UDK: 629.7.051.5:004.738.5
COSATI: 01-03, 12-05, 15-03

Open Source Solutions in The Development of Military Unmanned Aerial Systems

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This paper offers a concept of open source software, hardware and network solutions suitable for application in the development of unmanned aerial vehicles (UAV) and systems (UAS). Use of open source platforms significantly reduces costs of development and procurement without reduction in reliability factor and safety of military UAV and UAS for combat and support. The most suitable modern application is in the area of hardware microcontroller and microprocessor systems such as Arduino and Raspberry Pi, Linux operative systems and network protocols for mobile ad hoc networking.

Key words:.**unmanned aerial vehicles, autopilots, mobile network, open source.**

Introduction

BASIC requirements in the development of military technical systems are efficiency, reliability and safety of their use. Therefore high quality and durable materials are chosen for their development, their construction is complex, time for development long and development costs significantly. In accordance with the complex nature of modern conflicts, highly dependent on technology, the development of many modern combat systems is complex and lengthy, since they are required to have high performance and multifunctionality, which leads to reduction of required performances and high extra costs [1]. For example, the development of a new fifth generation multirole Joint Strike Fighter F-35 for the needs of the United States Military with universal purpose (ground attack, reconnaissance, air defence) and stealth capability, has lasted, in different phases, since 1996 and is already behind the schedule for a couple of years. One of the important factors for this delay is the inability of several hundred of employed highly qualified programmers to create and harmonize a vast amount of software (during the time the number increased from 15 to 24 million code lines) necessary for the operation of this fighter plane system [2]. At the beginning of its 50-year projected life, it was planned to expend over 1000 billion dollars, but the project is already behind for several years with losses exceeding 5 billion dollars. High demands and the size of software conditioned the selection of the programming language for programming of majority software modules. US Department of Defense uses versions of the programming language ADA for systems that require the highest security in work and safety. The software for a previous project, the airplane F-22, was written in ADA83. However, the majority of software of a new plane F-35 was programmed in a relatively old and highly spread universal purpose programming languages - C and C++, primarily due to the availability of programmers familiar with these languages. Besides this, a large part of ready software modules were taken from the previous projects. However, these measures have not eliminated the problems of the enormous complexity of software, therefore, according to the representatives of the US Army, the software is probably the greatest factor for the delay of the initial operational capability of F-35 [3]. For the purpose of project security during its life span (40 years of operational use), the US Department of Defense has decided not to share the software code for the F-35, not even with partner states that have pre-ordered a certain number of aircrafts [4].

On the opposite side of such closed, extensive projects is the open source movement. Development of information technologies has lead to the distribution of knowledge and technologies for production of mass to individual level. The networking of knowledge of many enthusiasts creates projects in the area of software and hardware that are intellectually mankind digital commons – open source projects. The open source concept does not relate only to software anymore, but to hardware as well. The opinion that the open source products cannot be successfully used in military industry is erroneous. The application of small open source microcomputers, programs and protocols, and other solutions in numerous technical systems is increasing everywhere in the world. According to the estimates of the US Army, there are over half a million active open source projects, around 20% of all programmed code is open source, and around 95% of all code bases contain open source software [5].

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Military application of open source technologies

Open source technical solutions are software and hardware for which the human-readable source code and technical assets are openly available for use, study, reuse, modification, enhancement, and redistribution by the users of that software and hardware. In other words, open source software and hardware is that for which the source is open.

Basic characteristics of such solutions are:

- The application of these technologies is inexpensive, easily available and does not require long research and design, since the architectures and the design of technical systems created by their combining are based on the existing solutions.
- Licensing is designed to protect the open distributability of the software and hardware.
- The use of open source solutions can encourage innovation, combination and reuse of these technologies that is not controlled.
- Low barriers to entry into projects research enables collaborative innovation.
- Many usable solutions already exist.
- Due to their modular nature these solutions may be used in other projects as well.
- Value added projects: increases cost-effective development, highly efficient, increases innovation productivity through collaboration
- They can equally be used as a basis and testbed for development of industrial military systems, for training, but also as final low cost solutions.

Main challenge in their application is creativity and combining of the existing solutions with the goal to implement the end objective and achieve the desired function of a system through new ideas. On the other hand, open source software and hardware technologies often do not provide for high military demands for fight power, reliability and other tactical and technical elements so their purpose must be carefully projected with the goal to provide high efficiency in a short period of time. This conflict of demands is possible to solve in a certain number of cases by reducing the price of an individual system, designing for single use and multiplication of individual systems engaged in one operation. Although safety is one of the most pointed out vulnerabilities of open source technologies, the experience in their application, particularly software, demonstrates that the safety of their application does not fall behind proprietary or cost-of-the-shell software and hardware technological solutions [12]. However, use of open source technologies cannot be unlimited in military systems since these technologies may have significant vulnerabilities, most important being incompatibility between open source and proprietary technologies, as well as between different open source solutions. The third important shortcoming of open source technologies, both software and hardware, and especially information and communication technologies (ICT) and electronic components may be reliability in extreme work conditions, characteristic for military application, especially in combat environment. Nevertheless, there are numerous examples of software with both high quality and low price, or even free. For example, the Linux operating system, which licenses its basic source code for free, is used today to run enormous number of servers in business, government and academia. Also, commercial products are rapidly moving away from proprietary development programming languages and increasingly prefer common open languages. Another important aspect is the high speed of development of ICT, computer and electronic devices. In order to keep up with the technology development in their surroundings, armies of the world demand fast changes of these technologies in order to effectively harmonize the technological level of their combat and support systems. However, proprietary programs or devices must be modified by the software's owners, which usually requires a longer time period than acceptable for the military purposes. Also, the chronic lack of financial means of the majority world governments further slows down implementation of such military requirements. Open source programs could be modified quickly, which is very significant for the military. Therefore it is crucial to properly select appropriate open source technologies for corresponding military systems, which puts forward their advantages and minimizes their shortcomings and vulnerabilities. Only in such a way, beginning in the planning phase, it may be achieved that open source solutions provide the same if not better features than proprietary ones, to be compliant with more industry standards than most of its proprietary counterparts and be reliable in all combat environments.

Open source community in the world is highly active. Web sites for publishing and exchange of programming solutions such as SourceForge.com, Github.com and Pastebin.com are visited by tens of thousands daily. After a long history of joint work on open source software solutions used by broad community, from boot code, drivers and OSs, such as Linux and FreeBSD operating systems, software from layer between OS and applications (middleware), application software like office software, internet browsers and other, to development tools, a trend of joint development of different open source hardware platforms. The basic purpose of these platforms is to serve as a basis for open source modifications, such as microcontroler and microprocessor platforms such as Arduino and RaspberryPi and many projects in the area of robotics. Interest in the development of such platforms, besides individuals, is present in the academic community, private capital, even military industry. Such a distributed approach to the development of new technologies does not fall behind the mainstream solutions in the area of industry, it even leads the way in some areas. Since there is no financial support of governments and economy for the members of the open source community, the basic thrust of most open source projects is the attempt for these solutions to have optimal functionality in relation to the development and application cost. The consequence is two important characteristics of open source solutions:

- low cost for the creation of platforms and solutions,
- universality of application of the open source solutions (based on non-standardized compatibility and modular approach).

The quality and functionality of open source solutions have led to their wide acceptance by industry and business (Linux and Android operating system, internet browsers, concept of PC computers and others). However, open source technologies globally still do not have wide military use. Maybe surprisingly, the greatest application of open source solutions in military systems is present in states that have the highest level of military industry such as USA, EU and Israel, not the developing countries [6, 7]. For example, American scientific research agency DARPA has initiated a project for application of open source UAVs model for the military purposes [8]. This fact speaks a lot of the significance of open source platforms, but also about the insufficient understanding of their technological advantages in military use. Application of open source technology for military aircraft is very significant, especially for the purpose of reducing the development costs and time. The experience has shown that the achievements of software and hardware platforms often do not deviate from achievements achieved by highly sophisticated development centers. The example of this claim are modern open source solutions in the area of cyber security that are just as efficient as commercial solutions, sometimes even more so.

Open source solutions may be found in many areas of military application, including firearms [9] and combat systems [10].

Figure 1. The TrackingPoint XS1, chambered in a .338 Lapua Magnum, Linux powered precision guided firearm (remote control monitor and rifle set)

Figure 1. shows an infantry combat system of an American start-up company TrackingPoint that uses open source technology for the purpose of achieving a perfect shot from a sniper rifle. This company produces “Precision Guided Firearms… or heavily customized hunting or combat rifles, all fitted with advanced computerized scopes” [9]. These rifles represent a highly sophisticated system that consist of the firearm itself, modified trigger mechanism with variable weighting, the computerized digital tracking scope, and hand-loaded match grade rounds. The central processing part of this system is a computer with an ARM processor that calculates a large number of relevant parameters of the environment, target, ammunition and other parameters and enables automated firearm precision improvement with a small margine of error. Targeting system that functions in combination with laser target designator is linux-powered and extremely simplifies the targeting process and improves precision. It also provides that each weapon usage situation is transferred to the command centre in real time. In this way serious combat situations may be made as easy as playing a video game.

The system even contains a small wireless Wi-Fi server, that connects through an iOS software application with the scope via an ad hoc Wi-Fi network and streams scope’s display to the application. This enables the shooter to act as a spotter with a mobile iPhone or iPad device. An image from the scope may even be transffered to an external display which enables an experienced shooter to observe the situation and give shooting advice.

Figure 2. An image of targeting by application of the computer optical system of TrackingPoint XS1 rifle at the distance of 922 meters

Integration of all these functions into one system is provided by application of a modified version of Angström Linux, with specific modifications made by BitBake programming tool whose special focus is on distributions and packages for embedded Linux cross compilation (and which is derived from Portage, the package management system used by the Gentoo Linux distribution and then existed for some time in the OpenEmbedded project). This tool enables development of kernel modules to support the rifle's proprietary hardware). Ångström Linux is highly adaptable and may be used for a wide scope of devices, from those with only 4 MB of flash memory to devices with terabytes of RAID storage. The above mentioned project of TrackingPoint may be compared with an advanced project which is still in its experimental phase, Cubic company's One Shot XG, initiated by Defense Advanced Research Projects Agency (DARPA) with a contract worth 6 million US dollars [11]. The described concept is not new and it completely fits into Land Warrior programme, a part of an even wider programme Future Force Warrior, managed by the United States Military which represents a combined application of commercial off-the-shelf technology (COTS) and applied military equipment for the purpose of small arms integration with high technology equipment, provision of communications for command and control functions to soldiers and infantry units and enabling individual infantry soldiers to be equipped and operate in a complex and multifunctional way. This example shows that the advantages of open source solutions' application are numerous, especially when keeping in mind their capacity to achieve technical and combat characteristics of specialized military systems, adjustability to different technical platforms and reliability.

One of basic requirements in introduction of technological systems in military application is safety. Although this requirement is precisely one of the most mentioned vulnerabilities of open source technologies, practice provides us with many examples showing otherwise – that precisely the requirement for improvement of technical systems safety is a common reason for introduction of open source solutions. A typical example for this claim is more frequent introduction of Linux operating systems in command centre for remote control of unmanned aerial vehicles or autonomous flight control.

Figure 3. Linux powered UAV control station in Creech Air Force Base in Nevada, USA (2011)

Figure 4. US drone Control Station based on Windows XP (2009)

Figure 3. shows a detail from remotely control drones centre at US Air Force Nevada's Creech Air Force Base (the central U.S. Air Force base for ground control systems of unmanned aircraft vehicles). The most common models of UAVs in this base are MQ1-Predator and MQ9-Reaper. On photographs of the control room computer monitors from different years interface of Windows and Linux OS may be seen. Besides U.S. Air Force, U.S. Navy has initiated projects of installing Linux OS to control some of its autonomous flying vehicles (Nothrop Grumman MQ-8B Navy Fire Scout autonomous helicopter). A programme named "Linux transition on the tactical control system software for vertical take-off (VTOL) unmanned air vehicle ground control stations", worth 28 million dollars with the goal for this OS to power an unmanned vehicle which "has the ability to autonomously take off and land on any aviation-capable warship and at prepared and unprepared landing zones in proximity to the soldier in contact" [12]. The U.S. Department of Defense has put out guidelines on how its agencies can use open-source code: "The US government can directly combine GPL and proprietary/classified software into a single program arbitrarily, as long as the result is never conveyed outside the U.S. government, but this approach should not be taken lightly… When taking this approach, contractors hired to modify the software must not retain copyright or other rights to the result (else the software would be conveyed outside the US government)" [13].

In accordance with its modular nature, open source technologies have practically unlimited application possibilities. Technical solutions for military systems due to the before mentioned requirements have long design time, their production is complex, maintenance expensive and complicated, they require high quality and reliable materials and their construction is complex, so trained staff has to handle them. The consequences are, almost regularly, high costs for development, production, maintenance and use of these military technical systems during their whole life span [14]. On the other hand, fast progress of technology has enabled its accessibility in all parts of the world, including poor states, different political and terrorist organizations and groups, even individuals. Technology gives power to developed parties in a conflict to lead network-centric and the weaker opponents' asymmetric conflict. For example, the terrorist attack on USA on September 11th 2001 was performed by violent plunge of large commercial airplanes on targets in New York and Washington, hijacked by teams of 4 to 5 terrorists who were technically trained to fly hi-tech airplanes. The reaction of the USA to these attacks included long-time military engagement in the wide region of Middle East, and in two wars (in Iraq and Afghanistan) the total number of soldiers employed annually reached even 300000 with direct cost of up to 140 billion USD [14]. The mentioned concepts (and characteristics) of modern warfare bring great changes in design, ways of selection, application and use of military combat and support systems. A significant change takes place that characterizes all new conflicts in the 21st century – classic warfare with conventional fighters with war technique combat systems in contact with irregular threats by civilians or fighters with their available means, becomes hybrid in its nature, and represents a convergence of these different forms of warfare.

Demands of hybrid warfare are:

- Combatant (civilian, fighter)/(civilian, military technical system-device or application) becomes focused on the given task; the combatant is functionally oriented not object oriented; he knows what to do, he knows the request for the final outcome and is oriented on the final goal and functions that may help him achieve it; unlike the object oriented approach where a function (or task) is only an elaborated method within a higher class (of the adopted system), in the new approach the function is completely independent and it can be manipulated with greater freedom, independently, as an object.
- Availability of weapons is a top criterion; in modern conflicts weapons of former generation is used (automatic rifle AK-47, anti-personnel mine), powerful combat weapons (cruising missiles, anti-aircraft and anti-tank rocket systems) and hi-tech autonomous weapons such as military robots for surveillance and combat (unmanned aerial, ground, naval robots) and warfare technology;
- Conflict tactics range from simple to complex and is highly coordinated with understanding of operational situation, and the requirement for information is immense;
- Combat environment is diverse from overcrowded urban environments with traffic and infrastructure, to completely uninhabited areas, without any technology or civilization;
- Combatants must be prepared to participate in conflicts that are asymmetric on many planes.

New strategic challenges are in their nature different, unstable environments with mass disruptive threats and uncertain availability of resources. Two basic concepts that simultaneously characterize the network centric and the asymmetric approach to modern conflict area:

- Mass application of robots of different military purposes (reconnaissance, logistics, special and combat operations) and
- High representation of information-communication technologies at all levels and areas (increase of capacity of individual systems, networking, virtualization of functions, etc.)

Although at first they seem very different, these technological concepts are interdependent and basic connections between them are digital information technologies. A significant role in this process is played by open source technologies that are widely available and inexpensive, and open the possibilities for creation of single use military combat systems and support systems.

How to select open source projects for military application

There are an enormous number of open source projects that may be seen at specialized internet portals. It is, therefore, very important to know how to choose the right projects that best suit the real needs. The best way to find a suitable open source software are general purpose search engines, specialized portals (forges and hubs), chat and social web groups, foundations, project sites, embedded platform distributions and other.

There are several specialized hosting sites for open source software (forges and hubs). For example, SourceForge [15] has a collection of over 450,000 project repositories. Even greater numbers of repositories are found on GitHub [16] (over 2,5 million), Pastebin [17], web application where anyone can store a text and is mainly used by programmers that has over 20 million users, CodePlex [18] with over 32,000 projects, GoogleCode [19], Gitorious [20], Apache Foundation, Outercurve Foundation, Eclipse and many more. In the area of UAV well known are the project sites that are more specialized and represent serious and already finished projects, such as DIY Drones [21], OpenPilot [22], Paparazzi [23], Association for Unmanned Vehicle Systems International (AUVSI) [24] and others. However, even more important than finding a suitable open source code is choosing projects that have the greatest technical utilization value of a corresponding platform. In general, projects that have high community history and dynamics, known origin, licenses and other similar characteristics are more applicable. However, regardless of documentation and licenses, keeping in mind that the origin of open source software is often unknown, it may represent only a baseline for application in military systems. This is why it is important to select a source code in a suitable programming language since it is frequently necessary to change and improve the basic source code. For example, if a programming code is programmed in C programming language, it is highly probable that problems and inconsistencies will appear in case of modification by upgrade of new modules that have been programmed in other languages, such as Python, Java, ADA and similar. It is exceptionally important to choose an open source programming code that has serious and detailed documentation. Modern open source device-based softwares contain a variety of parts programmed in traditional compiled and assembled languages (C, C++, assembly), scripted and interpreted languages (Python, Lua, PHP, and so on), or byte-code executed (Java). A very important parameter for software quality is the dynamics of community, frequency of changes and improvements of the solutions, as well as if there is licensing of the open source solution by some association.

Robotization of combat and support aircrafts

During the previous decade the number of robots used for military purposes rose suddenly. At the same time, the price of their development, construction and maintenance was significantly reduced. Parallel with these trends an idea appeared to use military robots as intelligent low cost systems intended for combat, scouting, reconnaissance, spy or combined operations whose basic mission is to perform a single operation [48]. This trend especially manifests in the area of Unmanned Aerial Systems (UAS). Basic factors enabling such robot use are low cost and accessibility of hardware and software. This kind of application requires that the cost of their one-time use is as low as possible which would compensate for their deficiencies in relation to cruising missiles. Also, exceptionally low cost and high accessibility can enable their multiplicated use in the form of swarms, i.e. simultaneous engagement of a number of aircraft that collaborate in a coordinated manner during the operation implementation [25].

According to US Department of Defense Dictionary of Military and Associated Terms, unmanned Aerial Vehicle (UAV) is „a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload“ (a recent issue of the Dictionary does not define the term UAV, although it is mentioned, but primarily explains the terms unamnned aircraft and unmanned aircraft system). So, UAVs are capable of operating without an internal pilot; are tethered by a radio control link; and can be pre-programmed for both flight and payload operations prior to launch [26]. Ballistic or semiballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles, because air vehicles are designed to come back and be re-used. But, there are some similarities with guided missiles, because UAVs are incorporating lightweight airframes, advanced propulsion systems, secure data links, and high technology control systems and payloads. The abbreviation UAV represents several different terms, such as Unmanned Aerospace Vehicle, Unmanned Air vehicle, Unmanned Autonomous Vehicle and other. Unmanned aircrafts are commonly called unmanned aerial vehicles (UAVs), and when combined with ground control stations and data links, form UAS, or unmanned aerial systems. Unmanned aircraft system is a system whose components include the necessary equipment (for launching, ground control stations and data links for remote navigation and control and similar), network, and personnel to control an unmanned aircraft.

No matter if abbreviation UAV or UAS is used, a common characteristic is that these aircrafts are remotely navigated by an operator and that they fly autonomously. Today, systems that will in the future become fully autonomous are being increasingly developed. Like advanced artificial intelligence these systems will be able to sense where they are, what they are doing, what they should be doing, where they should go to complete the pre-programmed task and how they can complete that task most efficiently and effectively and with a certain degree of luck return to base.

Modern UAS are designed on a modular principle thus achieving universality in their application, handling and maintenance. Also, they are highly dependent on information-communication technologies that provide them the possibility to network and coordinate, processor power to identify the target, flight and operation parameters as well as the connection with the operators on the ground. In order to provide for the high military demands, with the simultaneous maximal reduction of costs for development and procurement of software and hardware, the modern trend is the application of open source solutions in the area of software as well as hardware.

Figure 5. A soldier is launching the most numerous UAV in the US Army - AeroVironment RQ-11B Raven, intended for observing and reconnaissance [28]

In the US Army, a global leader in number of unmanned aircraft in the world, most unmanned aircrafts are small [27].

Figure 5. shows Raven RQ-11B, an aircraft whose mass is only 1.9 kg, operational radius around 10 km, flight speed between 45 and 97 km/h and maximal flying altitude 4600 m. It is used in 18 countries and the total number of aircrafts of all models is 19000 (according to data from 2012, this aircraft made up 71% of all unmanned aircrafts in the US army [27]. Its size, portability of use and numbers speak about the significance of small dimension UAS.

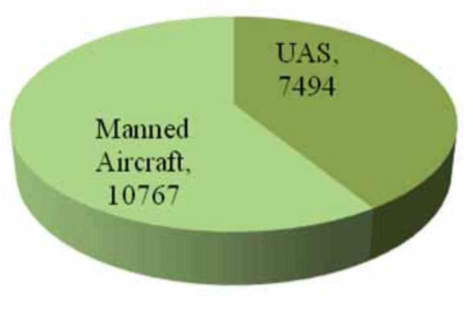

Figure 6. The ratio between unmanned and manned aircraft [27]

Unmanned aerial systems have become a significant factor in modern armies. All of the leading military powers of the world are intensively developing UAV and UAS support and combat models. Availability of the technology and efforts for development and manufacturing cost reduction have caused this trend to spread to other armies that develop modern, efficient and inexpensive systems for combat and support. For example, the Ministry of Defence of the Republic of Serbia has, for a series of years, been developing modern aerial unmanned robotised systems such as Pegaz (Pegasus) UAV (long-range tactical UAV, capable of sending data from a height of 3000 m and fly the maximum speed of 200 km/h), (Fig.7), and mini UAV named Vrabac (Sparrow) with functions of daytime and nighttime reconnaissance and surveillance at shorter distances, target finding and terrain mapping (Fig.8) [29, 47].

Figure 7. Pegaz 011, a Serbian medium range UAV, is being developed by Military Technical Institute in Belgrade [49]

Figure 8. Serbian mini UAV Vrabac at "Partner 2011" military fair in Belgrade [50]

All this shows that the strong trend in UAS design is the reduction of their dimensions with maintaining and expanding of functionality while reducing the cost. Development and application of cost effective reliable solution for single use or limited use UAS, with the goal to reduce and even completely eliminate maintenance costs, requires the application of simple, easily accessible and reliable subsystems. Having in mind these requirements, it is safe to say that a combination of the existing open source solutions for software and hardware and tried solutions of the existing UAV platforms. Moreover, there are numerous projects of open source non-military UAV and UAS projects in the world. The main limitation of their platform design is concerning the existing limitations of unmanned aircraft flight in accordance to the national legislation dealing with the altitude and range of flight. For example, in the EU, USA and Australia, UAVs can only fly up to an altitude of 120 meters, away from buildings and people, and within line of sight of their operators [30]. Since these requirements are significant for military use and relate to the platform of the aircraft, application of the open source solutions is most practical in the area of autopilot devices [31], information systems, networking and flight autonomy development. The application of open source solutions in this area is possible with a proper selection of application areas and subsequent upgrade and improvement especially in the fields of reliability and safety. Modern open source hardware systems have sufficient capacity in processor power and memory, small energy consumption, small dimensions and weight and high ability adapt to different needs. The requirement for the modern unmanned aerial vehicles to perform different combat and support tasks and move completely autonomously demands significant processor strength for the necessary data processing and reliable work [32]. For example, many UAS can be programmed to fly along a pre-set trajectory with defined coordinates of check points or to be capable to flight completely autonomusly[47]. All modern UAS are required to have a reliable target detection and identification.

The most practical experimental platforms for networking of small UAS for military purpose are the microcontroller board Arduino and microprocessor platform Raspberry Pi.

Microcontroller board Arduino

The most widely spread hardware microcontroller open source platform in the world is Arduino [33]. There is a great number of different versions with different characteristics and purpose. The advantage of its application is greater availability of information and resources created by the wide open source community. This knowledge enables prompt application of this platform on different systems which shortens the time necessary for their development. This is an important requirement, since software design and programming becomes increasingly hard due to the great complexity of modern combat systems and their software dependency. Basic version is Arduino Uno that has an 8-bit core microcontroller operating at 16MHz and has a processor sampling of 15 kilosamples per second. Arduino Uno is far from an operating system environment and any larger program will have to deal with concurrency, lack of memory (RAM) and structuring. Open Source software Cosa is a specific platform to try to fill this gap. Enhanced versions are Arduino Duo (Atmel SAM3X8E processor based on ARM's 32-bit Cortex-M3 CPU), Netduino and Pinguino, representing platforms of greater capacity than the basic version of the Arduino platform, since they dispose of significantly greater memory and processor capacity, so their processor sampling rate is 1.000 kilosamples per second. This characteristic enables them a significantly greater possibility for application in context aware positioning and autonomous mode of work.

Figure 9. Raspberry Pi and Arduino [34]

Although these models come at double the cost than the basic version (49 USD to 23 USD), its price difference does not damage potential competitiveness of UAS they are built in, since there are several hundred times lesser than these systems than commercial military autonomous systems. Besides this, their dimensions are not significantly larger (53 mm x 102mm to 53mm x 69mm), which provides them with an additional advantage.

Microprocessor platform Raspberry Pi

The second popular microprocessor platform Raspberry Pi [34] has in the brief period acquired a number of applications in all fields including UAS due to high performances, low price, modularity and practical universality. It has exceptionally low price (20-35 USD), and a significant computer capacity (in the range of older generation PC) that is contained on a small mother board, the size of a smaller graphics card or sound card of a classic PC computer. Depending on additional modules, this platform may be used as an autopilot, server, networking system and other purposes. Although there are several different models, most of them have a couple of USB ports, HDMI, audio component and audio out port, SD card slot, Ethernet jack. Current Model B version has 256 MB of RAM, and 700 MHz CPU clock speed. These computer capacities are enough to run mobile ad hoc networking or mobile mesh networking and UAV autopilot software [35]. Several procedures are developed to build up a mesh network from a several Raspberry Pi platforms or to form a computer system consisting of many individual processors in order to increase computing capabilities of the complete system.

Enhanced versions of Arduino have similar computer performances as Raspberry Pi which means they could hold a real operating system. However, they differ in their purpose, since Arduino processor is not intended to move a whole operating system, therefore it does not contain overheads of process scheduling, memory management and other activities that may impact the processor tact accuracy. On the other hand, its processor is more capable to offer a GUI that allows users to visualize processor management and to control it. Thus, Arduino is much better suited for low-level jobs (for example to run just one program at a time, usually without interruptions), and Raspberry Pi for high-level ones (multiuser/multitasking operating system). Choice of basic platform depends on the UAS purpose, mode of establishing the connection with a control center, technology and way of networking and the type of task performed completely autonomously by the combat system. However, one must keep in mind that these two systems are complementary and may support each other in complex tasks. Therefore, the relevance of these miniature platforms is not measured by processor strength and memory size, but their suitability to perform different processing tasks. For example, Raspberry Pi and Arduino very easily connect to a USB cable and use serial communications, which gives the possibility that every device performs tasks that are more suitable for it. There are also other, even smaller and less expensive devices, such as Texas Instruments MSP430 series of MCU, that use simplified low-level programming and that take up very little space on the mother board, so they may be used as specific small embedded devices. This modular convenience of creating design in accordance with the needs enables adaptation of devices to the needs for their purpose. However, regardless the current capacities, the operating systems suitable for application on such processor platforms are undemanding Linux open source operating systems.

Creating a MESH network between open source hardware platforms

Keeping in mind the fact that the majority of open source UAV belongs to the category of small and micro aircraft, a necessary condition for the multiplication of their effect is networking [25]. UAV networks may be achieved by the existence of two way communication with a command center on the ground, or when the aircrafts function completely autonomously when there is no outside network, global positioning system or connection to the command center. In both instances the most probable application of network technology relates to mobile MESH networks, i.e. mobile ad hoc networks (MANET). In principle, the term „mobile ad hoc network“ is used mostly to talk about the self-organizing capability of nodes, i.e when mobility is an important characteristic of a network in which nodes form a network on the fly. Term „MESH" is used to talk about the type of connection between nodes in the network where every node is able to communicate in a distributed fashion (point-to-point and point-to-multipoint) with all other nodes of the network (thereby forming mesh network). This means that mobile ad hoc network (MANET) is a subset of the MESH network. For example, MESH network can also be formed by wireless nodes that are static, which is more often the case. Name "Mobile Ad Hoc Network" mostly relates to a special group of standards and technologies under the auspices of IETF (The Internet Engineering Task Force) and at the same time to all technologies that are based on establishment of wireless connections by independent participation of mobile nodes in networks wit random topologies, by multi-hop data routing and based on principles of packet sending of data. Although such networks in practice may be based on a single standard (technology), it is not uncommon to combine them for the purpose of cancelling out the negative characteristics and combining the positive traits of different technologies. Likewise, such networks may function independently, and be a part of larger systems, including Internet. A minimal configuration and fast establishing with no need for external infrastructure make them suitable for application in different situations, such as sensor networks, in miltary and police communication, in search and rescue missions in areas without wireless and cable communication, in disaster mitigation operations, for communication in environments where the existing communication has been destroyed or unusable, in local motor vehicle networks (VANET) or as an expansion or addition to the existing infrastructure networks for the purpose of more efficient operation. Application of ad hoc networks in all possible areas of utilization is practically limitless, and is especially practical for application in unmanned aircraft swarming.

The case of networking without an outside system is more complicated since it is difficult to achieve the system function, i.e. a complete autonomous networking and orientation in space without application of an outside positioning system. Solutions relating to position calculation by geographic information system-GIS, image recognition and terrain videos [36, 37], by combination of laser and inertial measurement units (IMU) [38], locator and other types of targeting is complicated and requires additional information on the terrain where the positioning is performed, great processor power and reliable algorithm for processing of information. However, in both cases orientation and movement are enabled by functioning on autopilot and IMU system, that also require suitable processor strength necessary for a reliable and encrypted protocol for connecting into swarm networks.

There are many different hardware and software solutions for creating a mobile MESH network with the open source technology. These solutions may be modified by subsequent programming. As for the hardware, the most suitable is to use Raspberry Pi module, USB cable, SD card and a wireless adapter (with a total cost up to 60 USD). Concerning the software necessary for establishing networks between UAVs, there is an enormous number of finished open source solutions and the basic requirement for their proper composition is compatibility, reliability and safety of a system as a whole.

From the aspect of the existing solutions, a probable choice of technology for a practical implementation of a mobile MESH UAS network is:

- Hardware MB: Raspberry Pi, Arduino (32-bit ARM core microcontroller), Pinguino, Netduino, Arduino UNO, PandaBoard, BeagleBoard, Texas Instruments MSP430 Launchpad Kit.
- OS: Arch Linux, Debian, Ubuntu, different versions of tiny Linux distros.
- Routing protocol: BATMAN ADV [39], OSLR [40], SMesh [41], Babeld [42], Byzantinum, CoocaChili, Cjdns.
  BATMAN ADV protocol for ad hoc networking in some specific instances causes to much useless network traffic. In this case, a growing number of MESH servers or clients could cause a great increase in useless traffic. A suitable alternative is selection of OSLR protocol. **The project Byzantium protocol** enables simultaneous connections into a MESH network and connection with an individual node by using only one WiFi card. **CoocaChili** enables DNS Redirect in order to capture traffic and drive it to an internal website.
- Wireless technology: WiFi (open 802.11s or g), ZigBee (802.14.5).

The choice of the most suitable operating system, routing protocol and other suitable software is complex and cannot be made without any ambiguity, since these are open source solutions that are often upgraded and changed. Different routing protocols may have more or less efficient function in specific hardware and software environments, since it is possible that some options do not correspond with distro kernel, not being adequately compiled in, and certain Linux distros have variable stability and operating speed on selected hardware platforms, which is in case of open source solutions primarily a thing of experimenting, modifying and practical improvement. The cause for this is freedom in the creation and development of open source solutions and frequent absence of harmonized standards, or the use of different alternative solutions. Therefore, the application of the non-standard (additionally modified) software configurations is also probably necessary, since the official versions often do not provide a stable routing scheme.

Choice of networking technology depends on its capacities for ad hoc networking, range that influences the possible distance between the individual elements (the greater the distance between swarm elements, the harder they are to spot on the radar), power consumption for routing, operating frequency, complexity of hardware devices and application, security [43], the quality of services and other similar parameters. Three basic technologies that limit to some extent or completely the requests of such ad hoc routing are ZigBee, Wi-Fi and Bleutooth.

An especially popular network technology for UAVs is ZigBee. It is a low-power wireless mesh networking proprietary standard, simpler than other WPANs such as Bluetooth, with low price and low rate consumption, that is being used massively in wireless control and monitoring applications. It has the ability to go from sleeping to active mode in periods of 15 milliseconds or less, the latency can be very low and devices can be very responsive, particularly compared to Bluetooth wake-up delays, which are typically around three seconds. ZigBee operating frequency varies depending on region (868 MHz in Europe, 915 MHz in the USA and Australia and 2.4 GHz worldwide). ZigBee PRO is a stack profile of current *ZigBee 2007* stack release which offers several features, such as multi-casting, many-to-one routing and high security with Symmetric-Key Key Exchange (SKKE). Although the use of ZigBee technology is more suitable for sensor networking (RFID and similar), that are stationary in space, their low price, low power consumption and good routing protocol safety make this technology increasingly attractive for swarming UAVs for single combat use. Security and data integrity are important characteristics of the ZigBee technology.

The security model of the IEEE 802.15.4 MAC sub-layer specifies four security services:

- access control (the device maintains a list of trusted devices within the network),
- data encryption (uses symmetric key 128-bit advanced encryption standard),
- frame integrity (protects data from being modified by the parties without cryptographic keys),
- sequential freshness (rejects data frames that have been replayed).

Figure 10. XBee module example

Today, there are many ZigBee chip vendors which typically sell integrated radios and microcontrollers with between 60 KB and 256 KB flash memory and data transmission rates which vary from 20 to 250 kilobits/second. However, the greatest problem with this technology for application in UASs is the relatively small range and low data rates. Range of ZigBee devices may be increased by using commercial (or open source) signal extenders such as MaxStream Xbee 900 MHz 1-Watt Xtend RF modem (XTender) which is capable to extend the range of 802.15.4 devices up to 65 km.

Table 1. Overview of the most suitable standards for wireless mobile networking

Technology	ZigBee	Wi-Fi	Bluetooth
Standard	IEEE 802.15.4	IEEE 802.11	IEEE 802.15.1
Range	10-100 meters	50-100 meters	10 – 100 meters
Networking Topology	Ad-hoc, peer to peer, star, or mesh	Point to hub	Ad-hoc, very small networks
Operating Frequency	868 MHz (Europe) 900-928 MHz (NA), 2.4 GHz (worldwide)	2.4 and 5 GHz	2.4 GHz
Device and application complexity	Low	High	High
Power Consumption	Very low	High	Medium
Security	128 AES plus application layer security		64 and 128 bit encryption
Typical Applications	Industrial control and monitoring, sensor networks, building automation, home control and automation, toys, games	Wireless LAN connectivity, broadband Internet access	Wireless connectivity between devices such as phones, PDA, laptops, headsets

Conclusion

Open source hardware and software solutions have enormous potential for application with unmanned aerial systems, both combat and support systems. This potential is primarily represented in reduction of development cost and price of the aircraft itself, as well as availability of necessary technologies. Many open source software solutions have performances that may be compared with characteristics of business and military platforms. This is increasingly the case with hardware open source solutions, especially in the area of microcontroller and microprocessor boards, such as Arduino and Raspberry Pi. However, military systems have very strict performance requirements, combat power, reliability, safety and other technical and tactical characteristics. With the right choice of projects and system solutions these potential vulnerabilities of open source technologies may be overcome. This possibility is especially evident in unmanned aerial systems. Possible application of these aircrafts in the concept of merging characteristics of an aircraft and a projectile in one technical system that performs an action on a target by swooping on it. Such concepts have many advantages, such as an increase in the radius of movement, reduced need for driving energy and portability of use. However, in the absence of the possibility to apply the global positioning system and establishing a connection with command centre on the ground, it is necessary to apply specific methods of networking for several aircrafts, which multiplies their effect and achieves redundancy effect. For such an approach the most suitable is the concept of swarming of aircrafts that have fully autonomous effect. Most appropriate type of wireless networks for this purpose is mobile ad hoc network (MANET). In the event of non existence of reliable technologies for the establishment of a fully autonomous operation mode for an aircraft swarm by recognition of the terrain or environment of the flight, a transitional solution is the application of mobile MESH networks. Both concepts require computer capacities or networking, space orientation, discovery, monitoring and destruction of a target. Application of open source solutions is possible in all technical subsystems of UAS, from hardware and computer capacities to software, operating systems and networking protocols. Most significant modern open source platforms that enable these concepts independently or in different combinations are Arduino and Raspberry Pi.

Application of open source solutions in military systems is increasingly significant and there is a trend of growth parallel to increase of the significance of information-communication technologies used in their operation. The advantages these technologies provide in the area of costs and availability of technologies create new possibilities especially important to small and developing countries and their efforts to build efficient and reliable military technical systems, and also reduce dependency on international producers of arms and military equipment, increase of competitiveness on the world market, fast development and a strong feedback with a wide community of expert enthusiasts from outside military systems, which effectively promotes transfer of knowledge and technology. Significance of open source solutions in modern systems is not negligible anymore, and in some cases, such as development of new systems, it represents the most important factor for improvement in development.

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Received: 27.02.2013.

Open source rešenja u razvoju vojnih bespilotnih vazduhoplovnih sistema

U ovom radu je prikazan koncept *open source* softverskih, hardverskih i mrežnih rešenja koja su pogodna za primenu u razvoju bespilotnih vazduhoplovnih sistema. Primenom *open source* (tehnologija otvorenog koda) platformi se značajno umanjuju troškovi razvoja i nabavke bez značajnog umanjenja faktora pouzdanosti i sigurnosti vojnih bespilotnih vazduhoplovnih sistema za borbu i podršku. Najpogodnija savremena primena se nalazi u području hardverskih mikrokontrolerskih i mikroprocesorskih sistema kao što su *Arduino* i *Raspberry Pi*, specifičnih mikro-linuks operativnih sistema i mrežnih protokola za mobilno ad hok umrežavanje.

Ključne reči: **bespilotna letelica, automatski pilot, mobilna mreža, open source.**

Решения по *open source* в развитии военных беспилотных воздушных систем

В настоящей работе изложен конспект *open source* решений по софтвере, хардвере и сети, являющимися пригодными для применения в развитии беспилотных авиационных систем. Применением *open source* (технология открытого кода) платформ значительно уменьшаются затраты по развитию и приобретению, не оказывающие значительное влияние на уменьшение факторов надёжности и безопасности военных беспилотных авиационных систем боя и поддержки. Самое выгодное современное применение находится в области хардверских микроконтролёрных и микропроцессорских систем, в том числе *Arduino* и *Raspberry Pi*, специфических миро-линукс оперативных систем и сетевых протоколов для мобильного связывания в одну сеть по необходимости.

Ключевые слова: **беспилотные летательные аппараты, автопилот, мобильная сеть, open source.**

Les solutions *open source* dans le développement des systèmes aériens militaires sans pilote

Ce papier présente le concept des solutions logiciel, matériel et réseau appelé *open source* appropriées pour l'application dans le développement des systèmes aériens sans pilote. En utilisant les plates-formes *open source* (technologie de la source ouverte) les frais du développement sont diminués considérablement et les achats se font sans diminution significative du facteur de fiabilité et de sûreté chez les systèmes militaires aériens sans pilote de combat et de soutien . L'emploie le plus adéquat se situe dans le domaine des systèmes matériels micro contrôleurs et des systèmes micro processeurs tels que Arduino et Raspberry , des systèmes opératifs micro linuks spécifiques et des protocoles des réseaux pour la mise en réseau ad hoc.

Mots clés: **aéronef sans pilote, pilote automatique, réseau mobile, source ouverte.**