Development of an Electronic Paper Display E-Reader

Carlos Aloysius B. Aquino[1], Dax Gabriel M. Casanova[1], Kirk Gandril G. Madraga[1], Jan Raymund V. Montalvo[1], Neil Paolo D. Palabrica[1] and Engr. James Michael Cañete[2]

[1]Undergraduate Student, Department of Computer Engineering, University of San Carlos, Talamban, Cebu City

[2]Faculty Member, Department of Computer Engineering, University of San Carlos, Talamban, Cebu City

Abstract—**The purpose of this research is to develop a potential replacement for physical books used by schools today. The proponents designed and will develop an EPD (Electronic Paper Display) E-reader. The proposed study states the purpose of the device and an overview of its system and its features. The device will be different from available commercial E-readers because aside from the decided with the hardware and software components for the device, the proponents have come up with the added feature that gives users the capability to answer learning assessment activities, with the design of the device, the team has determined its capabilities and limitations. The study hypothesizes that the device to be developed can lessen the paper waste generated by physical books and it can be a viable alternative to these learning materials. The device can also be a tool for learning given its proposed capabilities and features.**

Keywords—e-paper display;e-book reader;single-board computer

I. INTRODUCTION

One of the major problems in the Philippines is the waste that is generated by paper. A reason for this is that most books are disposable once it has served its purpose. This waste contributes a big problem to the country because it may take 1-2 months before it can decompose [1].

Digital displays are becoming more sophisticated and increasingly present in everyday life [2]. It can be observed that “hard copies” are slowly turning into “soft copies” and they are being read by using an e-reader instead of having it physically.

An electronic reader or “e-reader” is an electronic device which is used to display electronic texts. This is usually used to display “e-books” or electronic books. Users can easily replace physical books because e-readers are well-suited for reading linear texts [2]. Furthermore, having digital copies for books is more advantageous because they can be updated easily when errors are present and additional information is needed for the said book. The digital book is also search-able which can greatly increase the user-navigation and the text can be adjustable which helps with people with reading disabilities as the text can be re-sized [3].

The researchers propose a locally-developed E-book reader for students. The e-reader is specifically designed for educational purposes and it displays electronic publication files (EPUB). An EPUB file is a zip archive that contains a collection of files that comprise the book. The contents of the book themselves are arranged in different HTML documents. The e-reader is able to display content from EPUB files. This is a design choice as EPUB is both free and open as a standard published by the International Digital Publishing Forum (IDPF). In this format, the books are reflowable, meaning text can be cascaded such that it will adapt to any device’s screen size and the text size set by the user [4].

This said e-reader can lessen the use of paper by being an alternative to physical books and display them digitally. The device would be different from commercial e-readers because it has learning-assessment activities which could further help lessen the papers used in learning activities such as seat works and exercises.

The proposed study has the following objectives:

- To design and develop an e-reader device
- To save and display EPUB books on the device
- To create an application that provides the capability to answer learning assessment activities.
- To create a device that has a battery life of at least 6 hours which is the average battery life of an e-reader [5]

The study is designed with the use of an electronic paper display or EPD. The behavior of EPD is similar to how ink is displayed on paper [6]. EPDs use reflected light to display objects while Liquid Crystal Displays operate by emitting light to make objects visible on the display [7]. This will make it easier for the students to adapt to using devices with EPDs as compared to those that use LCDs. EPDs can lower power consumption because it operates in a way such that objects being shown in the display are retained without consuming power. It only uses power when it is updating the display. This makes devices using EPDs to be environmentally-friendly and have a potentially longer battery life [4]**.** EPDs are tailored to be visible even when reading under direct sunlight because unlike LCDs, it is not self-illuminated and does not contribute to much eye strain [8].

II. SCOPE AND LIMITATIONS

The scope of this project only includes the design and development of the device and the software necessary for operation defined in the objectives. The proponents are not responsible for creating new e-books, converting existing non-EPUB files into EPUB and tampering with the content of e-book files to be used. All the e-book files that the project shall use are either free or open source. The device will be limited to only be able to read EPUB files.

III. METHODOLOGY

A. HARDWARE OVERVIEW

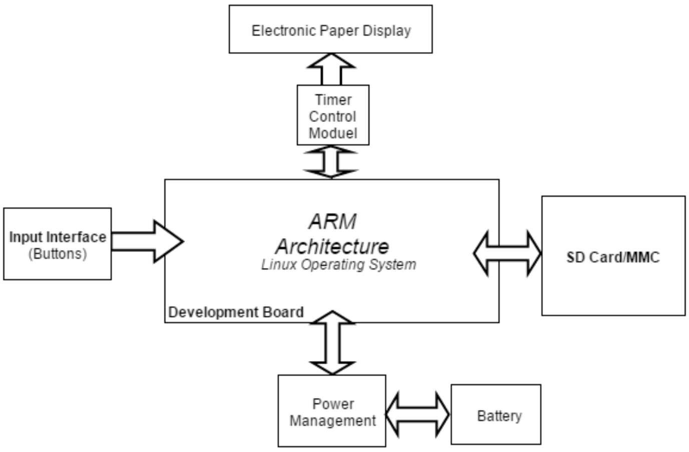


Fig.1 Prototype Block Diagram

Figure 1. shows the components identified and how they interact with the other components. The components identified to be used in this project are as follows:

- An ARM-based development board that supports system-on-chip (SoC) Architecture version 7-A
- Buttons that serve as input peripherals for navigation, selection, and cancelling selection.
- A MultiMediaCard (MMC) storage solution for the operating system, containing the EPUB files and the e-reader application;
- An Electronic Paper Display (EPD) that serves as the output device
- A battery unit that serves as the main source of power; and
- Power management circuitry.

B. DEVELOPMENT BOARD

The development board will use a CPU using the Acorn Risc Machine (ARM) system-on-chip (SoC) Architecture version 7-A. For this project, the development board to be used is the Raspberry Pi 2. The Raspberry Pi 2 has a typical power draw of 4W (800mA at 5V operation) [9]. Certain modules supported by the development board of choice such as sound, wireless communication services and image processing and capturing services will not be used in this project. The buttons that are to be used as input, will be connected to the GPIO pins of the Raspberry Pi. The timing control module for the display will also be connected to a few GPIO ports. The Raspberry Pi has a Serial Peripheral Interface as one of its pins. This SPI pin will be used to send commands to the timing control module.

C. INPUT PERIPHERALS

The device shall have the following buttons:

- A menu button
- Power button
- Select button
- Back button
- Four navigational buttons

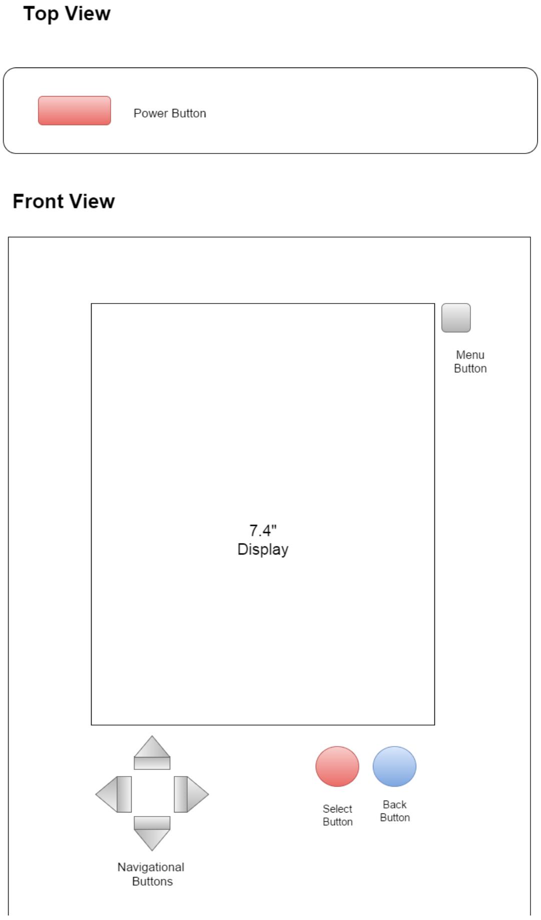


Fig.2 Prototype Button Layout

Figure 2 shows the button layout relative to the location of the display. The power button is located on top of the device. The menu button is located on the upper right side. This button is for displaying the options for changing font size and creating or accessing bookmarks. The four navigational buttons are located on the lower-left of the display. The select and the back button are located at the lower right side of the screen.

D. STORAGE

An MMC is the storage solution for the project. The operating system and data files for the books are all stored on the MMC. The MMC is readily interfaced in the development board and is removable. However, the MMC peripheral storage would not be easily accessible to the end users since the device will be enclosed. The device will feature a non-expandable ROM because the operating system and the program data reside in one peripheral.

E. OUTPUT PERIPHERALS

The screen uses electrophoretic display technology. The display is bistable in nature. The colors exhibited by the display are only either black or white and is determined by the polarity of the voltage applied to a pair of electrodes in a pixel. Also, bistable displays are able to display an image without any power source. Power is only used when updating the display. Thus, electronic paper displays are ideal for low-power applications.

The device will be using the MpicoSys 7.4" E-paper display. The kit provided by MpicoSys includes a timing control module(TCM) that is used to control the display. The TCM has a 10-pin single-row male header. In this connection, all the necessary electrical requirements and data lines are present. To send commands to the TCM the Serial Peripheral Interface(SPI) of the Raspberry Pi is connected to the TC_MOSI pin of the TCM. The appropriate commands from the development board are interpreted by the TCM and a reply is sent back to the Raspberry Pi through the TC_MISO pin [10].

During display update, power consumption has a maximum current draw of 108mA at a maximum operating voltage of 3.3V [10].

Figure 3 shows the two-way connection between the Raspberry Pi and the TCM, and the one-way connection between the TCM and the display.

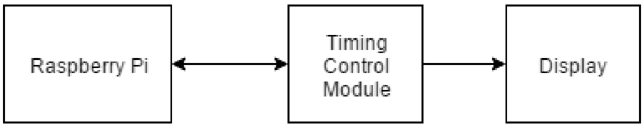


Fig.3 Raspberry Pi-TCM- Display Connection

F. POWER

The device shall be powered by a battery unit. The Raspberry Pi 2 can be powered by a portable rechargeable battery unit. The battery unit powers the Raspberry Pi 2 via the board's USB interface. Additional circuitry will be employed to support charging of the battery unit while the battery is still inside the device. Additional circuitry is required because the Raspberry Pi 2 cannot monitor the power levels of the voltages supplied.

Figure 4 shows the connection between the battery, power management circuitry and the development board.

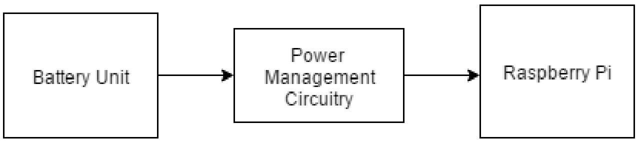


Fig.4 Battery-Power Management Circuitry- Development Board Connection

G. SOFTWARE OVERVIEW

The Raspberry Pi runs a Linux-based operating system. By default, a root user with the ability to access anything is logged in. It is possible to automatically log in the device with a less privileged account which only has read access to the system. This account should automatically start the e-reader application which displays content full screen on the display to the user. Input is restricted to hardware buttons further limiting them to basic e-book functionality. The boot process and the operating system account setup is hidden from the user and implicitly running in the background so that all the user has to deal with is the e-reader application that interacts with them.

Figure 5 shows the software framework. All the libraries, interfaces and the application itself is in the application layer.

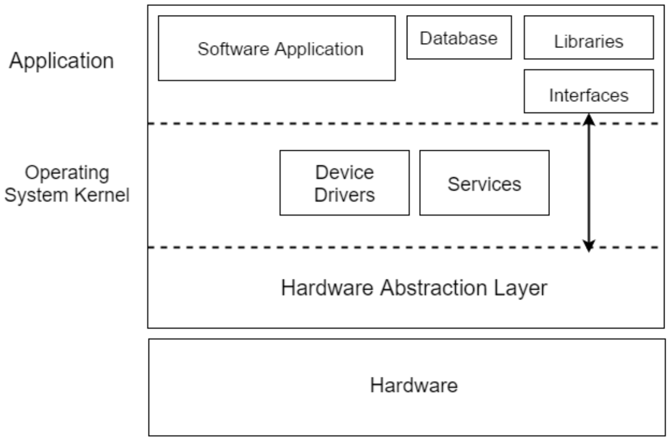


Fig.5 Software Framework

H. SOFTWARE IMPLEMENTATION

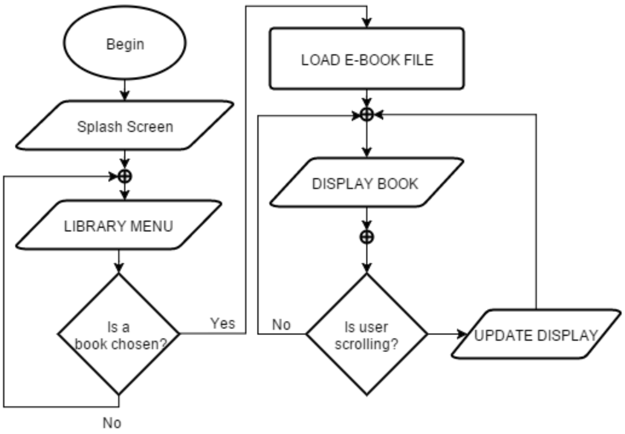
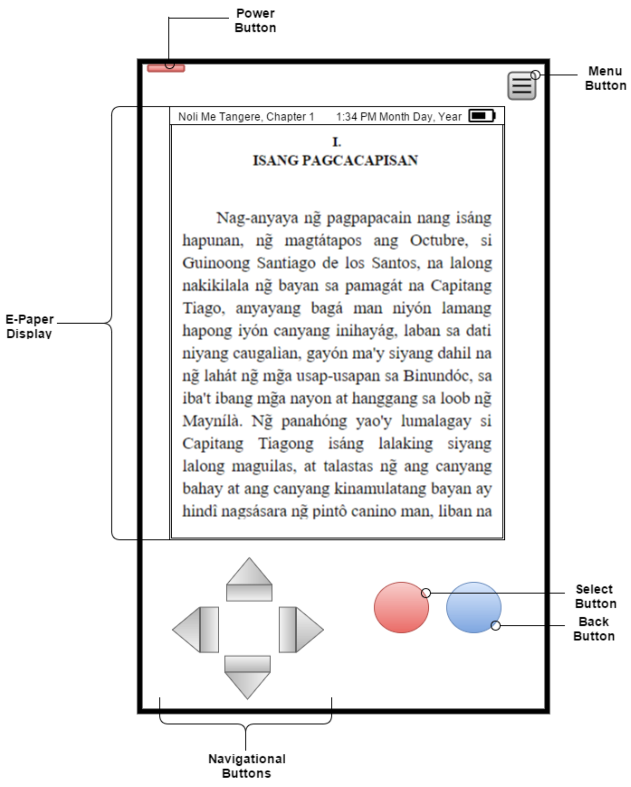


Fig.6 General Software Flow

Figure 6 describes the flow of how the software of the device. After booting the operating system, the device will have a boot service using a startup script to start the X Window System, and the e-reader application [11]. The window manager, as well as other services like audio, networking and High-Definition Multimedia Interface (HDMI), are not needed because the typical desktop input devices are not available. The e-reader application can be written in a general purpose programming language that is preferably small, fast and has libraries for communicating with the operating system and I/O via the hardware buttons. C and Python are primary candidates for building the application.

To load the EPUB file, the application must first determine the contents of the "Content.opf" file. Libzip is a C library for handling zip archives [12]. It will allow reading inside a zip files to be able to list its contents. The archive will contain a "META-INF" directory which contains a "container.xml". The container.xml file will point to the location of "Content.opf". This file contains the important metadata like the title, authors and publication date. More importantly, this file contains the index of all the files needed to render the ebook such as the HTML documents, stylesheets and images. The HTML documents can then be parsed to determine how the content will be displayed on the screen. The parsed document can be traversed to display whatever content that can fit on the screen to appear as a page. If a user bookmarks a page, the application will determine the location of the page in terms of ebook ID, chapter, paragraph number. The application can store this address in a database and be able to retrieve this information later when the user decides to check back into the page.



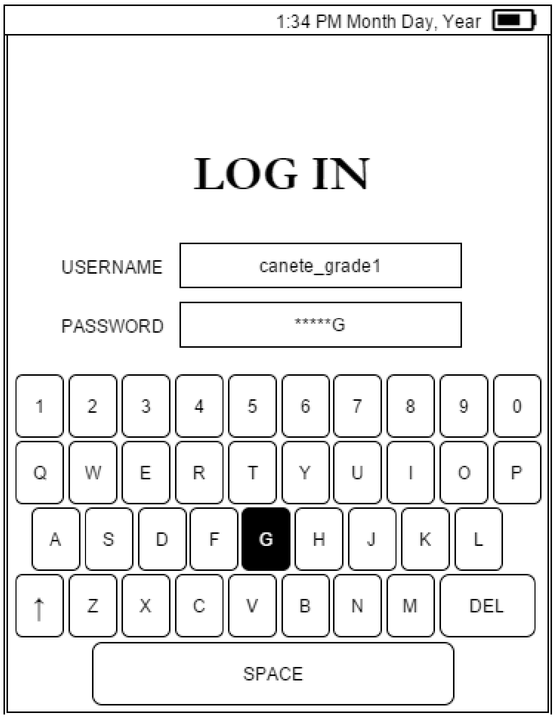
Noli Me Tangere, Chapter 1 1:34 PM Month Day, Year

I.
ISANG PAGCACAPISAN

Nag-anyaya nĝ pagpapacain nang isáng hapunan, nĝ magtátapos ang Octubre, si Guinoong Santiago de los Santos, na lalong nakikilala nĝ bayan sa pamagát na Capitang Tiago, anyayang bagá man niyón lamang hapong iyón canyang inihayág, laban sa dati niyang caugalian, gayón ma'y siyang dahil na nĝ lahát nĝ mĝa usap-usapan sa Binundóc, sa iba't ibang mĝa nayon at hanggang sa loob nĝ Maynílà. Nĝ panahóng yao'y lumalagay si Capitang Tiagong isáng lalaking siyang lalong maguilas, at talastas nĝ ang canyang bahay at ang canyang kinamulatang bayan ay hindî nagsásara nĝ pintô canino man, liban na

Fig.7 Concept View

Figure 7 shows the device layout in a conceptual manner. Below the display shows the navigation buttons: up, down, left, right and the two buttons that are used for user interaction. On the display, the battery is shown on the upper right while the title is shown opposite from the battery. The text is neatly displayed on the EPD.



1:34 PM Month Day, Year

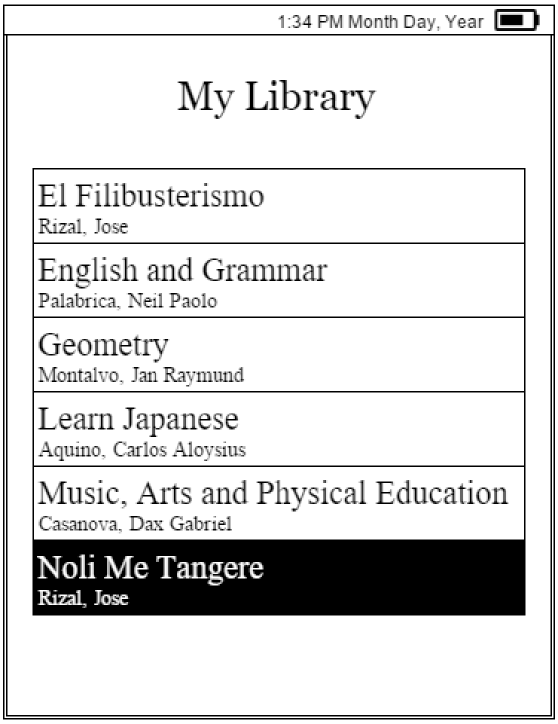
LOG IN

USERNAME canete_grade1

PASSWORD *****G

Fig.8 Log in Screen

After the device boots up and the application launches, Figure 8, is the first view that the user will encounter. In this view, the user is required to login. There is a virtual keyboard for inputting the username and password. The user can highlight the character of choice by using the navigational buttons. Pressing the select button confirms the selection. It determines if the user is either a student, teacher or publisher. The application determines which books are allowed for a particular user. Different grade levels have access to different books. Teachers have access to all books available in the device.



1:34 PM Month Day, Year

My Library

El Filibusterismo
Rizal, Jose

English and Grammar
Palabrica, Neil Paolo

Geometry
Montalvo, Jan Raymund

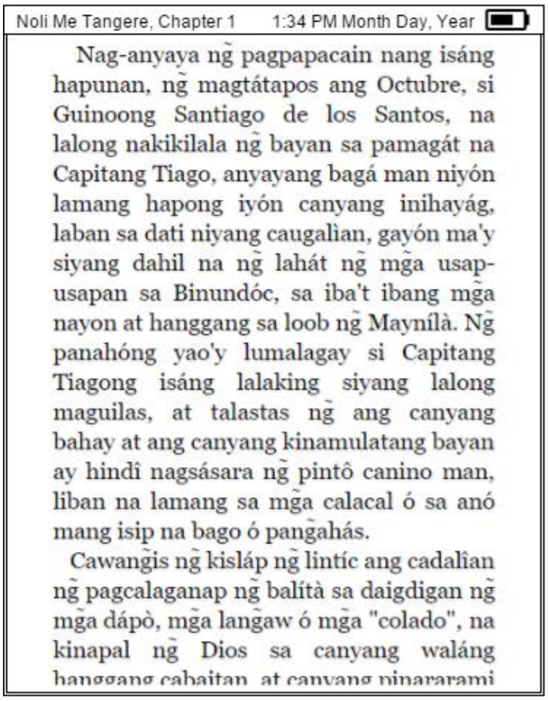
Learn Japanese
Aquino, Carlos Aloysius

Music, Arts and Physical Education
Casanova, Dax Gabriel

Noli Me Tangere
Rizal, Jose

Fig.9 My Library User Interface

Figure 9 is the view that is displayed after logging in. In this view, the user can navigate through the list of books that are available on the device by using the up and down navigational buttons. The current selection will be highlighted. If the user has chosen the book to view using the select button, only then shall the display update into the next view.



Noli Me Tangere, Chapter 1 1:34 PM Month Day, Year

Nag-anyaya ng̃ pagpapacain nang isáng hapunan, ng̃ magtátapos ang Octubre, si Guinoong Santiago de los Santos, na lalong nakikilala ng̃ bayan sa pamagát na Capitang Tiago, anyayang bagá man niyón lamang hapong iyón canyang inihayág, laban sa dati niyang caugalìan, gayón ma'y siyang dahil na ng̃ lahát ng̃ mg̃a usap-usapan sa Binundóc, sa iba't ibang mg̃a nayon at hanggang sa loob ng̃ Maynílà. Ng̃ panahóng yao'y lumalagay si Capitang Tiagong isáng lalaking siyang lalong maguilas, at talastas ng̃ ang canyang bahay at ang canyang kinamulatang bayan ay hindî nagsásara ng̃ pintô canino man, liban na lamang sa mg̃a calacal ó sa anó mang isip na bago ó pang̃ahás.

Cawang̃is ng̃ kisláp ng̃ lintíc ang cadalîan ng̃ pagcalaganap ng̃ balítà sa daigdigan ng̃ mg̃a dápò, mg̃a lang̃aw ó mg̃a "colado", na kinapal ng̃ Dios sa canyang waláng hanggang cabaitan, at canyang pinararami

Fig.10 Book View User Interface

Figure 10 is the view that displays the contents of the e-book. Content is displayed per page.

The contents of the books, being entities in HTML documents, can be represented as forms. The application should be able to support basic multiple choice examination with radio buttons. Using the device buttons, the user will be able to interact with the form. The answer keys are stored within an XML document inside the EPUB file but is not included in the index of displayable content. Each form should have its own unique ID and the choices are unique from each other in each form. The application can then compare what the user selected for each item to the answer key and determine the score the user obtained.

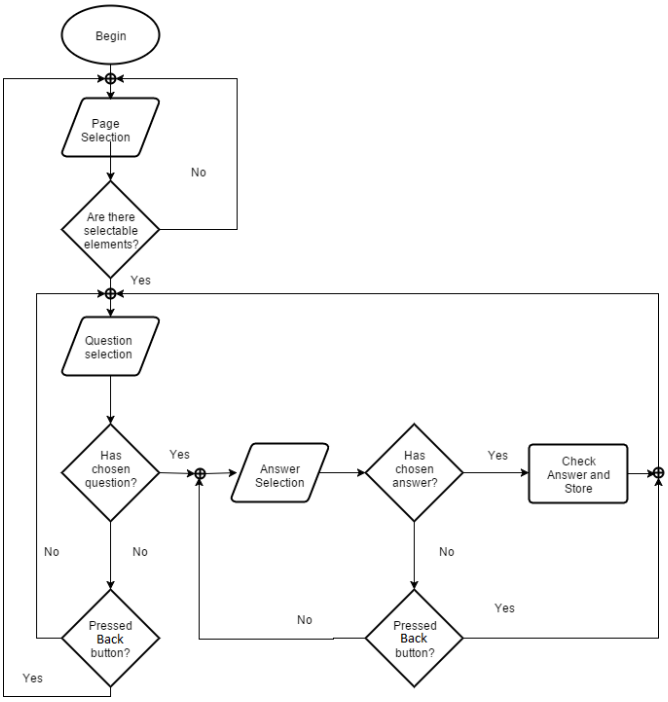


Fig.11 Handling Question Selections

Figure 11 is the flow chart for how the system handles learning assessment activities. While navigating the book, the user may encounter a learning assessment activity. The application will highlight the form and allow the user to perform the activity. The first question will be highlighted and the user may choose which question to answer first using the device buttons. If the user selects a question, the application will allow the user to choose their answer from a list. The user may cancel answering a question and go back to choosing another question. The user's selected answers are saved in a database after they have chosen to submit the activity.

IV. USE CASE

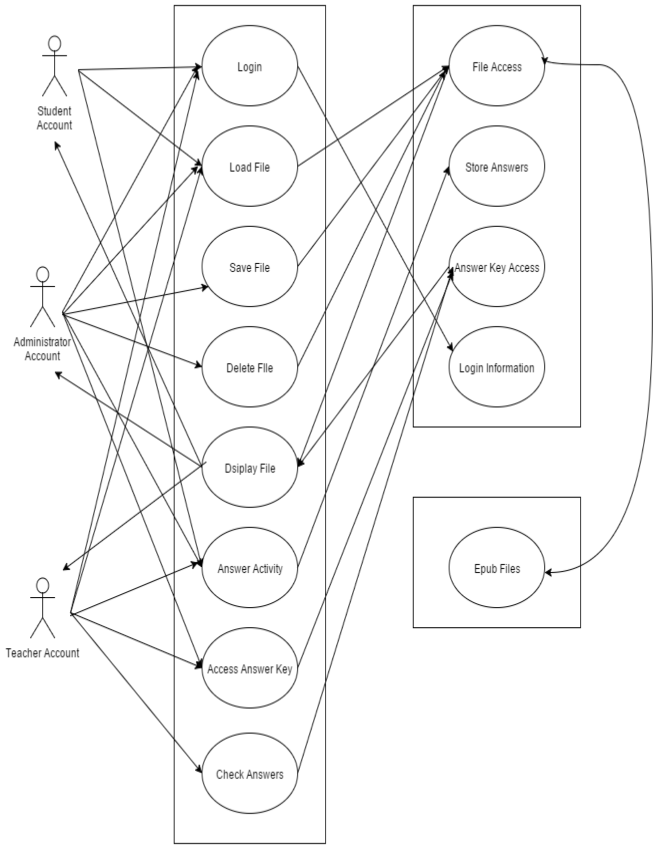


Fig. 12 Use Case Diagram

The system will have a database system for users' books and bookmarks.

Actors:

- Student Account
- Teacher Account
- Administrator Account

Functions:

- Device
  - Login
  - Save File
  - Delete File
  - Display File
  - Answer Activity
  - Access Answer Key
- Database
  - File Access
  - Store Answers
  - Access Answer Key
  - Login Information
- Storage
  - EPUB Files

Usage of the device in general is explained as follows:

1. The Use Case starts when the user starts up the device.
2. The system will display a splash screen while booting up.
3. A login screen will be displayed for users to login.
4. After logging in, the library of EPUBs will be displayed for the users to choose from, if the account logged in is a student account, it displays the books available to the student and his year level. If the logged in account is a teachers account, the library will display all books in the device and the teacher can also view and check students' answers. If the account logged in is an administrator account, the answer key to activities can also be accessed.
5. An option to answer an activity inside the book will be available.
6. After having answered the activity, the answers will be stored in the database and checked by comparing it to the answer key.
7. The user may go back to the library menu anytime or continue reading.
8. The administrator account will have access to save/delete files in the device.

V. HYPOTHESIS

The proponents hypothesize that by the end of this research, a designed device will be developed with the proposed functionalities: display EPUB files, give the users the unique capability of answering learning assessment activities and that the device can operate based on the average operating hours of an E-reader. Furthermore, the device can decrease the paper waste generated by physical books and that it can be an alternative to printed books and a tool for learning.

REFERENCES

[1] U.S. National Park Service, "Time it takes for garbage to decompose in the environment," in *Newspaper.* [Online]. Available:http://www.des.nh.gov/organization/divisions/water/wmb/coastal/trash/documents/marine_debris.pdf. Last Accessed Oct. 20, 2015.

[2] E. Siegenthaler, P. Wurtz and R. Groner, "Improving the Usability of E-Book Readers," in *E-Reading.* vol. 6, no. 1, p. 27, 2010.

[3] D. Zambarbieri, E. Carniglia, "Eye Movement Analysis of Reading from Computer Displays," in *eReaders and Printed Books.* 2012.

[4] M. Gylling, W. McCoy, M. Garrish, "ePUB Publications",[Online].Available:http://www.idpf.org/epub/301/spec/EPUB-publications.html. 2014. Last Accessed Oct. 20, 2015.

[5] M. Schcolnik, "A Study of Reading with Dedicated E-Readers," in *Table 10 E-Readers.* p. 95. 2001.

[6] ITWeb, "E Paper Brings Benefits," in *Evolving Technology.* [Online]. Available: http://www.itweb.co.za/index.php?option=com_content&view=article&id=24476. 2009. Last Accessed Oct. 20, 2015.

[7] J. Doherty and E. Rieffel, "Controlling reflected light using electronic paper", U.S. Patent 7832904 B2, November 16, 2010.

[8] “Do E-readers Cause Eye Strain?” [Online]. Available: http://www.bits.blogs.nytimes.com/2010/02/12/do-e-readers-cause-eye-strain/?_r=0. 2010. Last Accessed Oct. 20, 2015.

[9] E. Brown, “Raspberry Pi 2 has quad-core SoC, keeps 35$ Price” [Online]. Available: http://linuxgizmos.com/raspberry-pi-gets-quad-core-soc-keeps-same-price/. 2015. Last Accessed Oct. 20, 2015.

[10] MpicoSys, “Developer's Guide Timing Controller Solutions for Pervasive Displays 4.41″, 7.4″ and 10.2″ Panels,” in *Electrical Characteristics.* p. 6. 2014.

[11] M. Garrels, “Introduction to Linux,” Chapter 4. [Online]. Available:http://www.tldp.org/LDP/intro-linux/html/sect_04_02.html. Last Accessed Oct. 20, 2015.

[12] D. Baron, T. Klausner, “NiH: libzip.” [Online]. Available:http://www.nih.at/libzip/libzip.html. 2015. Last Accessed Oct. 20, 2015.