Use of Emergent Mid-Level Computational Devices in the Creation of Robust and Affordable Auxiliary Infrastructure Subsystems

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Abstract: - This paper presents an examination into the potential role of emergent computational devices as a catalyst in pursuing Kenya's local and international development agenda. These emergent technologies can be used to create tailor-made solutions that are robust, adaptable and affordable to solve the countries development problems. The current emergent technologies analysed are the Arduino micro-controller and the Raspberry Pi single board computer. Several case scenarios have been made to assess these devices and from the inferences made, they can offer a significant contribution to the nation by providing both local engineering opportunities and capacity building.

Key-Words: - Arduino, Auxiliary subsystems, Emergent computational device (ECD), Internet of Things (IoT), Micro-controllers (uC), Raspberry Pi (RPi), Single board computer (SBC).

1 Introduction

Advances in engineering have been central to human progress ever since the invention of the wheel. In the past two centuries, engineering and technology have transformed the world we live in, contributing to significantly longer life expectancy and enhanced quality of life for large numbers of the world's population. UNESCO in a recent report [1], their first on engineering, cited the profession as the catalyst for both local and international development.

As the world accesses its performance on the fulfillment of the United Nation's Millennium Development Goals (MDG) [2], [3] this year, engineering as a discipline will come to the fore to address two things. Firstly, to mitigate the discrepancies between the desired outcomes and the actual progress made with the 2015 MDGs. Secondly, engineering with be the propellant to drive the post-2015 agenda [4] that details sustainable economic development at its core.

For a majority of nations, a robust economic and infrastructural development model is desirable and they have in place internal post-2015 development goals. In the local landscape, sustainable infrastructural growth is captured in the economic pillar [5] of the Kenya Vision 2030. The Vision 2030 development process also will require the engineering discipline to fulfill the various sectors outlined in its mandate [6]. These are:

1) Macroeconomic Stability for long-term development
2) Land reform and Continuity in governance reforms
3) Enhanced equity and wealth creation opportunities
4) Infrastructure
5) Energy
6) Science, technology, and innovation
7) Security
8) Human resources development

For developing countries, development faces a unique challenge of trying to catch up to developed nations. These nations, however, are not static and are constantly growing themselves. This scenario of concurrent growth exacerbates the aim of parity desired by developing nations.

This paper proposes that a unique opportunity exists for developing countries as these nations can employ emergent computational devices (ECD) to bridge the gap. At the same time, emergent technologies can be used to provide variable, tailor made solutions for problems faced solely by the developing world. For example, Kenya has a tourism and agro-centric economy. Emergent systems can be used in farming: efficient monitoring and use of soil and water and tourism: wildlife profiling, tracking and automating anti-poaching measures.

Additional benefits of emergent computational devices apart from their variability are that in general they are easy to adopt, affordable and promote the local and international development agendas. They also auger well with the new global advancement into the field of smart devices and the Internet of Things (IoT).

Due to the sheer scope that emergent systems may be used, the author analyses their use in auxiliary infrastructure subsystems. These are areas of usage in industry and agriculture that may not be mission critical but their presence greatly enhances the overall objective of the central system.

This paper restricts itself to offering contributions mainly to the infrastructure and science, technology and innovation (STI) sectors of the Vision 2030. However, it should be noted that improvement in one sector benefits the others by extension. Furthermore, this paper is biased towards the author's area of electrical and electronic engineering and focuses on micro-controller (uC) and single board computers (SBC) as the emergent computational devices.

The remainder of this paper is divided as follows. Section 2 gives a brief treatise of ECDs citing some pertinent examples. Section 3 explains the capabilities of the afforementioned devices. Section 4 to 6 provide simple scenarios highlighting uses of ECDs in the local Kenyan landscape. Section 7 gives ideas on how to educate people on these technologies to provide capacity building and section 8 gives some final comments.

2 A Description of Emergent Computational Devices

In general, a computer or computational device is one that contains three essential elements:

- A Processing Unit (CPU)
- A Storage Unit (Memory)
- An Interaction Method with the External World (Input/output Mechanism)

The history of computing is long and complex with a sufficient survey handled by Ceruzzi [7]. In the interest of this discussion, the author has adopted a simplified classification based on amount of tasks a computational device is built for. This scheme is illustrated in Figure 1. A computational device can be divided into a single purpose or multi-purpose one. Single purpose devices seek to do one task and that one task well. Multi-purpose devices enable a single machine to perform a myriad of functions with the same hardware. A discussion into the most commonly occurring system in each class is presented prior to discussing the emergent systems.

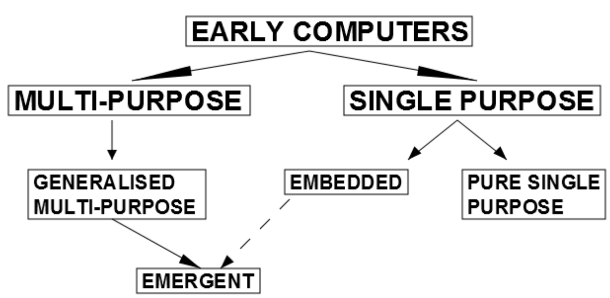

Fig. 1 Simplified Computer Type Classification

2.1 Embedded Systems

The embedded system has been a feature in human society for about fifty years. However, it has only been in the last third of this time period that this technology has been accessible to individuals outside major electronic corporations.

By definition, an embedded system is an applied computer system, usually hidden from view, designed to perform a specific dedicated function [8]. The classical example of such a system is the artificial pacemaker used to regulate the beating of the human heart. Most embedded systems are additional constrained to do the specific task at a specific time period [9]. This makes their operation both function and time critical.

2.2 Generalised Multi-purpose Systems

This class of computational systems is designed to perform a varied number of tasks. Generalised multipurpose systems are made up of several generic hardware components that allow for universal use over a wide array of job tasks. They then have a wide suite of software applications that allow the system to adapt to the required task [10]. The personal computer falls into this category. Functionality can be extended by addition of new hardware and software components to the original device.

2.3 Emergent Systems

From Figure 1, emergent systems are an offshoot of the multi-purpose types that share some of the tenets of embedded systems. It is this hybrid nature of the emergent systems that makes them ideal candidates for robust, affordable custom-built solutions.

The hybrid nature of emergent systems comes from the fact that these devices are first and foremost resource-limited variants of the multi-purpose class. They therefore have reduced functionality like the embedded systems. However, they allow for extensibility of hardware and software up to a point like the generalised multi-purpose systems they are derived from.

To this end, emergent system can be defined as a class of computational devices that seek to do a limited range of tasks in a dedicated and optimal manner, where the optimality implies the embedded methodology and the range of function the multi-purpose paradigm.

Two pertinent emergent computational devices that are currently under extensive development and usage are the modern micro-controller devices and the single board computers. The driving force behind this is the concept of The Internet of Things (IoT) [11]; which refers to interconnecting low-level computing devices using the Internet to create smart devices.

2.4 Modern Micro-controller Devices

Traditional micro-controllers such as the popular Intel MCS-51, commonly called the 8051, have been in existence since 1980 [12]. These devices were mainly used by specialists in the field of electronics.

In the last ten years, micro-controllers have become resurgent due to the hobbyist movement and the open source revolution. These ideologies seek to empower computer users with software and hardware design knowledge - and prevent them from becoming pure consumers. A purely consumer-centric user base has led to a bottle neck in computer development.

Modern micro-controllers provide an inexpensive and easy way for hobbyists, students, and professionals to create devices that interact with their environment using sensors and actuators. A common example is the Arduino platform based on the AVR ATmega series of micro-controllers [13].

The Arduino platform is quite popular as it provides an open-source electronics ecosystem comprised of both easy-to-use hardware (the Arduino boards) and software (the Arduino Software package). An example of this platform is the Arduino Uno R3 board shown in Figure 2.

While micro-controllers may be considered as wholly embedded systems, the modern variants are more in tune with the emergent systems. Using the Arduino platform as an example, Arduino and Arduino compatible boards use shields that are printed circuit expansion boards that plug into the normally supplied Arduino pin-headers. Shields provide additional functionality to the standard Arduino board such as motor control, GPS, Ethernet, LCD, or bread boarding (prototyping).

Other modern offerings rivaling the Arduino platform are the Tiva-C Launchpad Series from Texas Instruments [14] and development kits from Atmel AVR.

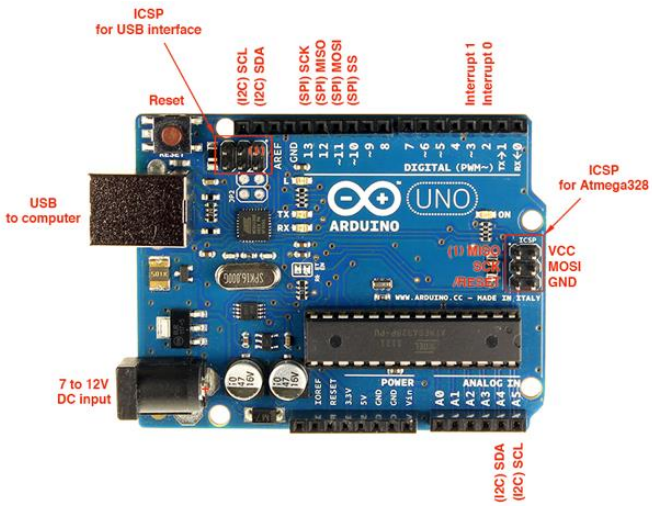

Fig. 2 The Arduino Uno R3

2.5 Single Board Computers

A single-board computer (SBC) is a complete device built on a single circuit board, with microprocessors, memory, input/output (I/O) and other features required of a functional computer. These were designed for development systems, educational systems, or use as embedded computer controllers.

The first true SBC was developed in 1976 [15]. Two of the most popular current SBCs are the Raspberry Pi developed at the University of Cambridge and its American rival, the BeagleBone.

2.5.1 The Raspberry Pi

The Raspberry Pi is a credit card-sized single-board computer developed in the UK by the Raspberry Pi Foundation with the intention of promoting the teaching of basic computer science in schools. The Raspberry Pi Model B board is shown in Figure 3.

Fig. 3 The Raspberry Pi Model B SBC

The Raspberry Pi is based on the Broadcom BCM2835 which includes an ARM1176JZF-S 700 MHz processor, Video Core IV GPU, 40 general purpose input-output (GPIO) connectors, on-chip Ethernet, and 256 or 512 megabytes of RAM. The system has Secure Digital (SD) or MicroSD sockets for boot media and persistent storage. The Raspberry Pi Foundation provides Debian and Arch Linux ARM distributions for download. Tools are available for Python as the main programming language, with support for BASIC, C, C++, Java, Perl and Ruby [16]. As of October 2014, about 3.8 million boards had been sold [17].

2.5.2 The BeagleBone

The BeagleBone is a low-power open-source hardware single-board computer produced by Texas Instruments in association with Digi-Key and Newark Element14. The Raspberry Pi Model Black board is shown in Figure 4.

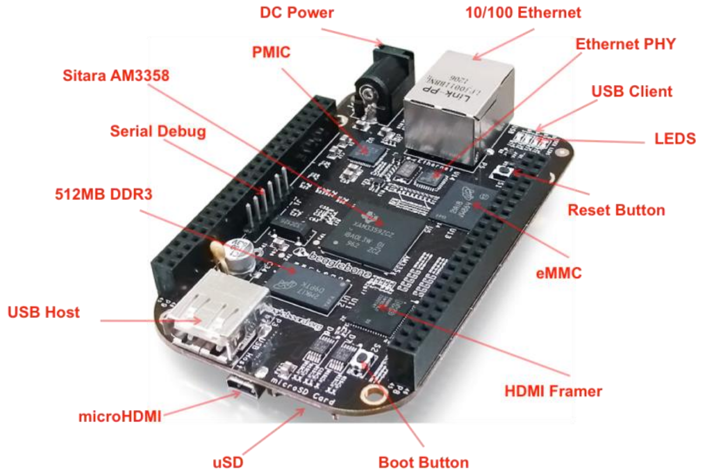

Fig. 4. The Beagle Bone Black SBC

The standard BeagleBone is made up of a Sitara ARM Cortex-A8 processor running at 720 MHz – 1 GHz, 256 or 512 megabytes of RAM, two 46-pin GPIO connectors, on-chip Ethernet, a MicroSD slot, a USB host port and multipurpose device port and up to 2 gigabytes of eMMC flash memory. [18].

2.6 Other Emergent Devices

Modern micro-controllers and SBCs are not the only emergent computational devices. Other devices include field programmable gate arrays (FPGAs), complex programmable logic devices (CPLDs) and System-on-chip devices (SoC). It should be noted that this list is not exhaustive.

3 Capabilities and Cost of Some Emergent Technologies

ECDS have a myriad of uses, highlighting their adaptability. The Arduino platform has been used to develop embedded cameras, power metering and wearable electronics in clothing. The Raspberry Pi SBC has been used to create personalised web servers, home security systems, mid-range automated drones and even low earth orbit satellites.

From the point of view of cost; in Kenya, the Arduino platform board retails at Ksh. 3000 and the Raspberry Pi SBCs retail at Ksh. 5500. These prices are much less than conventional machines used for the same purposes.

4 Sample Case Scenario I: Technology-Centric Farming

A report on the 1st AgriTech Africa International Exhibition and Conference from the Ministry of Agriculture [19] cited that African grain production yields stands at 1 Ton/Ha which is less than half of those seen in other regions. Also the fertilizer uptake in Africa averages at 9 kg/Ha which is less than 1% of the developed world uptake.

Kenya was cited in the aforementioned report as one of the African countries not maximising its yield potential. As Kenya is an agricultural based economy, it strives to improve its crop yields both to assure food security for its citizens as well as generate a sufficient export commodity.

One possible way of improving agriculture locally is to adopt emergent technologies in assessing and improving current farming methods and auxiliary farming practices such as irrigation. Consider the fictional example of a mid-level cash crop farmer, wishing to irrigate his farm. Some of the issues to be monitored during the irrigation process are:

- Soil humidity levels
- Soil nutrient content and soil salinity
- Precipitation and temperature quantities
- Over- and under-irrigation issues

The most common practice currently adopted locally is drip irrigation. In all likelihood, the farmer in this example would adopt a drip irrigation scheme. While this is an easily accessible form of farming, poor implementation can lead to unbalanced nutrient and salinity soil levels as well as problem with over- or under-irrigation.

Assume instead an emergent based irrigation was created. A block diagram of such as system is shown in Figure 5. The ECD in the form of an Arduino board or a Raspberry Pi SBC is connected to a simple solar powered battery to allow for continuous use. The ECD is then connected to a bank of sensors that are monitoring the environment variables - humidity, temperature, soil salinity and nutrient levels among others. Based on the information picked from the sensors and using a pre-written program resident in the ECD, a response is sent to a set of actuators. The actuators in this case are valves to open piping to allow for water to seep into the soil, irrigating it.

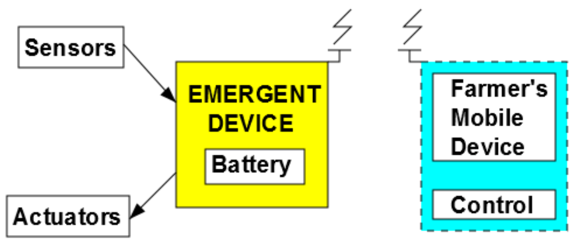

Fig. 5 Block diagram of Emergent-based Irrigation System

To ensure such a system can be monitored and controlled by the farmer, the emergent device is equipped with wireless connectivity. This allows the ECD to regularly update the farmer on the farm’s status. The farmer may be updated and conversely send commands either through a mobile device via short message service (SMS) texts or through a generic control mechanism such as an online Internet-enabled computer.

The cost of deployment of such a system would be recovered in the improved yields experienced by the farmer. The work done by Mbari et al. [20] called”MkulimaHodari” proves the viability of this concept and is currently under the later stages of development.

5 Sample Case Scenario II: Automated Monitoring of Industrial Subsystems

In line with the theme of the 2015 IEK International Conference, the second case scenario illustrates the use of ECDs in the maintenance of natural resources; in particular, oil and gas exploration. Consider the process of monitoring several untapped natural gas wells in close proximity in an inaccessible part of the country. Emergent devices can be deployed as affordable, robust information relay stations. This is shown in Figure 6.

Each well is equipped with a remote ECD station setup compromising of the ECD, a solar powered battery-pack and a set of sensors and actuators. The sensors provide information as to the gas and temperature levels and the battery pack ensures the ECD station is always-on.

The remote ECD stations relay the information they receive from the sensors to a central hub ECD located on-site. The central ECD station has two primary functions. Firstly, to act as a forwarding station to relay individual remote station information to the control system off site. Secondly, the central ECD station can delegate and determine non-critical tasks to the remote ECD stations. Micro-controllers may be used as robust remote ECD stations with a central station implemented by a single board computer.

The central ECD station and the off-site control have more than one communication mechanism to ensure redundancy in the information path. The result of such a system is a continual stream of information about each well being made available on demand at the offsite control system either for the purpose of data logging and productivity assessment.

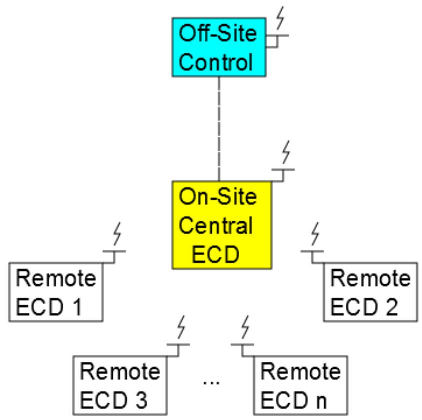

Fig. 6 Block diagram of Emergent-based Well Monitoring System

6 Sample Case Scenario III: Wildlife Management

Consider, as a final scenario, the problems associated with wildlife management in Kenya. These are mainly centred on wildlife tracking and protection (anti-poaching techniques and human-wildlife conflicts). Several ECD solutions can be introduced. Several innovative schemes employing ECDs have been presented. The Pico copter [21] developed by Ondula et al. is a Raspberry Pi controlled drone that can be fitted with a camera to allow for wildlife tracking. This drone technology can also be used to remotely monitor parks for poaching activity, as an alternative to helicopter surveillance. Human settlements can have their fences equipped with ECD stations similar to those seen in Section 5 except they can be equip with proximity sensors and cameras to allow wildlife service personnel to record and document areas of frequent human-wildlife conflict.

7 Education of Emergent Technologies and Capacity Building

Locally, the uptake of emergent technologies is only seen in tertiary institutions. The innovations of ”MkulimaHodari” [20] and the Pico copter [21] have been initiatives created by university students and recent graduates.

There are several tertiary institutions that promote these emergent technologies. The University of Nairobi’s FabLab [22] and Strathmore University’s iHub [23] provide introductory semi-formal tutorial sessions with Arduino platform and the Raspberry Pi.

The Kenya Education Network (KENET) recently had a call for proposals for the purpose of awarding 10 Raspberry Pi mini-grants [24]. KENET hopes the outcome of these awards will be a formal teaching structure for the Raspberry Pi platform that can be adopted by institutions country-wide.

The author believes that for these emergent computational devices to really make an impact on the local development; these systems should be introduced at an earlier age - possibly in secondary school education under the curriculum of Computer Science Theory. This would create an innovative spirit that would be required to be tailor-made solutions to local development problems.

8 Conclusion

A brief discussion of the potential role of emergent computational devices as a catalyst in local infrastructure development was performed, highlighting in particular their benefits from an adaptability and cost viewpoint. Two types of ECDS: the modern micro-controller and the single board computer were introduced and explained.

Several case scenarios were developed and in each case, the role of the ECD in relation to the overall job task was outlined and described. From these situations simulating local national problems, it was evident that adoption of ECDs would greatly benefit each problem area. It also showed that despite the type of problem: agricultural, industrial or resource, the ECDs presented a simple, robust solution.

It was finally noted that while adoption of ECDs is slow and steady nationally, exciting and incubating a younger generation of Kenyans with this knowledge would ensure these devices find more common use.

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