# Electronic-Paper: The Electronic Display of the Future.

**V.V.N. Akwukwuma and F.O. Chete***

Department of Computer Science, University of Benin, Benin City, Nigeria.

E-mail: odichet@yahoo.com*

## ABSTRACT

Made of flexible material, requiring ultra-low power consumption, cheap to manufacture, and most importantly, easy and convenient to read, E-papers of the future are just around the corner, with the promise to hold libraries on a chip and replace most printed newspapers before the end of the next decade.

This paper discusses the history, features, and technology of the electronic paper revolution. It also highlights the challenges facing E-paper and its various applications. The paper concludes that E-paper, which can be termed as the second paper revolution, is closer to changing the way we read, write and study; a revolution so phenomenal that some researchers see it as second only to the invention of the printing press by Gutenberg in the 15th century.

(Keywords: electronic paper, invention, printing, innovation, print media)

## INTRODUCTION

Electronic paper was developed in the seventies by Xerox. In the nineties the principle of electronically loaded balls turning under influence of tension and therefore showing either a black or white side was improved upon by Joseph Jacobson. He developed microcapsules, filled with electronically loaded white parts that were dissolved in a dark colored oil. In 1997, Jacobson founded the company E-ink to develop the invention commercially (Endless Ideas BV, 2010).

In the 1970s, Xerox PARC was a power house of innovation. Many aspects of the modern computer, namely the mouse, laser printer, ethernet, GUI (Graphic User Interface), computer generated color graphics, as well as a number of important computer languages were invented at PARC, around that time. Yet another development, nearly lost among those important breakthroughs was invented in 1974 by PARC employee Nicholas Sheridon. The Gyricon, a Greek term for rotating image, was to be the new display technology for the ALTO personal computer; eventually it became the basis for modern e-paper technology.

Made of flexible material, requiring ultra-low power consumption, cheap to manufacture, and most importantly, easy and convenient to read, e-papers of the future are just around the corner, with the promise to hold libraries on a chip and replace most printed newspapers before the end of the next decade (Genuth, 2007). It is a display technology designed to mimic the appearance of ordinary ink on paper. Unlike a convectional flat panel display, which uses a backlight to illuminate its pixels, electronic paper reflects light like ordinary paper. It is capable of holding text and images indefinitely, while allowing the image to be charged later (Wikipedia, 2010).

To build e-paper, several different technologies exist, some using plastic substrate and electronics so that the display is flexible. E-paper has the potential to be more comfortable to read than convectional displays (Sarno and Pham, 2010). This is due to the stable image, which does not need to be refreshed constantly, the wider viewing angle, and the fact that it reflects ambient light rather than emitting its own light. An e-paper display can be read in direct sunlight without the image appearing to fade. The contrast ratio in available displays as of 2008 might be described as similar to that of newspaper (Greenberg, 2008).

Electronic paper should not be confused with digital paper, which is a pad to create handwritten digital documents with a digital pen. Electronic paper or e-paper is a technology that allows the text in a piece of paper to be re-written. The paper is actually made of organic electronics that use conductive plastic which contains tiny balls that response to an electronic change, changing

the page in much the same way that pixels change on a computer (Wikipedia 2010).

Electronic paper was developed in order to overcome some of the limitations of computer monitors. These limitations include the backlighting of monitors which is hard on the human eye, while electronic paper reflects light just like normal paper. In addition, e-paper is easier to read at an angle than flat screen monitors. Electronic paper also has the potential to be flexible because it is made of plastic. It is also light and potentially inexpensive (Wikipedia, 2010).

The paper discusses the history and technology of e-paper and highlights its advantages and disadvantages. It also discusses the level of e-paper adoption in Nigeria and the various applications of e-paper.

## E-PAPER TECHNOLOGY

Electronic paper was first developed in the 1970s by Nick Sheridon at Xerox, Palo Research Centre. The first electronic paper called Gyricon consisted of polyethylene spheres between 75 and 106 micrometers across. Each sphere is a Janus particle composed of negatively charged black plastic on one side and positively charged white plastic on the other.

The spheres are embedded in a transparent silicon sheet, with each sphere suspended in a bubble of oil so that they can rotate freely. The polarity of the voltage applied to each pair of electrodes then determines whether the white or black side is face-up thus giving the pixel a white or black appearance (Wikipedia, 1999). At an exhibition in 2008, Japanese company, Soken demonstrated a wall with electronic paper using this technology (Otani, 2008)**.**

Another electronic paper technology is the Electrophoretic display. Electrophoresis is a process, which enables separating molecules according to their size and electrical charge by applying an electric current. In an electrophoretic front plane, small charges submicron particles are suspended in a dielectric fluid that is enclosed into a sub-pixel size cell or microcapsule. When an electric filed is applied across the cell or capsule, the ink particles will move towards the electrode with the opposite charge. With a transparent electrode, the cell or capsule takes in the color of the ink when current is applied. The contrast is improved by using opposite colored particles such as black and white- and charging them with opposite polarities.

When current is applied, all the black particles will migrate to one side, and all the white to the other. Switch the field, and the capsule will change color. This enables switching between all black particles and all white particles on the transparent front electrode of the cell or microcapsule. This is how the high contrast ratio of electrophoretic display is created (E-paper central, 2010).

The electrophoretic technology used by E-ink is the most widely known and used form of E-paper. Known as electronic ink, it is a proprietary material that is made into a film for incorporation ink a paper-like display (Figure 1).

Another approach to the problem of low-power, high quality color in E-paper comes from the Novel devices lab at the University of Cincinnati. The technology, called electiofluidic display, uses voltage to manipulate colored ink in much the same way that print heads operate in color printers.

Jason Heikenfeld, a Professor of Electrical Engineering at the University of Cincinnati, formed Hamma Dynamics LLC in 2009 to create products based on his electrofluidic display technology. He and his colleagues are considering a wide range of applications from E-readers to E-windows to tunable casings for electronic devices(Kroeker, 2009).

Heikenfeld says, the Kindle™ and other E-readers have created a trapping point for E-paper, but maintains the technology hasn't yet come of age because consumer will eventually want video capabilities bistable pixels (giving displays the ability to operate for long periods on very little or no power) thin or flexible designs, and of course vivid colors. No product or technology in the market is even close to offering this (Heikenfeld as cited in Kroeker, 2009).

Heikenfeld's electrofluidic display technology is based on a process called pigment dispersion. The pigments look as good as they would on paper.

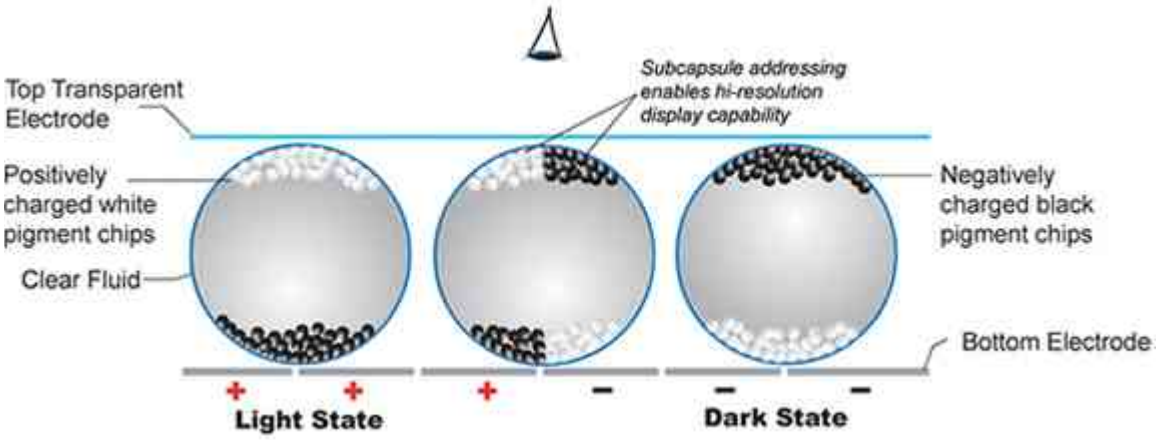


**Figure 1:** Cross-Section of Electronic –Ink Microcapsules (source: E-central 2010).

The technology consists of an insulator film situated between the pigment dispersion and an electrode film. When voltage is applied to the electrode film, it creates an electrical force that can stretch the pigment dispersion. When the voltage is removed, the pigment dispersion bounces back to its favored geometry of small droplet or bead shape (Kroeker, 2009).

Other research efforts into E-paper involved using organic transistors embedded into flexible substrates (Huitema, et al., 2001 and Gelinck, 2004) including attempts to build them into convectional paper (Anderson, et al., 2002). Simple color E-paper consists of a thin colored optical filter added to the monochrome technology. The array of pixels is divided into triads, typically consisting of the standard cyan, magenta and yellow in the same way as CRT monitors. The display is then controlled like any other electronic color display.

**Figure 2:** iLiad E-Book Reader Equipped with an Electronic Paper Display (Source: Wikipedia, 2010).


**Figure 3:** LG Debuts E-paper (Source:E-Paper Central, 2010).

Some notable features of E-paper technology includes the following (Bridgestone Corporation, 2010):

**◆Keeps the image in the memory until it is erased.**

No electrical power is required to maintain the image. Since it saves energy, it will contribute to the future low-carbon society.

**◆ Reflective Characteristics.**

Because it is reflective-similar to paper-it doesn't require a backlight. As a result, a thin and simple structure in which the thickness at the display

portion is less than 1.5 mm (in case glass substrates are used) was achieved.

◆ **Excellent Visibility.**

Because its angle of visibility is very wide, it is easy to read under direct sunlight and puts less strain on the eyes.

## HOW E-PAPER WORKS

E-paper comprises two different parts, the first is electronic ink, sometimes referred to as the 'frontplane', and the second is the electronics required to generate the pattern of text and images on the E-ink page, called the 'backplane'.

Over the years, a number of methods for creating e-ink has been developed. The Gyricon E-ink developed in the 70s by Nick Sheridon of Xerox is based on a thin sheet of flexible plastic containing a layer of tiny plastic beads, each encapsulated in a little pocket of oil and thus able to freely rotate within the plastic sheet. Each hemisphere of a bead has a different color and a different electrical charge. When an electric field is applied by the backbone, the beads rotate, creating a two colored pattern. This method of creating E-ink was dubbed Bichromal front plane.

Another such technology is electrophoretic front plane developed by the E-ink corporation. Electrophoretic front plane consists of millions of tiny microcapsules, each approximately 100 microns in diameter (about as wide as a human hair). Each microcapsule is filled with a clear fluid containing positively charged white particles and negatively charged black particles. When a negative electric field is applied, the while particles move to the bottom of the capsule and are thus hidden from view. When a positive electric filed is applied, the black particles migrate to the top and the white particles move to the bottom generating black text or a picture. The brightness and resolution of electrophoretic based E-ink is better than that of bichromal-based E-ink, but both are monochromatic in nature. To create color, E-ink joined hands with the Japanese company Toppan printing which produces color filters (Genuth, 2007).

## ELECTRONIC PAPER IN NIGERIA

The Nigerian media enjoys considerable liberty, especially with the recent signing into law of the Freedom of Information (FOI) Bill by the government. The Nigerian newspapers have played a very significant role in achieving a sincere and responsible government in the fourth republic by being vocal about the social and political class (E-paper Catalog, 2011). One of the ways of achieving this is by making information available to an unlimited number of its citizenry online. With internet services now available in mobile phones, and reasonable access charge by the network providers, citizens can now have unlimited access to newspaper information online. This feature is mostly powered by Nigerianmasterweb, with the website (Nigerianmasterweb.com) that hosts most leading Nigerian newspapers and magazines online. Some of the leading online newspapers from Nigeria include: *The Nigerian Tribune*, *The Punch*, *The Vanguard*, *The Sun*, *The Guardian*, among others. *The Punch*, *The Vanguard*, and *The Guardian* newspapers do have notable online presence with an electronic paper.

## MARKET DEVELOPMENTS

Kroeker (2009) outlined the developments in E-paper market as follows:

- Even with mass market E-readers being limited to monochromatic display, mush is happening in this area. Prime view international, a Taiwanese company that manufacture the Amazon and kindle and other electronic readers has put up $215 million to buy E-ink corp., the company that develops the digital-ink technology for these readers.
- Also brand-name companies are entering the E-reader market in droves, with Samsung being the most recent entrant with an E-reader that is only available in South Korea, with plans to show prototypes of its reader for international market in 2010.

- Plastic logic, another company making headlines is positioning its forthcoming E-reader as a device designer for business users. The company will have 3G and Wi-Fi connectivity and a gesture-baked torch interface specifically designed for reading and working with business documents.

- Also making headlines is FUJITSU, which recently released the FLEpia, a color-capable tablet featuring windows CES 5.0 software and also designed for business documents. While Fujitsu claims the FLEpia is the first color E-reader in the market, it can only display only 260,000 colors (in contrast to the majority of desktop monitors which can display 16.7 million colors) and is priced in the range of tablet PCs. Currently available only on Japan, the FLEpia cost $1,000. By comparison, Amazon's monochrome kindle costs $299. The killer application however of E-paper is color and it is expected to be a real mass market in 2012 (Hampshire, 2007 as cited in Genuth, 2007).

## CHALLENGES OF E-PAPER

The biggest technological hurdle facing E-paper is the fact that current E-paper color displays are either of poor quality or too expensive to be commercially viable. In addition, current E-paper technology cannot render moving images as well as other display technologies. This, however, may soon change as improving the color and rendering capabilities of E-paper is the focus of general research labs (Kroeker, 2009). There also exist some obstacles facing the mass adoption of E-paper technology. First, no technology is sufficiently paper like yet. That is, a display medium that is thin, flexible, capable of strong readable images without power consumption, highly readable in ambient light and has good resolution, high whiteness, good contrast and is pretty cheap. Though organic thin film transistors (TFTs) will produce flexible addressing at a low cost this technology is not quite ready, as it is still being intensively developed by a number of organizations (Sheridon, 2007 as cited in Genuth, 2007).

Another major obstacle is price. Research shows that the price of E-paper must fall below $1000 before a significant percentage of population will buy one. The another obstacle again is availability of suitable content (Hampshire, 2007 as cited in Genuth, 2007)

## ADVANTAGES AND DISADVANTAGES OF ELECTRONIC PAPER

Electronic Paper offers several advantages over printed paper. For example you can use electronic bookmarks, choose you preferred level of magnification, you can also use search to find information quickly, you have the option to print on to real paper if required (Wikianswers, 2012).

Advantages of electronic paper include low power usage (power is drawn when the display is updated), flexibility, and better readability than most displays. Electronic-ink can be printed in any surface, including walls, billboards, product labels, and T-shirts. The ink flexibility would also make it possible to develop roll-able displays for electronic devices.

A major disadvantage of electronic paper technology is very low refresh rate compared with other low-power display technologies like liquid crystal displays (LCDs). This prevents products from implementing sophisticated interactive applications (using fast moving menus, mouse pointers or scrolling) like those which are possible on handheld computers (Wikipedia, 2010).

Piracy has become a huge source of problems for organizations in certain types of markets, such as music, movies, and games. With e-books, it could be easy for organizations to lose a lot of money from piracy (Manuel, 2008).

The technology behind E-paper cannot support animation**.** With such a feature missing from e-paper, advertising is limited to pictures only, which is bad news for any organization that wishes to use animations in their ads with e-paper (Dejean, 2008).

Another limitation is that an imprint of an image may be visible after refreshing parts of the screen. Those imprints are known as ghost images, and the effect is known as "ghosting". This effect is reminiscent of screen burn-in but unlike it, is solved after the screen is refreshed several times. Turning every pixel white, then black, then white, helps normalize the contrast of the pixels. This is why several dances with this technology "flash" the entire screen white and black when loading a new image, in order to prevent ghosting from happening(Wikipedia, 2010).

In addition, E-paper only has the option of displaying in black and white and a range of gray tones. This lack of color is a huge disadvantage since colored images are of great value in newspapers and magazines (Dejean, 2008).


**Figure 4:** An E-ink Showing the Ghost of a Previous Image (Source: Wikipedia, 2010).

## FUTURE OF E-PAPER

The E-paper will be embedded as a cylindrical tube (about 1 centimeter in diameter or 15 to 20 centimeters long), that a person can comfortably carry in his or her pocket. The tube will contain a tightly rolled sheet of E-paper that can be spooled out of a slit in the tube as a flat sheet, for reading, and stored again at the touch of a button.

Information will be downloaded (there will be a simple user interface) from an overhead satellite, a cell phone network, or an internal memory chip. The document reader will be used for E-mail, the internet, books download from a digital library, technical manuals newspapers, magazines etc. anywhere in the planet. It will cost quite less than $10, and nearly everyone will have one. The surest way to produce the future of E-paper to invent it. E-paper is rich in potential (Sheridon, 2007 as cited in Genuth, 2007).

Judging by recent developments in terms of display size and power consumption in E-readers coming to market, the future of E-paper technology is bright. In 10 to 20 years, consumers might see large E-paper modules that are as thin and as flexible as magazines are today, with display brightness approaching that of conventional print. In Heikenfeld's imagined future, these solar-powered devices will have touch interfaces, communication capabilities, and be so energy efficient that changing them will be an afterthought. You might click on an image in a story, and it will provide video or animation (Heikenfeld as cited in Kroeker, 2009)

## USES AND APPLICATIONS OF E-PAPER

Electronic paper is the way out for people who read off the screen. The E-paper revolution will involve handheld displays of high contrast that are readable in direct sunlight, followed by low power–consuming book readers, then the electronic signs and billboards and expectedly the pocket document reader (Sheridon, 2007 as cited in Genuth, 2007). Some notable applications of electronic paper include:

**Education: Digital School Books**: In January 2007, the Dutch specialist in E-paper, edupaper.nl started a pilot project in a secondary school in Maastricht, using E-paper as digital school books to reduce costs and students daily burden of book (Wikipedia, 2010).

**Wristwatches:** In December 2005, Seiko released their Spectrum SVRDOOI™ wristwatch which has a flexible elestrophoretic display (Daimaou, 2005) and in March 2010, Seiko released a second generation of this famous E-ink watch with an active matrix display (Baseworld, 2010).

**E-books:** In late 2007, Amazon began producing and marketing the Amazon Kindle™, an E-book with an E-paper display. In February 2009, Amazon released the Kindle2™ and in May 2009, the larger Kindle DX™ was announced. In November 2009, Barnes and Noble launched the Barnes and Noble Nook™, based on the Android™ operating system. It differs from other big name readers in that it has a replaceable battery and a separate touch screen below the main reading screen (Wikipedia, 2010).

**Newspapers:** In February 2006, the Flemish daily *De Tijd* distributed an electronic version of the paper to select subscribers in a limited marketing study, using a pre-release version of the iRexi.Lad. This was the first recorded application up electronic ink to newspaper publishing (Wikipedia, 2010).

**Cell Phones:** Motorola low-cost mobile phone, the Motorola F3™ uses an alphanumeric black/white electrophoretic display. The Samsung Alias2™ mobile phone incorporates electronic ink from E-ink into the keypad, which allows the keypad to change character sets and orientation while in different display modes (Wikpedia, 2010)

**Status Displays:** Some devices, like USB flush drives have used electronic paper to display status information, such as available storage space (E-ink Corp, 2010).

**Figure 5:** The Motorola F3 uses an E-paper display instead of an LCD (Source:Wikipedia, 2010).


**Figure 6:** Active Matrix Watch. (Source: Baseworld, 2010)

Today, Seiko brings you the next generation of Electronic Ink watches. This new watch has the same high legibility and the same 180 degree angle of visibility, but with an even more advanced technology, an active matrix display (Baseworld, 2010):

- The active matrix system allows figures, text and graphics to appear on the dial in a much smoother and infinitely programmable way.
- The 300 dpi resolution delivers sharp, clear images even in a small size and the four shades of grey that are now available allow us to highlight whatever details we like.
- This new E-Ink watch is an amazing advance in electronic watch making, as it required SEIKO to build a new IC with very high energy efficiency. It uses just one hundredth of the power needed to run a same size screen using the current E-book technology.
- This is not a "concept watch" or a provisional prototype, but real watch.

## CONCLUSION

Today, paper remains the most popular document medium because of its credibility, tangibility, ease of use, flexibility, portability, and compatibility which has made it difficult to replace. Even with the prevalence of computers and online documents, the paperless office is more distant than when it was proposed. With paper documents flowing at a faster pace than ever, the need for more document management system becomes increasingly inevitable. Sheridon (2007) believes that E-paper will eventually be able to make power hungry desktop displays obsolete and help make heavy back-breaking textbooks something school children might learn about in a history class on their lightweight E-readers. Though new technologies are misperceived as total replacements for old ones, when in fact, the introduction of a new technology can simulate a synergy between old and new (Liu and Stork, 2000), we should reconsider the argument to completely replace all paper documents with electronic documents, and consequently, we predict a co-existence between paper and E-paper.

## REFERENCES

1. Anderson, P., D. Nelson, P. Svenson, M. Chen, A. Malonstrom, T. Remonem, T. Kugler, M. Berggren. 2002. "Active Matrix Displays based on All-organic Electrochemical Smart Pixels Pointed on Paper". *Adv Mater 2002*. 14(20):1460-1464.

2. Daimaon, G. 2005. "The First Watch that uses Flexible E-Paper hits the Stores". Retrieved 30/08/2010 from http://en.akihabaranaus.com/15738/mis/the-first-watch-uses-flexible-e-papaer-hits-the-stores.

3. Dejean, D. 2008. "The Future of E-Paper". http://www.computerworld.com/s/article/320085/the_future_of_E_paper

4. Gelinck, G. 2004. "Flexible Active-Matrix Displays and Shift Registers based on Solution Processed Organic Transistors". *Nature*. 3(2):106-110.

5. Genuth, I. 2007. "The Future of Electronic Paper". Retrieved 30/10/2010 from http://thefutureofthings.com/articles.

6. Greenberg, A. 2008. “Irex takes on the Kindle”. Retrieved 10/09/2010 from http://www.forbes.com/2008/09/23/amarzon-irex.ebook-tech.

7. Huitena, H., G. Gelinck, J. Van der Putter, K. Kuijk, C. Hark, E. Cantatore, P. Harwig, A. Vanbreemen, and D. De Leenv. 2001. “Plastic Transistors in Active Matrix Displays”. *Nature*. 414(6864):599.

8. Kroeker, K.L. 2009. “Electronic-Paper Next Chapter”. *Communications of the ACM*. 52(11) Nov 2009.

9. Liu, Z and D. Stork. 2000. “Is Paperless Really More? Rethinking the Role of Paper in the Digital Age”. *Communications of the ACM*. 43(11). Nov. 2000.

10. Mackay, W.E. 2003. “The Missing Link: Integrating Paper and Electronic Documents”. *Communications of the ACM*. Retrieved 20/08/2010 from http://delivery.acm.org/10.1145/1070000/1063671/p1-mackay.pdf.

11. Manuel, V. 2008. “Ebooks: Advantages and Disadvantages”. http://www.manuelviloria.com/archives/ebooks-advantages-and-disadvantages

12. Otani, T. 2008. “Soken Shows off Twist Ball Type E-paper Covering a Full Wall”. Retrieved 15/09/2010 from http://techonikkobp.cojp/english/NEWS-EN/20081104.

13. Sarno, D. and A. Pham. 2010. “Kindle not ready to Surrender to Ipad”. Retrieved 20/09/2010 from http://www.latimes.com/business/la-fi-apple-books.

14. Sheridon, N. 2007. “The future of Electronic Paper”. Retrieved 20/08/2010 from http://www.thefutureofthings.com/articles.

15. Shah, A. 2010. “LG to make E-Paper for New Generation of Devices”. Retrieved 28/08/2010 from http://www.pcworld.com/article.

16. Baseworld. 2010. “Seiko Press Conference-Future Now. EPD Watch”. Retrieved 20/09/2010 from http://www.seikowatches.com/baseworld/2010/precom.

17. Bridgestone Corporation. 2010. Retieved 20/09/2010 from http://www.bridgestone.dp/jp/adv-materials.

18. EndlessIdeas BV. 2010. “E-Paper”. Retrieved 28/08/2010 from http://mybebook.com/15/epaper/article-infohtl.

19. E-paper Central. 2010. “E-Paper Technologies Reference Guide”. Retrieved 29/08/2010 from http://www.epapercentral.com/epaper-technologies-guide.

20. E-paper Central. 2010. “Newspapers and Magazines: E-Paper or Burst in 2010”. Retrieved 29/08/2010 from http://www.epapercentral.com/newspapers_and_magazines.

21. E-paper Central. 2010. “Electronic Paper News, Information and Analysis”. Retrieved 28/10/2010 from http://www.epapercentral.com.

22. E-paper Catalog. 2011. “List of Online Papers and E-papers”. Retrieved 16/08/2011 from http://www.epapecatalog.com/nigeria-epapers.

23. E-ink Corp. 2010. “Lexar Adds Innovative Storage Capacity Meter with Electronic Paper Display from E-ink”. Retrieved 20/09/2010 from http;//www.e-ink.com/press/releases/pr90.html.

24. Wikipedia. 1999. “New Scientist Paper goes Electronic”. Retrieved 25/09/2010 from http://www.enwikipedie.org/wiki/New-Scientist.

25. Wikipedia. 2010. “Electronic Paper”. Retrieved 29/08/2010 from http://www.enwikipedia.org/wiki/electronic-paper.

26. WikiAnswers. 2012. “Advantages of Electronic Paper”. http://www/wiki.answers.com/Q/What_are_the_advantages_of_electronic_paper#ixzz28EtL5VtL.

## SUGGESTED CITATION

Akwukwuma, V.V.N. and F.O. Chete. 2012. “Electronic-Paper: The Electronic Display of the Future”. *Pacific Journal of Science and Technology*. 13(2):173-180.

Pacific Journal of Science and Technology