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Linux Programming Curriculum Reform in the Era of Open Source Hardware and Software

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Abstract: *The operating system (OS) is the basic software on top of the computer hardware system, which can provide necessary support for the operation of other application software. In addition, the OS is also a fundamental tool for application development, and an integrated development environment (IDE) is installed on top of it. Consequently, Linux OS is introduced into the computer science related majors and as an advanced course. In this paper, the Linux programming curriculum reform is discussed in the era of open-source hardware and software. Different from the traditional Linux courses on server related operations, we focus more on desktop level program development or embedded system software development based on Linux operating system. Moreover, communication between two hardware systems installed with Linux operating systems is also considered. The effectiveness of the proposed reform methods has been verified through practical teaching work.*

Keywords: *Linux OS; Curriculum reform; Open source; Hardware and software*

1. Introduction

With the booming development of open-source hardware and software, the open-source and free-used OS is also attracting people's attention. Most people use operating systems based on graphical interfaces and operating methods, such as Microsoft's Windows series operating system. The advantage is simplicity and convenience, but the disadvantage is closed source, memory consumption and large disk occupation. Unlike the Windows series OS, Linux kernel code is open source and can be pruned that usually requires professional computer workers to use it. In addition, it is a free to use and freely spread UNIX like operating system, with its kernel first released by Linus Benedict Torvalds on October 5, 1991. It is mainly inspired by the ideas of Minix and Unix, and is a POSIX based multi-user, multitasking, multithreaded, and multi-CPU supported operating system. Usually, the Linux operating system is not unique, but has many distribution versions. Previously, Linux was commonly used in the computer server field [1]. Afterwards, with the rise of big data and cloud computing, the application of Linux operating system is vigorously promoted [2,3]. As a mater of fact, due to the characteristic of Linux that can be cropped, it has been applied in the embedded field of industrial scenarios for many years [4,5]. However, the common Linux course teaching content is still the basic shell commands, system management, network management and the construction of various servers [6,7].

Nowadays, the open-source hardware and software are gradually becoming popular, especially the popularity of embedded artificial intelligence [8]. As far as we know, many primary and secondary school students in many countries have already been exposed to the advanced computer knowledge. In this paper, we analyze the application of Linux operating system in these open-source software and hardware systems. Then, the use of automated compilation tools is introduced in Linux systems. After a semester of teaching practice, students are satisfied with this teaching content and methodology and their interest in learning has also been stimulated.

2. Linux Operating System Used in Open Source Hardwares

2.1. Simple Open-source Hardware

STEAM (science, technology, engineering, arts and mathematics) education has been promoted for many years, and due to its scientific nature, except for the art part, the other parts have always been the mainstream of education [9]. STEAM emphasizes knowledge cross-border, diverse scenarios, problem generation, critical construction, and innovation driven, reflecting many characteristics of curriculum

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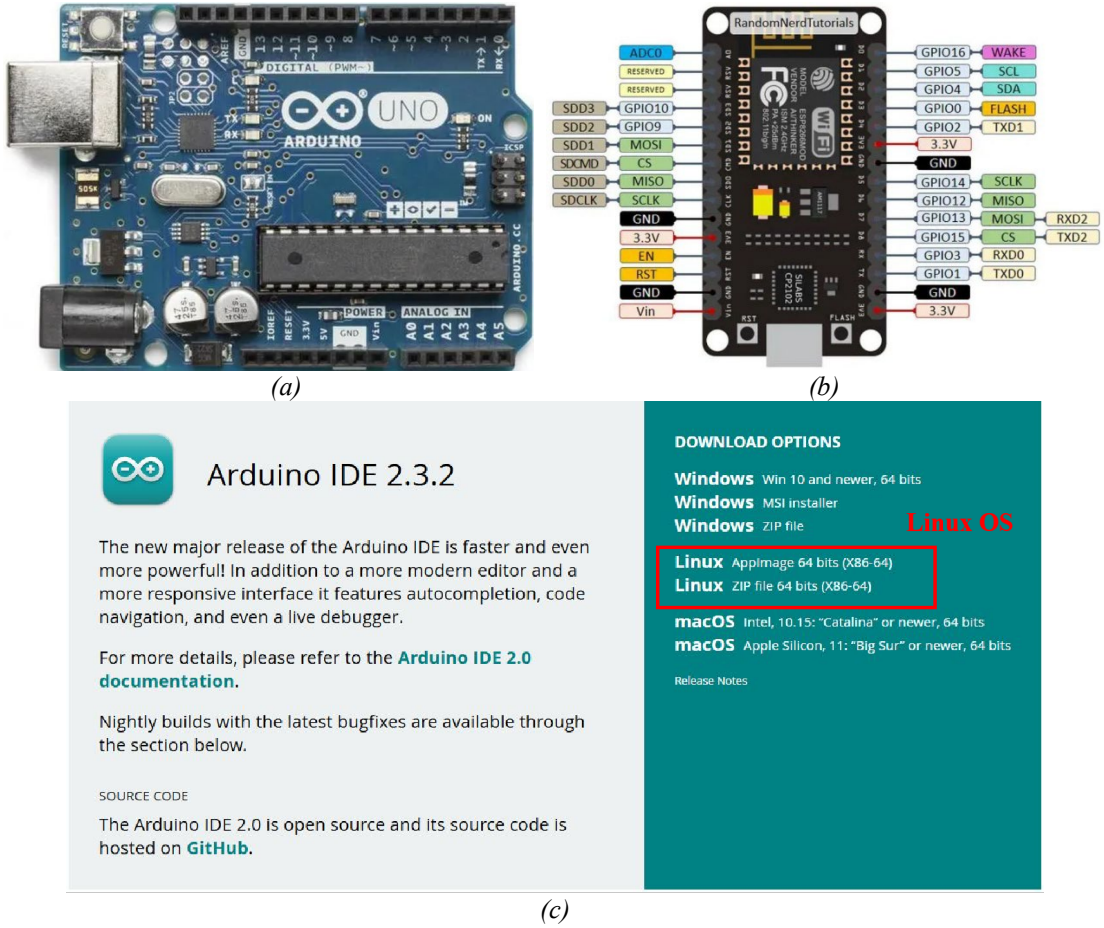
comprehensiveness, practicality, and activism. For primary and secondary school students and lower grade students in universities, intelligent systems based on open-source hardware have always been one of the popular research devices. Figure 1(a) shows the famous and commonly-used 8-bit microcontroller module which is called Arduino development board [10]. The Arduino board is a convenient, flexible, and user-friendly open-source electronic prototype platform [11]. The module can perceive the environment through various sensors, and feedback and influence the environment by controlling lights, motors, and other devices.

If a single intelligent terminal needs to be connected to the network or controlled through the network, the network communication module is definitely essential. Another simple open-source hardware with WiFi communication function is esp8622/32 which is commonly used in smart home scenes [12]. Figure 1(b) shows the WiFi module which also includes microcontroller unit.



(a) *(b)* *(c)*

Figure 1: Simple open-source hardware that can be developed under the Linux operating system. (a) Arduino Development Board. (b) WiFi Module. (c) Arduino IDE Download Options.

The above two open-source modules seem unrelated to the Linux operating system, but the program development needs to be implemented on a desktop computer. In a desktop computer environment, it can be seen that the Arduino IDE (Integrated development environment) can be installed on the Linux operating system, as shown in figure 1(c). That is to say, users can install the IDE into the computer with Linux OS to study which also indirectly indicates the popularity of Linux usage. When the host operating system in a physical machine is Windows, the virtual software can be used to install Linux OS if the users are willing.

2.2. Embedded Artificial Intelligence Devices

An open-source electronic module with slightly stronger functionality than Arduino is the circuit board of a 32-bit microprocessor. The mainstream low-power embedded processor core is ARM's Cortex -M series and the STM32 packaged chips based on it are very popular [13]. Although these processor modules cannot run the operating system, they can run lightweight neural network models to recognize objects in the images. The improved version based on this open-source module is shown in figure 2(a)

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which includes a camera to achieve images. A stronger open-source electronic module is based on ARM's Cortex A-series kernel and can run the operating system. A very famous microcomputer is Raspberry Pi which is a single board computer based on the Linux system and is only the size of a credit card [13]. It was developed by the Raspberry Pi Foundation in the UK with the aim of stimulating basic computer science education in schools with low-cost hardware and free software.

Raspberry Pi can install various different operating systems, including but not limited to the following:

(1) Raspbian: This is the official recommended operating system for Raspberry Pi, based on Debian Linux [14]. It provides a graphical desktop environment and command-line interface, making it very suitable for beginners.

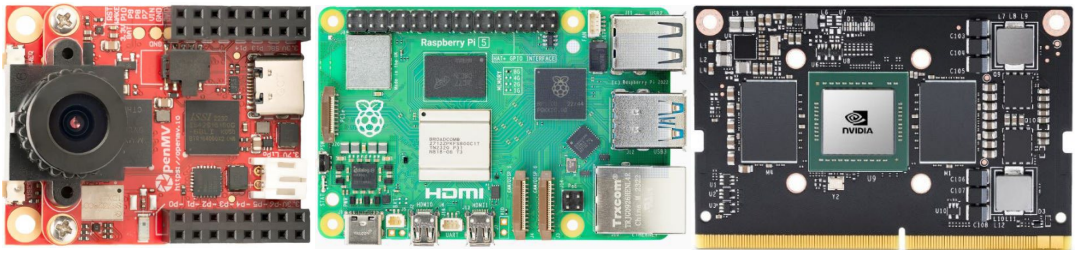
(2) Ubuntu Mate: This is an Ubuntu version suitable for Raspberry Pi, which provides a graphical desktop environment and command-line interface, powerful and easy to use.

(3) Kali Linux: This is an operating system designed specifically for network security and penetration testing. It contains many network security tools and is the preferred choice for hackers and security researchers.

(4) RetroPie: This is a Raspbian based system specifically designed for building and simulating vintage gaming consoles. It provides many emulators and games, allowing you to relive classic games.

(5) OSMC: This is a media center operating system based on Kodi. It can turn Raspberry Pi into a powerful multimedia center that supports playing local media files and streaming.

In addition to the systems listed above, there are many other operating systems and distributions that can be installed on Raspberry Pi. The specific release version to choose depends on the specific needs of the user.



(a) *(b)* *(c)*

Figure 2: Embedded artificial intelligence devices. (a) OpenMV: visual detection board. (b) Raspberry Pi development board. (c) Embedded GPU board.

Furthermore, if the processing capabilities of the previous two devices are insufficient in the field of embedded microprocessors, the embedded GPU devices will be introduced. As we know, NVIDIA Inc. designed several low power GPU processors like jetson series, as shown in figure 2(c). The ubuntu distribution Linux version is recommended to be installed on the micro-computer with GPU units [15]. Many deep learning neural networks can run on those devices. If not, then desktop or workstation level processors will be considered.

2.3. Robot Platforms

With the development of artificial intelligence technology and the advancement of interdisciplinary integration, the development speed of mobile robots is fast, and their commercial applications are widespread. Robot education has entered STEM education in primary and secondary schools, and is one of the important experimental platforms in innovative education [16]. Decades ago, when people talked about robots, they usually referred to industrial robotic arms in factories. However, for ordinary people, it is difficult to access these robots and they do not need them. Unlike industrial robotic arms, mobile robots have entered multiple fields of human life. Mobile robots can be divided into indoor mobile robots and outdoor mobile robots based on their working environment. When classified by movement mode, there are wheeled mobile robots, walking mobile robots, snake robots, tracked mobile robots, crawling robots, etc. The most common robots are wheeled mobile robots, quadruped robots or robotic dogs, and humanoid robots [17]. Figure 3(a) shows the wheeled mobile robot with multiple sensors and figure 3(b) shows the quadruped robot which is used for competition purposes. Humanoid robots are commonly used for toy level dance demonstrations, and large humanoid robots have become popular with the rise of embodied intelligence.

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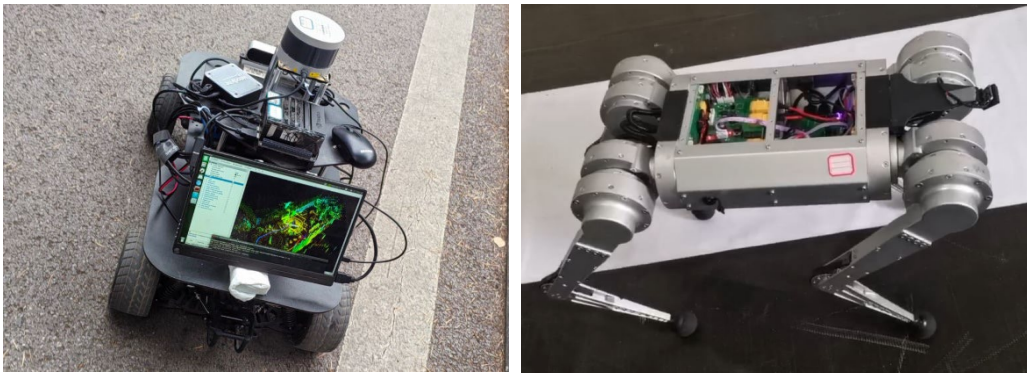
For mobile robots, the motion structure is only an external executing mechanism. In fact, the main components are the main control computer and the algorithms and software running within it. Currently, mainstream robot software development is based on robot operating systems (ROS). ROS is not a true OS, but a fundamental software which provides message communication mechanism for services and sensors. Due to advantageous performance and historical factors, ROS is mostly depended on the ubuntu Linux distribution version. Namely, a robot is mainly depending on the microcomputer and Linux OS. Practically, the Raspberry Pi and NVIDIA Jetson series are the mostly used microcomputers in academic and commercial robot systems [18,19].



(a) (b)

Figure 3: Robotics using Linux. (a) Autonomous mobile robot. (b) Quadruped robot.

Table 1 shows the teaching and learning knowledge of Linux course that can be implemented on the robotic platform.

Table 1: Linux teaching knowledge based on robotics.

Experimental Content	Learning Knowledge and Description
System image installation	Learn how to install Linux operating system into robot system (Built-in micro-computer)
Network configuration	Learn how to configure the network of the robot and connect to the internet
Installation of third-party software and dependency libraries	Learn how to install the software using online tools or source code installation methods
Programming skills	Learn how to edit the C/C++, Python, and Shell scripts code, how to compile or interpreter them, how to run.
Remote login	Learn how to login another device by remote method and operate like on one's own computer
Remote motion control	Learn how to control the robot motion using remote commands and tool

Figure 4 shows robot experiments in actual scenarios where the left figure is the wheeled mobile robot with Linux OS and the right figure is the students controlling the robot by remote login.

(a) (b)

Figure 4: Robot used for Linux teaching. (a) Experimental platform. (b) Students in the experiment.

If students can master the basic operations of mobile robot systems, the basic operations of outdoor

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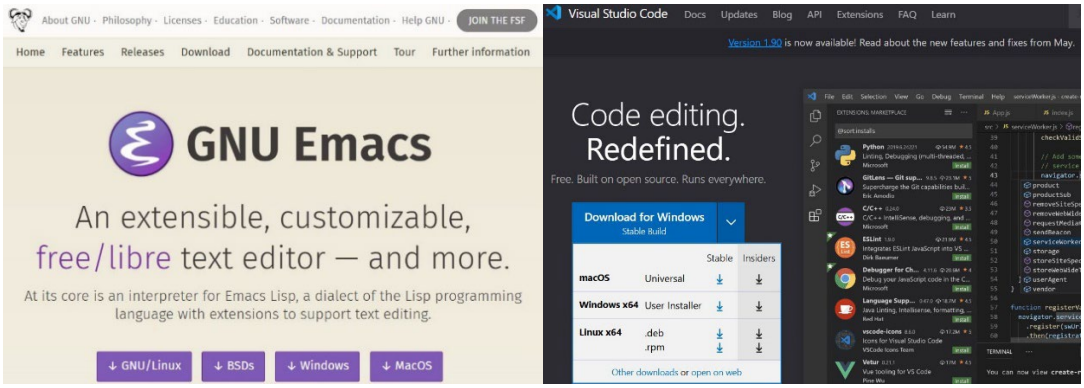
unmanned vehicles or autonomous vehicles are also similar. In practical applications, the operating system used by Baidu's autonomous driving system Apollo is Ubuntu Linux [20].

3. Linux Operating System Used for Open Source Softwares

Due to the needs of scientific research, especially the computer science discipline, many software and libraries are developed based on Linux OS. Before starting all work, it is necessary to have text editing tools. Afterwards, there are code compilation and debugging tools that generate executable files. In fact, there are also office software similar to Microsoft Office on Linux systems. In addition, there are many third-party basic software libraries available for application calls. Unlike operations under the Windows operating system, these tools operate in command line mode.

3.1. Text Editors in Linux OS

In Linux OS, the idea that everything is a document. Consequently, the text editor is a very basic and important tool to edit the content and configure the parameters. The classical text editor is Vi which uses a command line mode. Commonly used version is its improved one that is named Vim [21]. Another stronger tool is the GNU Emacs which can be extended and customized by the users [22], as shown in figure 5(a).



(a) (b)

Figure 5: Text editors in Linux. (a) GNU Emacs. (b) Microsoft Visual Studio Code.

Table 2 lists the most commonly used text editors in Linux operating system. Some of them are cross operating system platforms and can also be used under the Windows operating system. In order to enhance the user experience, some text editors also provide graphical user interfaces on Linux systems, making it convenient for beginners to use. The representative tool with GUI interface is the VS code [23], as shown in figure 5(b).

Table 2: Most commonly used text editors in Linux OS.

Text Editor	Official Website
Vim (Improved Vi)	https://www.vim.org/
GNU Nano	https://www.nano-editor.org/
Gnome gedit	https://help.gnome.org/users/gedit/stable/index.html
GNU Emacs	https://www.gnu.org/software/emacs/
Sublime Text	https://www.sublimetext.com/
Microsoft Inc. VS Code	https://code.visualstudio.com/

3.2. Office Software in Linux OS

For non-programmers, office software is a necessary tool for most computer users. Usually, the office software refers to software that can perform tasks such as text processing, table making, slide production, graphic and image processing, and simple database processing. The commonly seen office software is the graphical version under the Windows operating system. In Linux OS, it needs to add graphical tools in command line mode. Table 3 lists the commonly used office software in Linux OS. It is worth noting that the last one is a domestically produced office software with a relatively large user base in China. The Linux version can be downloaded from the official website [24].

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Table 3: Most commonly used text editors in Linux OS.

Office-software	Official Website
LibreOffice	https://www.libreoffice.org/
ONLYOFFICE	https://www.onlyoffice.com/
Calligra	http://www.calligra.org/
OpenOffice	https://www.openoffice.org/
Siag	http://siag.nu/
Feng Office	http://www.fengoffice.com/web/index.php?lang=en
WPS Office	https://linux.wps.cn/

3.3. Classic Open-source Software Library in Linux OS

In academic research and industrial software application scenarios, open-source software libraries can save software development time. Usually, they are basic algorithm implementation libraries and mathematical function libraries [25]. Table 4 lists the commonly used open-source libraries in Linux OS, certainly, some can also run under Windows.

Table 4: Most commonly used open-source libraries in Linux.

Open-source Library	Official Website	Function Description
OpenCV	https://opencv.org/	Open computer vision library Mainly processing 2D images
PCL	https://pointclouds.org/	Point Cloud Library Mainly processing 3D data
Open3D	https://www.open3d.org/	A Modern Library for 3D Data Processing
OpenVINO	https://docs.openvino.ai/	Open Visual Inference and Neural Network Optimization
Caffe	https://caffe.berkeleyvision.org/	Convolutional Architecture for Fast Feature Embedding
g2o	https://github.com/RainerKuemmerle/g2o	A General Framework for Graph Optimization
Eigen	https://eigen.tuxfamily.org/index.php?title=Main_Page	A C++ template library for linear algebra

4. Automated Compilation Tools and Rules

In Linux OS, most program development is based on the C/C++programming language. Single or few source code files can be compiled using the GNU GCC tools, such as gcc and g++. However, large projects have thousands of source code files and multiple directories that is difficult to manually compile files one by one. To solve this tricky problem, automated compilation tools are proposed, such as the make and makefile. Makefile is a rule document which instructs the make command on how to compile source files in the directory. A classic case is the source code directory of the Linux kernel [26], as shown in figure 6.

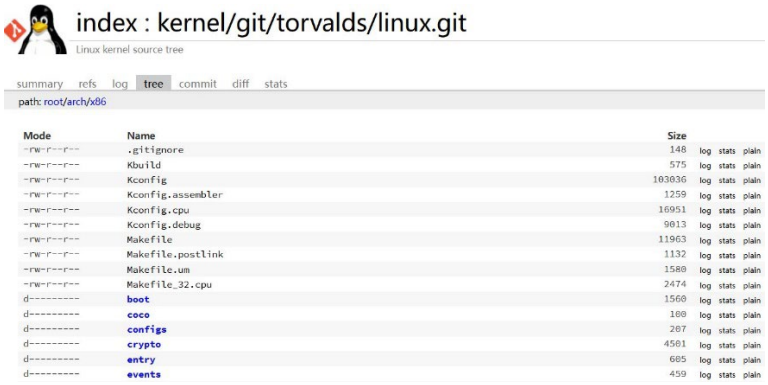

Figure 6: Online tree-display of Linux source code directory.

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The makefile rules seems like it's already good, but it is too complicated. Each subdirectory in the source code directory requires a makefile file. If some files or code snippets are updated, it can be difficult to modify the entire rule file. A very successful improved version is CMake and cmakelist rules. No matter how many source code files or subdirectories there are, only one CMakelists.txt file is needed in the root directory. Figure 7 shows a classical example of the navigation package in mobile robot filed where the localization subpackage is the amcl codes [27].

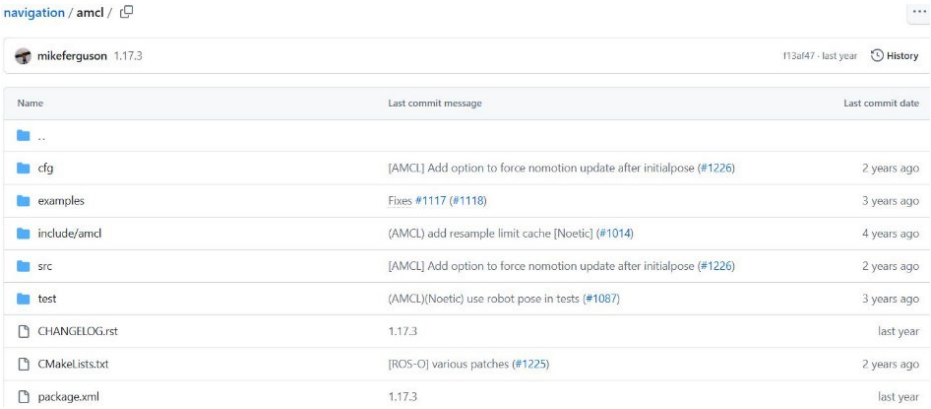

Figure 7: Online directory display of amcl package.

5. Conclusion

In the era of open-source hardware and software, almost all computer resources are free and modular. Especially with the rise of artificial intelligence and robots, Linux OS and programming skills attract people's attention. For the teaching reform of the computer major, the traditional Linux teaching mode and content are no longer suitable for the development of the times. Introducing open-source hardware and software content in undergraduate teaching can attract students' interest in learning. In practice, it has been found that students have high enthusiasm and are willing to participate in course practice

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