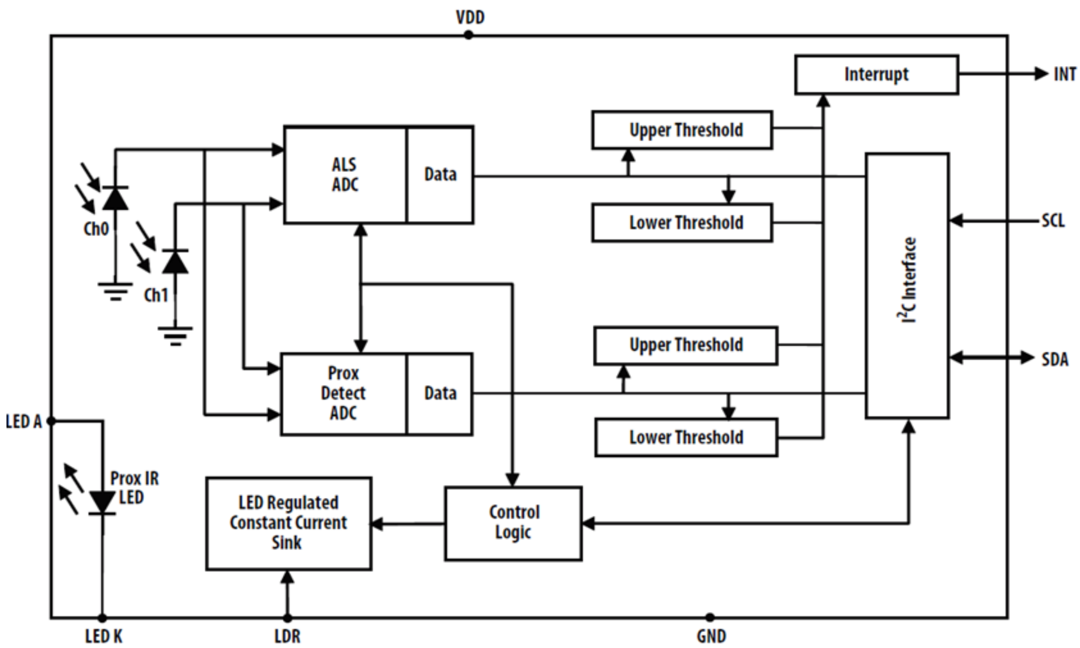

Figure 2.2: Functional block diagram of Avago APDS-9930 sensor chip as adopted from the datasheet [7].

of 0.01 Lux [7]. Figure 2.2 shows the functional block diagram of Avago APDS-9930 sensor chip.

This sensor chip provides on chip integrating amplifiers, ADCs, accumulators, clocks, buffers, comparators, a state machine and an I^2C interface needed for device functioning. Upon detecting any light signal by the photodiode channels CHO and CH1, the amplified photodiode currents are converted to 16 bit digital values by the ADC unit. The converted digital values are then transferred to the CH0 and CH1 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 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. To validate the applicability of the ALS to measure light intensity, the response of the ALS has been compared with that of a laboratory grade photo-detector. As shown in figure 2.3 (a), a collimated light beam from a fiber optic diode laser (2mW, 650nm) is allowed to incident on both the detectors by using a 50:50 beam splitter. It has been found that high intensity value leads to fluctuations in the ALS reading. To mitigate this issue, a thin nylon sheet has been used as a diffuser and place it in front of the ALS to reduce the incident intensity. The standard device used in this study is a laboratory grade photo-detector which is incorporated with a digital μ-Voltmeter to measure intensity in terms of voltage. The ALS reading has been recorded with a custom designed smartphone application. The intensity of the laser source has been changed by varying the source current in steps of 10 mA. Figure 2.3 (b) shows the corresponding response characteristics. It has been observed that the smartphone ALS shows similar characteristics as that of the laboratory grade photodetector. The ambient lighting condition can significantly affect the device performance. As shown in figure 2.3 (b) there is an offset in the laboratory grade photo-detector even when the laser source is turned off. The smartphone ALS has been packaged in such as way that only near normal incident light can reach the photodiode. Thus, no offset is observed in the intensity reading when the light source is turned off [7]. From this investigation, it can be concluded that the smartphone ALS is an excellent alternative over laboratory grade photo-

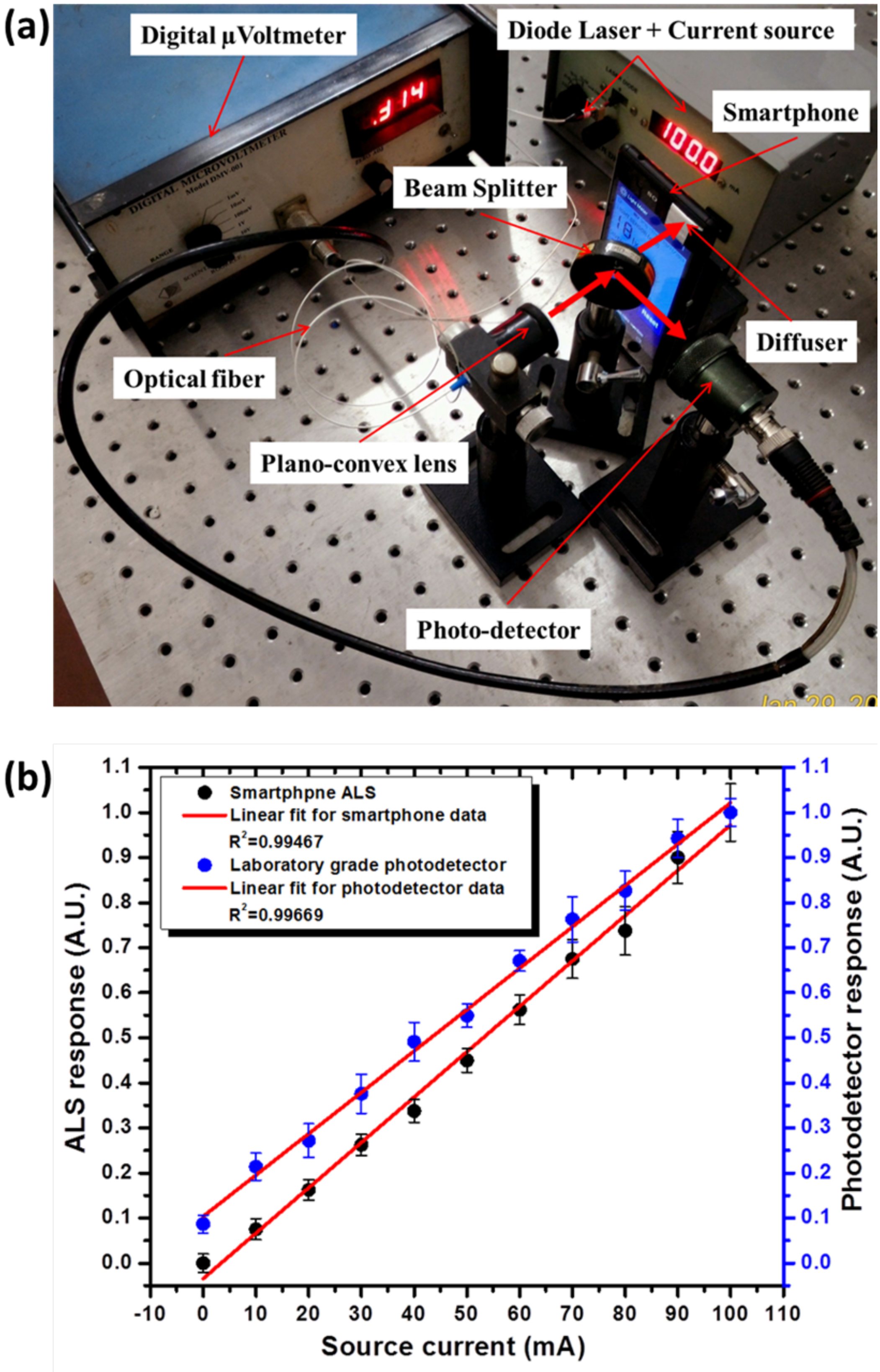

Figure 2.3: (a) Optical set-up for evaluation of ALS performance with that of a laboratory grade photo-detector and (b) Response characteristics for both the detectors.

detector which may find its usability in many optical sensing applications. In the present work, the usability of the ALS has been explored to develop various optical platforms.

Again, **the smartphone camera** has been extensively exploited as an imaging sensor for various applications such as microscopy, spectroscopy and colorimetry [11]. Yang et al. has extensively discussed about the embedded CMOS sensor of a smartphone in his PhD thesis [12], therefore, only a brief overview of the CMOS sensor has been given here. The optics design of the embedded camera module may vary from phone to phone. For simplicity, it can be considered as an assembly of a focusing lens and a CMOS sensor as shown in figure 2.4. The camera module is primarily developed in the smartphone for consumer applications such as photography, therefore, its response is limited to only visible region. The sensor

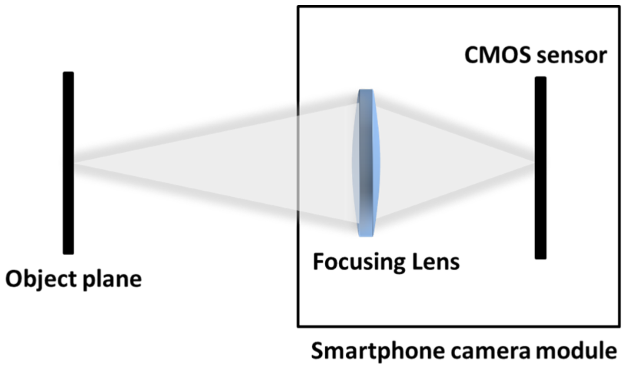

Figure 2.4: Optics design of a smartphone camera.

chip includes an infrared (IR) filter which limits the response of the smartphone camera in the wavelength range 400 nm to 700 nm. All the current generation smartphones are embedded with Bayer image sensor, which is a pixel array with red, green and blue filters arranged in a Bayer pattern [13]. Figure 2.5 shows the schematic of the Bayer pattern generation and the corresponding digital color image formation in the CMOS image sensor of the smartphone. Since each pixel is filtered to record only one of three colors, the data from each pixel cannot fully specify each of the red, green, and blue values on its own. To obtain a full-color image, various demosaicing algorithms can be used to interpolate a set of complete red, green, and blue values for each pixel. These algorithms make use of the surrounding pixels of the corresponding colors to estimate the values for a particular pixel. The photodiodes employed in an image sensor record intensity value in shades of grey in terms of 8-bit number (0 to 255 levels). Within the smartphone system these numbers can be manipulated to reconstruct the colour image and display in the phone screen. The images can be analysed to determine pixel intensity or other image processing applications through custom developed smartphone applications for further use in many applications such as microscopy, spectrophotometry and colorimetry.

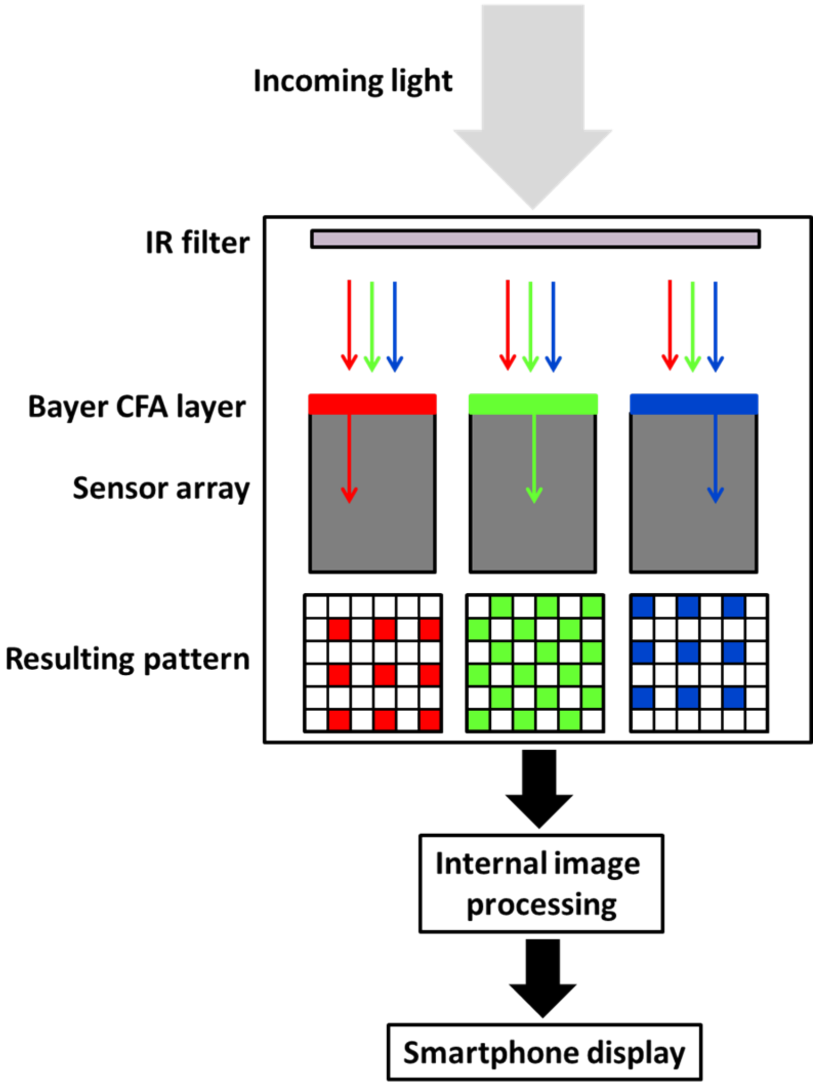

Figure 2.5: Schematic of Bayer pattern generation and digital colour image detection by a smartphone CMOS sensor.

The LED flashlight used in the smartphone is a super bright white LED with the emission wavelength ranging from 400 nm to 750 nm. Using required optical filters, the embedded LED flash can be used as a light source for many sensing applications. Figure 2.6 shows the emission spectrum of the LED flash embedded in the Sony Xperia E3 smartphone.

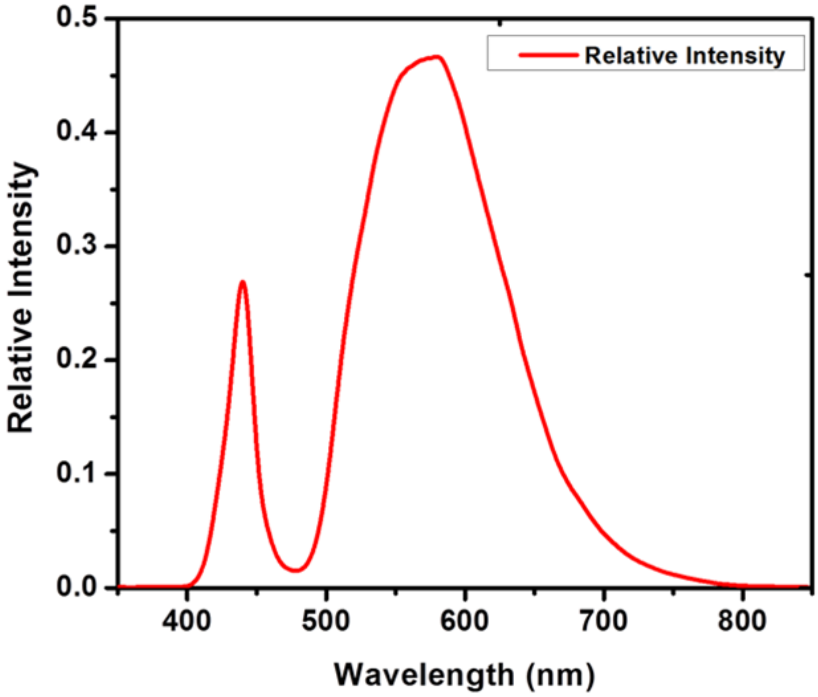

Figure 2.6: Emission spectra of the LED flash embedded in the Sony Xperia E3 smartphone recorded by optical sprectrometer.

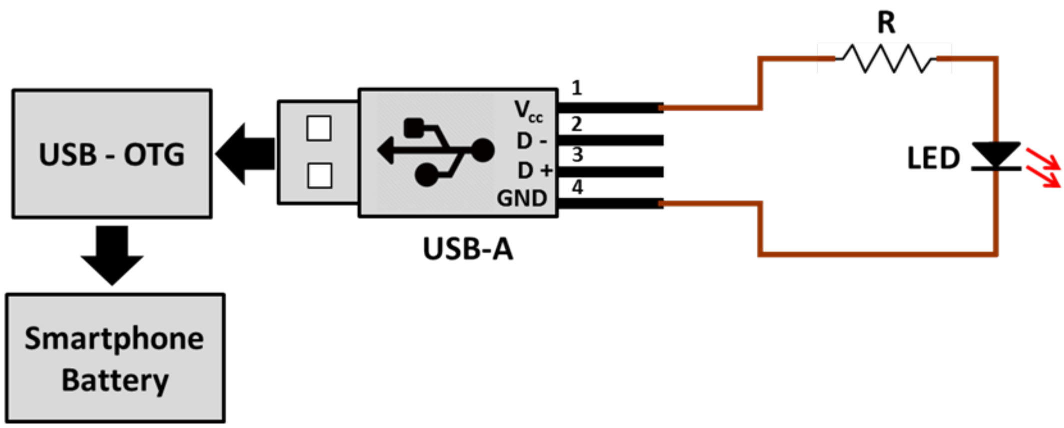

Figure 2.7: Circuit diagram for powering an external LED by the smartphone battery.

The micro USB port of the smartphone is used to charge the battery. The micro 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 be used to power external LEDs. Figure 2.7 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 Overview of the software platform used for application development

As discussed in the above section, the sensing data of the embedded sensors can be accessed from the Android sensor manager module. Figure 2.8 shows the flow diagram of the Android sensor sub system. The intensity data of the ALS can be

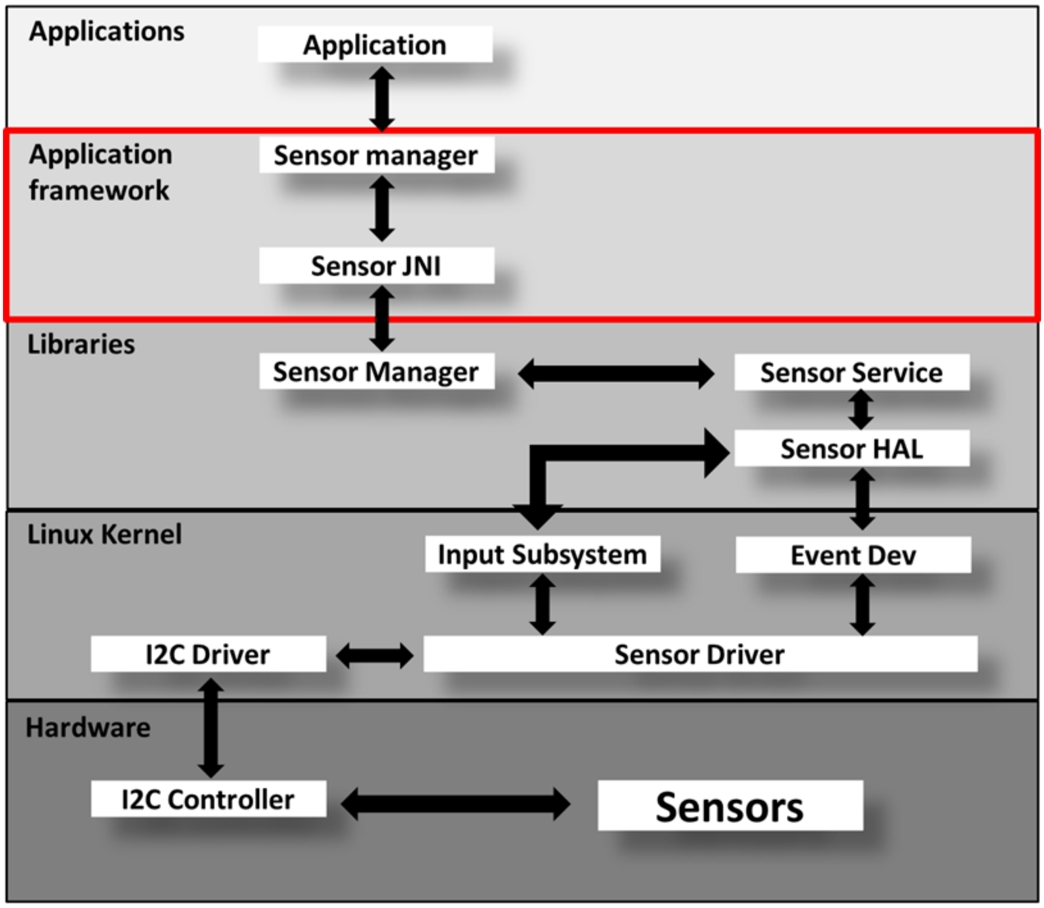

Figure 2.8: Functional block diagram of Avago APDS-9930 sensor chip as adopted from the datasheet [7].

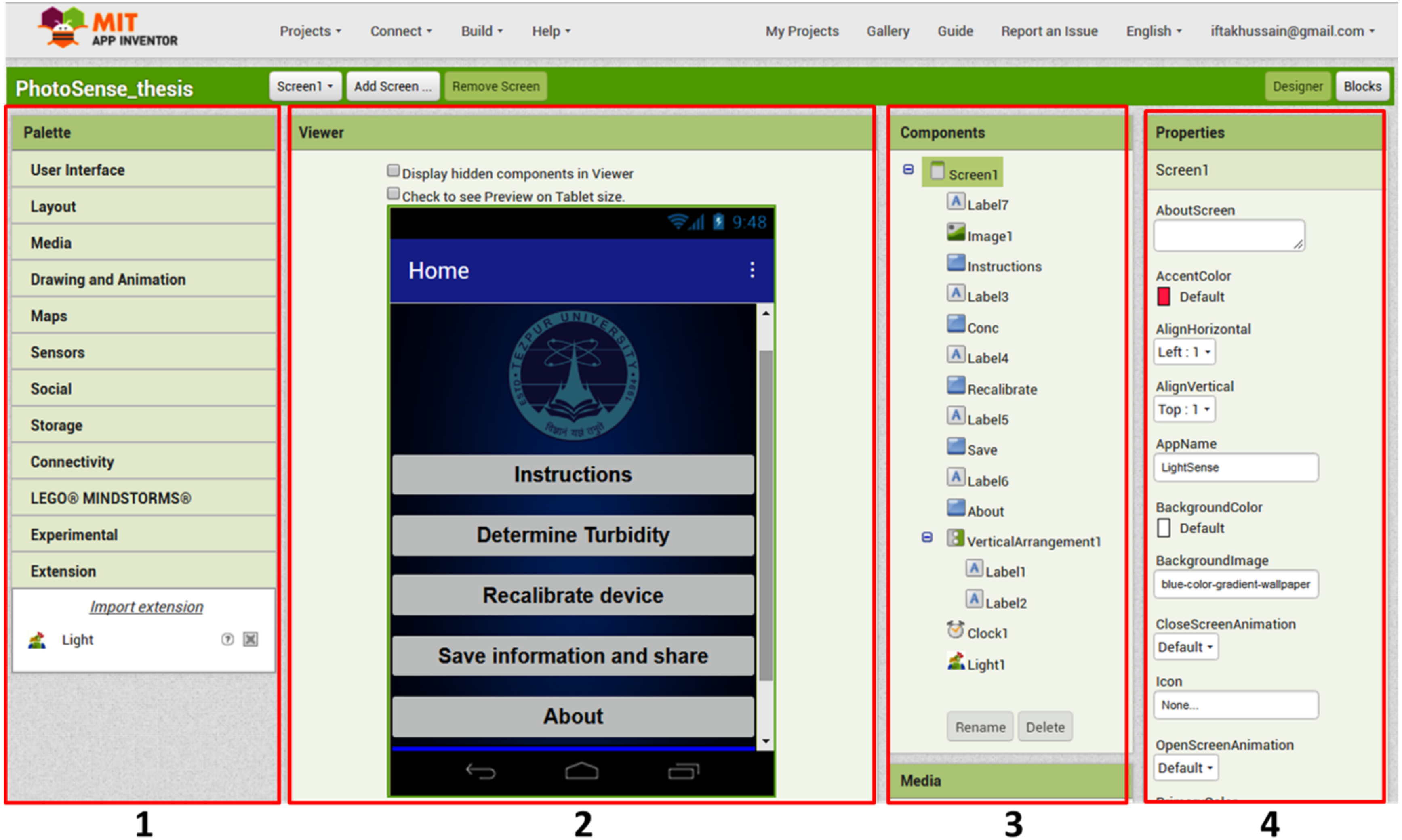

Figure 2.9: MIT App inventor Designer webpage.

accessed by developing a custom application intensity data from the ALS can easily be accessed. To develop the smartphone applications, the 'MIT App inventor' platform has been initially used [4]. This is an open source source cloud based software platform developed by Google and currently maintained by Massachusetts Institute of Technology (MIT) [15]. In this platform the apps can be developed by using drag and drop blocks of code known as block codes. User needs to sign in to this platform using a Google account. The platform provides two webpages: Designer and Blocks editor which contain all the functionalities required to develop an android application.

The designer webpage is shown in figure 2.9 where the four red marked regions show the different functionalities provided in this webpage. Region 1, the 'Palette' contains all the components such as buttons, sensors and extension which are

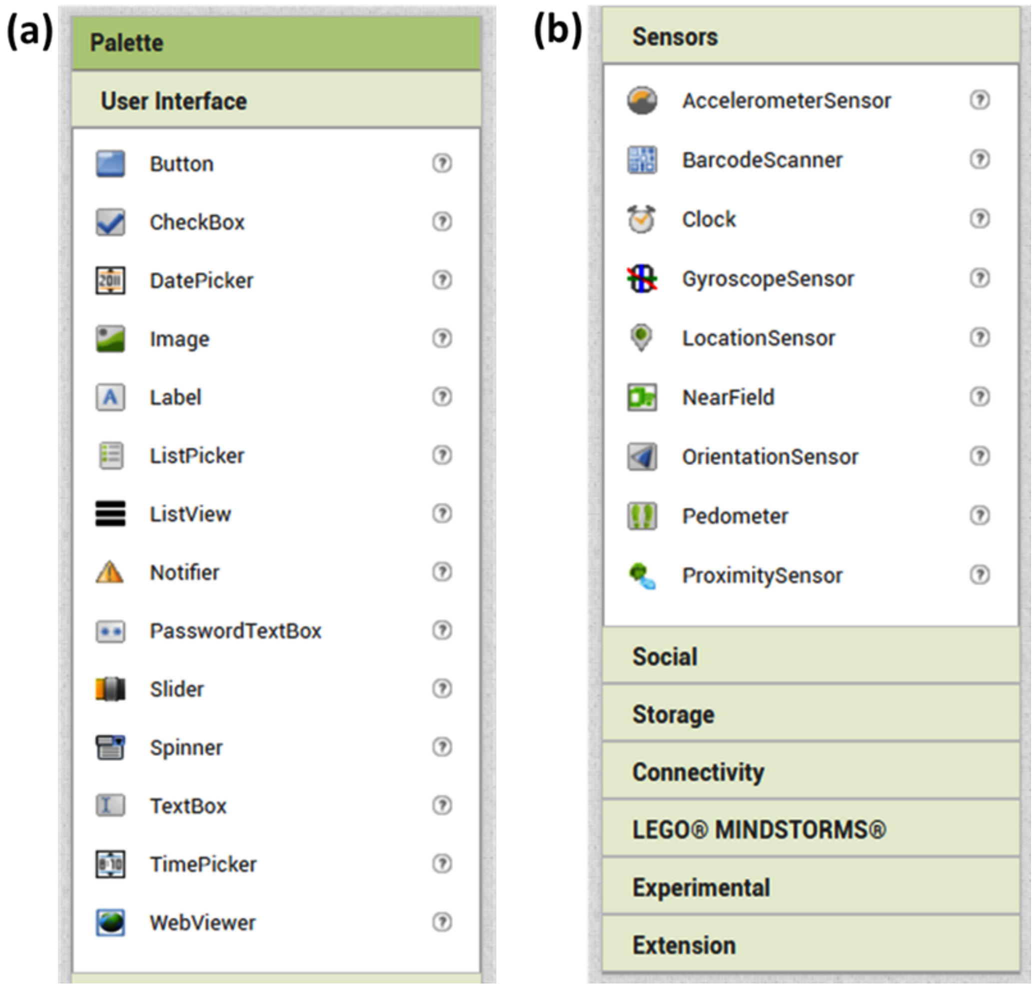

Figure 2.10: Components in Designer webpage for designing user interface of the application.

required for desining of the smartphone application. As shown in figure 2.10 (a) upon clicking the ‘User Interface’ the user can have access to all the components to develop the user interface of the application. Similarly, all sensor components can be accesses by clicking the ‘Sensors’ shown in figure 2.10 (b). Region 2 shows the ‘Viewer’ where the user can drag and drop the required components from the ‘Palette’ shown in region 1. Region 3 of the web interface is used to show the different components’ used to develop the user interface. Region 4 shows the properties of the components used to develop the user interface in the ‘Viewer’. This region can be used to change the parameters of the components and the style of the user interface.

The Blocks editor is the workspace for writing the codes that will run in the background of the smartphone application. Figure 2.11 shows the Blocks editor provided by the used platform which is composed of two parts indicated in red colored regions. Region 1 shows the ‘Blocks’ which contains all the required programming tools to develop an application. The options provided in this region can directly be implemented within the application by dragging to the ‘Viewer’ as shown in region 2 of figure 2.11. All statements used in general programing languages for examples loops such as ‘For’ and ‘while’ etc. can be implemented as blocks shown in figure 2.12 (a). The user can create the required variable by clicking the ’Variable’ option in the Blocks editor as shown in figure 2.12 (b). To determine the light intensity recieved by the ALS, a sensor extension ‘Light’ has been imported to the platform since MIT inventor does not provide the ALS sensor component. Figure 2.12 (c) shows the blocks provided by the ‘Light’ extension which has been used to develop the smartphone application throughout the thesis to determine the light intensity. Figure 2.13 (a) shows the implementation of the block codes provided by the extension to determine the light intensity. When the ALS detects any light intensity data, the block will communicate through the android sensor manager and access the intensity value and store the device for further use. As shown by the rectangle marked in red color in figure 2.13 (b), the intensity data can be shown in the user interface of the application. Since, the resolution of the embedded ALS of the smartphone is 0.01 Lux, the intensity value recorded by the application has been set to second decimal point only. The intensity data can be further processed by implementing statistical algorithms.

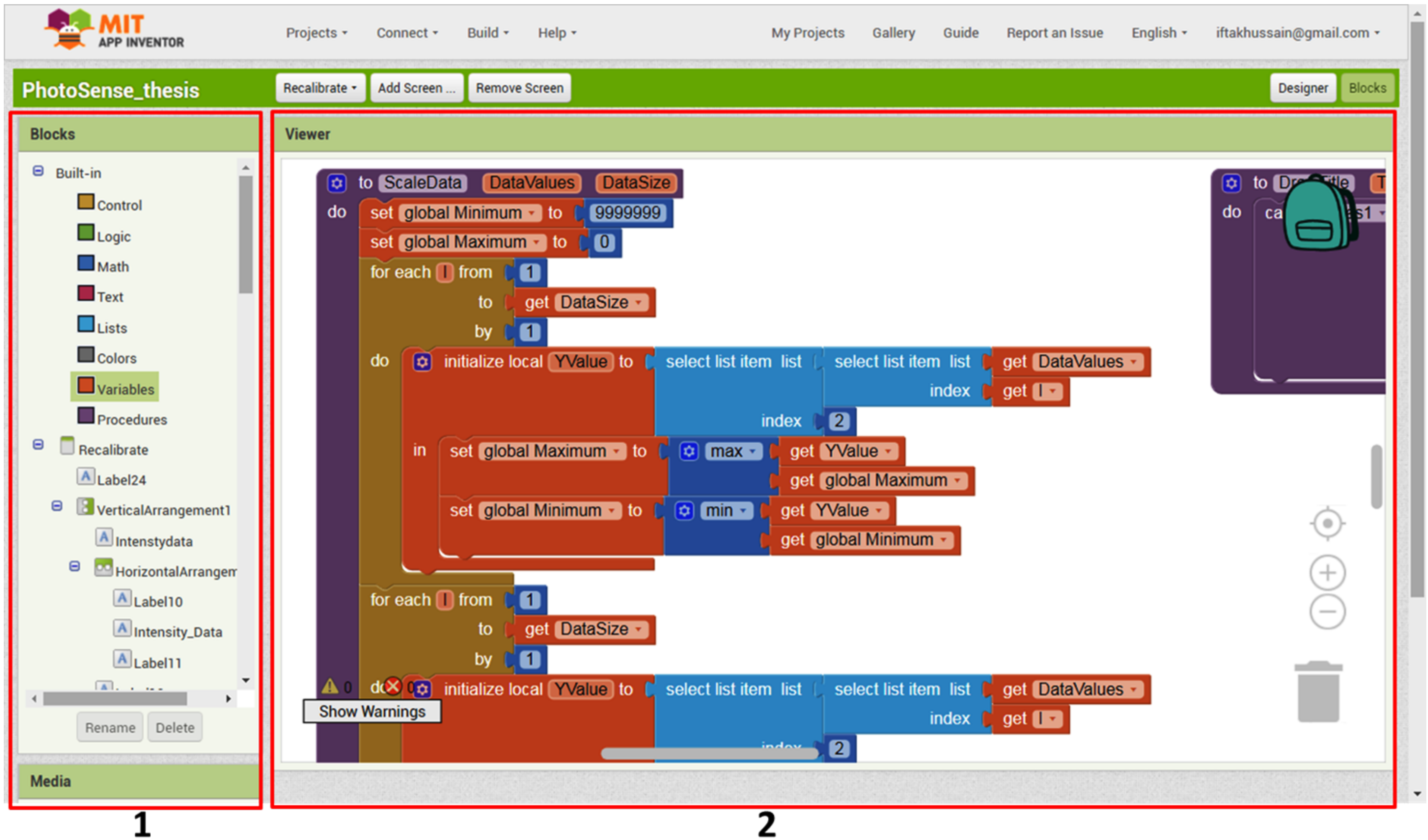

Figure 2.11: MIT App inventor Block editor webpage.

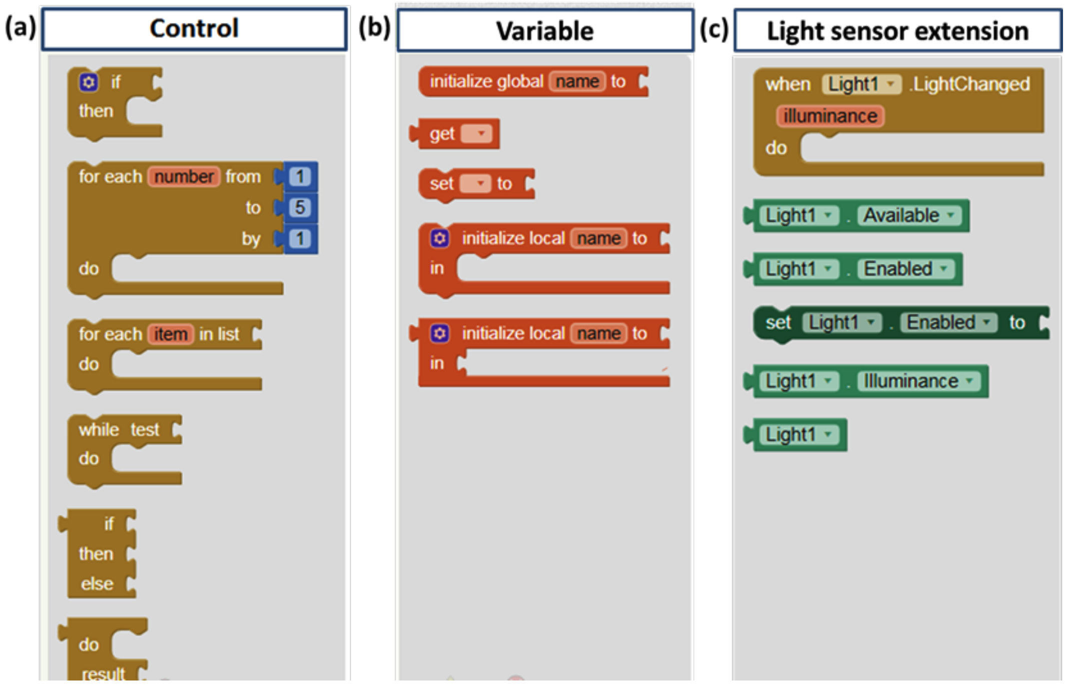

Figure 2.12: Examples of MIT App inventor block codes.

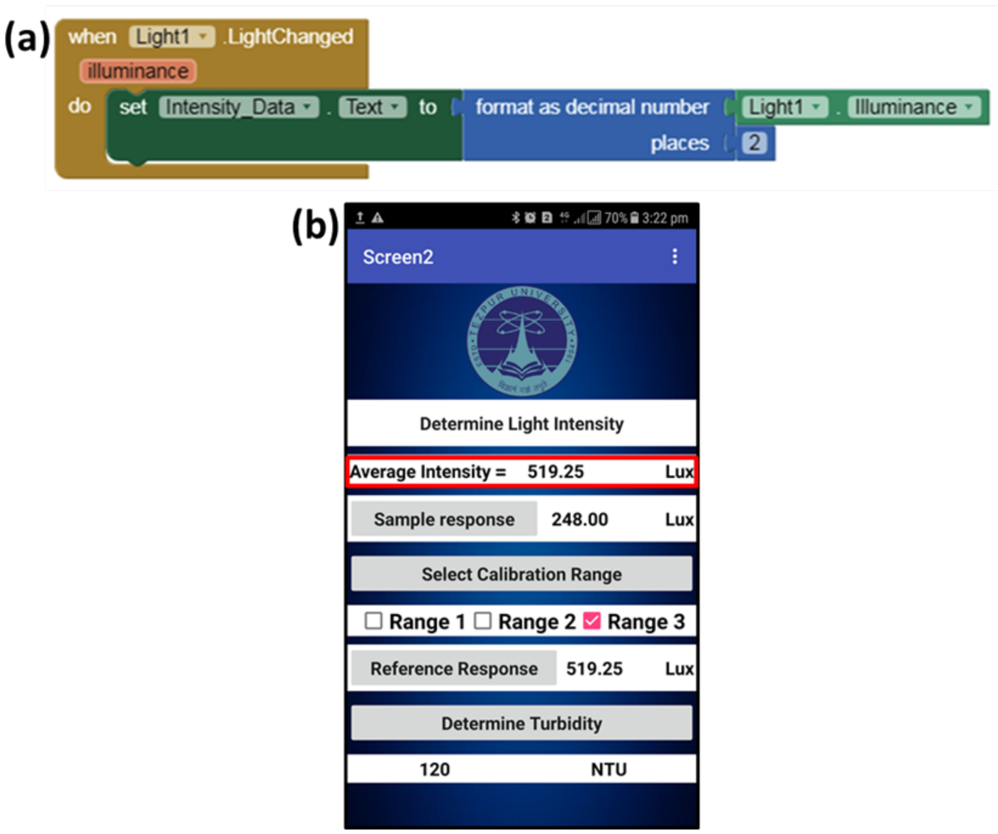

Figure 2.13: Block code used to determine light intensity and a screenshot of the developed application.

2.4 Summary

In summary, the details about the sensors and functional components embedded in a modern smartphone has been discussed. The usability of the embedded ALS has been discussed as an optical detector which can be used for sensing investigations both in visible and NIR spectral regime. The response of the smartphone ALS has been compared with a laboratory grade photo-detector system and similar response characteristics has been observed which implies the applicability in light sensing applications. Besides the sensors, the usability of the embedded functional components such as the LED flash is shown as an optical source and the potential use of internal battery as a power source for external LEDs has been discussed. Using freely available software platforms such as MIT app inventor, required application can be developed for extracting data from the inbuilt sensors and the same application can be used for data processing.

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