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Comparative analysis of different Operating systems for Raspberry Pi in terms of scheduling, synchronization, and memory management

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ABSTRACT

Deep learning, big data, and the internet of things (IoT) have changed the world entirely. As an embedded computer, Raspberry Pi is playing a dynamic and prominent role in the era of ubiquitous computing. In ubiquitous computing, performance and real-time throughput are still an area of focus for Raspberry Pi. Indeed, process scheduling, page swapping, and process synchronization techniques are essential and crucial parameters of the operating system for Raspberry Pi. The key study objectives were; (i) explore the recent trend of applications of Raspberry Pi and (ii) comparison of process scheduling, page swapping and process synchronization techniques with different Raspberry Pi operating systems. The study concluded that Linux-based operating systems are offering an optimized and efficient computing environment for Raspberry Pi.

1. Introduction

The advancements in embedded computers have revolutionized ubiquitous computing [1]. Raspberry Pi is one of the innovative single-board embedded computer developed by researchers [2]. The latest development in wireless and hardware technologies [3-5] has reduced the cost and size of Raspberry Pi system. Numerous Linux based Operating systems availability and support of several programming languages including C, C++, Python, and Java have played a vital role in the popularity of Raspberry Pi system [6].

Deep learning and Big data [7-8] are the driving forces in the evolutionary process of Raspberry Pi. Raspberry Pi 4 is the latest emergence due to the continuous development and enhancement in Raspberry Pi. This model is equipped with a powerful 64-bit quad-core ARM Cortex-A72 with up to 4 GB memory support. The Raspberry Pi 4 Model B is much more powerful compared to its predecessor the Raspberry Pi 3B+ and features dedicated Gigabit Ethernet without the USB overleap while offering twice the speed and four times higher range. So, in summary, the Raspberry Pi 4 offers Quad core Cortex-A72 processor, up to 4GB SDRAM, Bluetooth, Gigabit Ethernet, 40 pin GPIO header, two micro-HDMI ports, OpenGL ES 3.0 graphics, Micro-SD card slot, Power over Ethernet and 4-pole stereo audio and composite video port [9].

Over the past several years, a wide range of applications has been developed for Raspberry Pi [10] system including home automation, security, and surveillance [41], healthcare embedded systems. But, still, robust and real-time applications demand efficient and optimized operating system techniques besides of powerful hardware specifications of Raspberry Pi. For this purpose, we explored different Operating systems for Raspberry Pi. The objectives of this study are listed as follow.

1. Review the latest trending applications of Raspberry Pi
2. Identify the state-of-the-art operating systems designed for Raspberry Pi
3. Compare the process scheduling, memory paging and process synchronization techniques available in the identified operating system (OS)
4. Bottlenecks and challenges in an OS for embedded computer / Raspberry Pi
5. Find the best alternates of Raspberry Pi

The remaining paper is organized as follows. In section 2, latest trending applications and related work have been reviewed. In section 3, the prominent OS for Raspberry Pi has been discussed. Different features of Operating systems and comparison between process scheduling, memory paging, and process synchronization techniques have been discussed in section 4. Challenges and Bottlenecks have been reviewed in section 5. Section 6 presents review on the best alternatives for Raspberry Pi. The conclusion is given in Section 7.

2. Trending Applications

A. Kumar et al. [11] proposed a Raspberry Pi-based system to monitor health-related parameters such as body temperature and heartbeat. To mine and analyze the geospatial big data, R. K. Barik et al. [12] developed a Mist computing-based framework. The solution built an embedded microprocessor prototype using Raspberry Pi. A. Baskaran e al. [13] proposed a Smart HealthCare System. S. Basu et al. [14] designed a system to monitor critical parameters and provide reports with a high level of accuracy for heartbeats, peripheral capillary oxygen saturation (SpO_2) and the temperature. The system has been designed using Raspberry Pi 3B+ minicomputer. N. Rathour et al. [15] Proposed a Euphony, a hand sanitation monitoring and indication system based on Raspberry Pi. To detect glaucoma, a framework has been proposed and designed [16]. The entire framework (CNN + ANN + MATLAB) runs on Raspberry Pi 3B.

I.-H. Chen et al. [17] utilized Raspberry Pi to develop a structural settlement monitoring system. M. Condorí et al. [18] proposed a control system to assess the quality of tobacco leaves in real-time. Information on the color patterns of the yield is measured in the laboratory utilizing Raspberry Pi with the help of the camera. R. Adhikari et al. [19] developed a system to estimate whole plant tissue content in floriculture crops. Low-cost sensors, smartphone, and Raspberry Pi have been core components of the system. L. R. Williams et al. [20] designed a system to record drinking behavior in cattle. The sensors are placed intelligently on entry and exit gates with the help of electronic RFID panel reader as part of the Raspberry Pi

D. J. A. Rustia et al. [21] used Raspberry Pi 3 embedded system to develop an automated insect pest counting. The system is capable to monitor the environmental condition. An optimized microcomputer Raspberry Pi and RFID based system has been designed [22] to monitor small rodent activity. N. do V. Dalarmelina et al. [23] proposed a Raspberry Pi based vehicle Identification System built on the Optical Character Recognition technique to enhance the intelligent transportation systems. A segmentation technique for brain tumors has been proposed [24]. A fuzzy-based clustering algorithm running on Raspberry Pi is the core part of the proposed system.

L. Zhong et al. [25] used Raspberry Pi to design a system for home internet connectivity. B. Geethanjali et al. [26] implemented the wireless observance system to measure the temperature and soil's dampness on real-time basis. The information is stored in SQLite databank in Raspberry Pi. P. K. Das et al. [27] discussed Raspberry Pi equipped with the latest apparatus to monitor data collection. Sensors with Raspberry Pi were used to monitor rain, pressure, and temperature from the nearby environment. M. Gummineni et al. [28] developed a framework to establish communication between the sensors and Raspberry Pi for monitoring the environmental parameters.

3. Operating systems

Raspberry Pi is an intelligent combination of technology. Like other hardware it is silicon, fiberglass and semiconductor materials put together but it needs an OS to support functions. Raspberry Pi supports several different Operating systems including RISC OS, Pidora, Arch Linux, and Raspbian.

Although, there are numerous Linux based Operating systems available to support Raspberry Pi, Raspbian Pi [10] is one of the most popular among them. It is based on Debian and source code is made freely available and can be redistributed or modified. Debian is customized for Raspberry Pi and ultimately named as 'The Raspbian' and is usually accompanied by the Raspberry Pi kit. Raspbian has now become an official OS of the

Raspberry Pi foundation [10, 29]. Raspbian supports is specially designed and optimized for the Raspberry Pi hardware and consists of over thousands of Raspbian packages. Currently, Raspbian is the most prominent OS for Raspberry Pi. Raspbian is a Linux-based Open Source OS based on Debian. Raspbian is user friendly and is the recommended OS for Raspberry Pi for beginners.

Pidora is another Raspberry Pi OS based on an optimized version of Fedora [30]. Arch Linux is one of the most popular Linux Operating [31]. Arch provides users the ability to build their systems from scratch and they only require the software. This significantly reduces the amount of SD card memory consumed to store the OS for Raspberry Pi. Open Source Media Center is an Open Source media player built-in Linux. Optimized Sliding Mode Control (OSMC) [32] allows users to access information from their local network either from the internet or storage devices. OSMC is a leading media center since 2014 when it was initially launched.

Retropie is based on Raspbian OS i.e. Emulation Station [33]. Once integrated with Raspberry Pi it provides a complete set of features and utilities to perform as a Retrogaming Machine. RISC OS is a computer OS. It was designed to run on the ARM chipset and perform efficiently [34]. The pioneer ARM team developed RISC OS Computer OS. In any way, it is not connected to windows and neither is a version of Linux. Firefox OS is an OS designed for smart phones and tablets. Firefox OS [35-36] is also known as Boot to Gecko/B2G and is more of a Linux Kernel-based Open-Source OS. Firefox OS is a competitor OS of Android and Windows and recently extended his reach to Raspberry Pi.

Kali Linux [37] is maintained and funded by Offensive Security Ltd. and is a Debian-based security auditing Linux distribution. It is designed specifically to perform Digital Forensics and Penetration Testing with the help of in-built packages which includes variety of testing modules. The installation on the Raspberry Pi can easily be done. While Linux is progressing rapidly, Windows introduced an exceptional version for the Raspberry Pi - Windows 10 internet of things (IoT) [38]. Windows introduced a development platform for developers to test-case connected devices in an Internet cluster that is using Raspberry Pi and Windows 10. Windows 10 IoT is a special version of Windows built for the Raspberry Pi. RaspBSD is another OS based on FreeBSD for Raspberry Pi computers [39]. Ubuntu has designed a Linux-based OS named “Ubuntu Core” [40] and it is easy to use with Raspberry Pi with the help of Ubuntu Snappy Core.

Operating system performance and reliability depend upon the process scheduling, memory page swapping techniques in memory management and process synchronization techniques. In Table 1, a comparison is discussed among the different operating systems of Raspberry Pi in terms of process scheduling, memory page swapping techniques and process synchronization techniques. Most of Raspberry Pi operating systems are based on Linux-based kernel. Some operating systems are the extended version of previous operating systems. Very few Operating systems are proprietary.

4. Bottleneck and Challenges

The Following are some major challenges in Raspberry Pi OS nowadays.

1. Initially, 32-bit OS of Raspberry Pi was developed and upgraded to run on all models of Pi. Now the Raspberry Pi 4 was powered by 64-bit processor. There is memory protection between the Kernels (sized less than 16MB) whereas the remaining space is available for user but to note that the inter-process protections do not exist which means that the kernel at present conducts similar to an MMU-less Linux (ucLinux).
2. The Executables utilizes the “Binary Flat” composition/configuration. The implementation was initially constructed into standard “ARM Linux ELF” and eventually converted into an uncomplicated form of Binary Flat. The executable then becomes much more convenient to implement when compared with ELF (Executable and Linkable Format) and becomes supportive for sophisticated and complex attributes: run-time connections and shared information centers. Usually standard Linux type C programs can be migrated conveniently however a few precincts makes it complicated. The Raspberry Pi assists many devices on the system on a chip (SoC). However, a very few have drivers in existing operating systems.
3. Coding and development for new applications is complex due to the lack of documentation.
4. Page table is usually complex and difficult in memory management unit (MMU). To mark the memory mapped I/O regions as non-cacheable, the user must have the MMU running before the cache being enabled. For multi-core setup, there are approximately twenty bits that are necessary to be programmed before the virtual memory. Some

additional issues are encountered during the process e.g. some cores are inadvertently put in hypervisor-mode whilst the primary core is not. Such issues lead to exasperation in the process of bringing up the multi-core support.

5. Users have to utilize the load-link/store-conditional ldrex or strex instructions to lock. MMU needs to run initially where these directives only work provided the caches are operating. This makes it complicated to bring up the system since above-mentioned processes need to be toiling before locking. Appropriate locking in the serial I/O console becomes difficult in-case of the same routines for boot messages.

6. Some processors clean caches via various techniques where these become essential once Multi-Core Support is enabled. Linux kernel is the top source/location to identify the working cache flushing code.

7. Raspberry Pi has a convoluted connection with the Graphics Processing Unit and several non-cacheable memory addresses range for conversing with the Graphics Processing Unit utilizing a mailbox Interface. On many occasions, it is essentials to cleanse after such interactions which however are not properly recorded.

Table 1

Comparisons of different Raspberry Pi operating systems in terms of scheduling, paging and synchronization

Operating system	Scheduling	Paging	Synchronization
Raspbian	Fair Queue scheduling	LRU	Atomic operation, Sequence Lock, Spin-lock, Semaphore
Pidora	Fair Queue scheduling	LRU	Atomic operation, Sequence Lock, Spin-lock, Semaphore
ArchLinux	Fair Queue scheduling	LRU	Atomic operation, Sequence Lock, Spin-lock, Semaphore
OSMC	Fair Queue scheduling	LRU	Atomic operation, Sequence Lock, Spin-lock, Semaphore
Retro PIE	Fair Queue scheduling	LRU	Atomic operation, Sequence Lock, Spin-lock, Semaphore
RISC OS	Fair Queue scheduling	LRU	Atomic operation, Sequence Lock, Spin-lock, Semaphore
Firefox OS	Round Robin	LRU	Atomic operation, Sequence Lock, Spin-lock, Semaphore
Kali Linux	Fair Queue scheduling	LRU	Atomic operation, Sequence Lock, Spin-lock, Semaphore
Windows 10 IoT	Round Robin	Clock algorithm (LRU)	Spin Locks, Event, Mutex, Semaphore, Waitable timer
RaspBSD	Round Robin	Random-page replacement	Semaphore, Spin-lock, Sequence Lock
Ubuntu Core	Fair Queue scheduling	LRU	Semaphore, Spin-lock, Sequence Lock

5. Alternates of Raspberry Pi

Raspberry Pi is recognized as a renowned platform and its features make it a better choice over its competitors primarily due to it being a single board computer.

As the Raspberry Pi substitutes are increasing rapidly, the ideal choice still varies from one’s requirements such as the aims that are intended to be achieved e.g. The Pi Zero accomplishes rudimentary tasks and could not be an ideal option for demanding to process. Furthermore, Odroid-XU4 improves the outputs/results. Some single-board computers are congruent with devices that user wishes to utilize whereas Raspberry Pi cannot. Following are some best alternates of Raspberry Pi:

Orange Pi has seen a remarkable evolution in recent past. It is now comparatively affordable (from $9.90) and has been upgraded to meet the requirements of the new age. Many customizations have been made e.g. it is now capable of processing 2K videos using advanced Mali GPU and Operating systems such as Ubuntu, Debian as well as Raspbian Pi in conjunction with Linux that can be employed on this board. Orange Pi is powerful to an extent to support the Android systems. Although the Orange Pi 2G-IoT has a built-in 2G modem for data transfer it is powerful enough to be considered as an affordable substitute.

Banana Pi M3 is deemed as the rival and the most alluring alternative to the latest Raspberry Pi and offers a dynamic processing unit comprising of 8 cores and is capable of processing videos utilizing the Power VRGraphics processing unit. It provides flawless power to Single-board computer however it is comparatively expensive and costs roughly $80. Banana Pi M3 users can use a range of applications that were designed for Raspberry Pi.

Rock64 is another Raspberry Pi alternative developed by Pine64. It offers A53 RK3328 SoC with GbE and USB 3.0 ports. Rock64 has a Quadcore processed built by Rockchip. The alternate uses

AllwinnerA64. It can be utilized as an Open-source project as well as Full schematics and community support. UDOO Bolty is a breakthrough supercomputer providing desktop like performance from Single-board computer. It offers advanced features and specifications. The project overall is crowd funded and can support advanced development such as games. Users can also play heavy games on 1080p swiftly.

Odroid XU4 is one of the most potent Raspberry Pi alternatives that is also priced reasonably too with high-end features and is capable of providing efficiency of almost all the projects. This is an SBC that is as efficient as a Desktop. It provides high performance in terms of benchmark score in C-Ray, FLAC audio encoding, and MAFFT alignment. It supports many Operating systems and is capable of supporting almost all Linux based Operating systems.

6. Conclusion

Raspberry Pi is state-of-the-art embedded computer with a large amount of real-life applications in all areas of domain. The architecture is evolving due to the high demand. Lots of Raspberry Pi Operating systems are coming in the market with different features to capture the opportunity but right now Raspbian is official and recommended OS for Raspberry Pi. Linux based operating systems are offering an optimized and efficient computing environment for Raspberry Pi. In future, further OS will be introduced with great computation performance optimization in term scheduling, memory management and synchronization.

7. Future Work

In our future study, CPU energy efficiency, IO devices and GPU support comparison will be included. New more trending single-board embedded computer, different types of benchmarking and cost analysis will also be the part of our future study analysis.

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