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ONE SATELLITE PER COUNTRY - HOW EMERGING SPACE-FARING NATIONS CAN BENEFIT FROM TECHNOLOGY TRANSFER THROUGH FREE OPEN-SOURCE PROJECTS

Claas Ziemke
University of Stuttgart, Germany, ziemke@irs.uni-stuttgart.de

Dr. Toshinori Kuwahara*

Today many developing countries are implementing or planning to implement a national space program. One of the main goals of these emerging space-faring nations often is the establishment of an own national space industry in order to avoid brain-drain and to foster the national economy A problem faced by many of these nations is the inherent lack of heritage in the field of space technology. Because of this lack, these nations are dependent of technology transfer from other space-faring nations. A multitude of different mechanisms for technology transfer exist. Free open-source technology is one of the cheapest, yet most effective solution for technology transfer. This is because the source-codes and designs are free of charge and the underlying technology is open for inspection. This fact also minimizes transaction costs of communication, licensing and negotiations. Thus the available funds can be spent effectively for technology advance. In this paper the mechanism of technology transfer through free open-source projects is described and the mechanism is applied to space projects. Many universities and amateur groups in developed as well as developing countries maintain small-satellite projects. The vast majority of these projects are closed-source and thus are inherently redundant in technology aspects. If only a small percentage of these projects decide to open their sources and designs it seems to be possible to develop a catalogue of free open-source satellite hardware components and interfaces. The establishment of free interface definitions and communication protocols is especially important to foster interoperability and interchangeability. Also many small-satellites have very similar mission designs, leading to the belief that it is possible to define a set of baseline designs for free and open small-satellite platforms. The design principles for such a open small-satellite platform are established and described in this paper. The main design principles are the usage of commercial of the shelf parts and the focus on the "keep it simple, stupid!" principle. The conclusion is, that a "One Satellite per Country" project similar to the "One Laptop per Child" project is feasible and may lead to a huge increase in the speed of technology transfer not only in the area of space technology. The core of this project is formed by a set of existing open-source software projects which will be integrated to the OpenSatDK. The aim of this is to provide the possibility to do system engineering with dedicated open-source tools.

I. INTRODUCTION

In early 2005, drawing from his previous success with distributing laptops to children in developing countries, Nicholas Negroponte conceived the initial idea of the $100 laptop. The project quickly gained a lot of momentum as the idea was quickly backed by big companies such as AMD, Google and Red Hat and soon was known as the "One Laptop Per Child" or OLPC project. In 2011 about two million units have been deployed to over twenty countries and already in 2009 Nicholas Negroponte stated that the OLPC XO-2 will be open-source hardware. Although the project is considered to be a failure by many analysts,nevertheless it shows the great potential of open-source hardware projects if they are backed by big companies [1].

Fig. I: OLPCs in classroom in Africa [25]

*Tohoku University, Japan, kuwahra@astro.mech.tohoku.ac.jp

A direct side-effect of this digital divide is the huge brain drain that developing countries have to deal with and which is one of the biggest problems in the development of these countries. One of many countermeasures taken by developing countries is to set up a national space program in order to create jobs for the highly educated and to bridge the "space divide". Nevertheless a problem faced by many of these space programs is the lack of adequate budgets and the general lack of on-site know-how. This leads either to inferior solutions or to inefficient spending of the already scarce budgets by buying know-how from already established space faring countries. On the other side of the "space divide" a huge number of university small-satellites and community based "hobbyist" satellites (for example the SSETI, AMSat and the "Hacker Space Program" [2,3,4]) are currently under development in the established space faring nations. These small-satellite projects despite the fact of being located in space-faring nations face similar problems as the space programs in developing countries.

This fact constitutes a common interest between universities and hobbyist communities and institutions in developing countries. This common interest is the availability of good and bad practice examples, open available know-how and cheap and proven hardware designs and implementations. Since most of the university projects do not have a opportunity of commercialization and are funded by governmental money, the success of these projects would not be endangered if the design documents and implementation details would be open-sourced. Quite the contrary the projects would benefit from lessons learned by other projects and by the opportunity to share knowledge and to contribute and collaborate. The space programs of developing countries also would greatly benefit by the knowledge transfer.

Another great advantage of turning proprietary technology open-source is the opportunity to quickly turn specific implementations into de facto standards. This has been shown by the commercial company "Gaisler research" which turned the LEON IP-Core library open-source and established its architecture as de facto standard in the European space community [5].

Already today a multitude of space relevant open-source software projects are in existence and can be leveraged to create a open-source space-craft design or open-source hardware library in order to harvest the potential of collaboration and to minimize spendings on developing key technologies. Peer-reviewing of designs and implementation through the community is easy in open-source environments in contrary to proprietary solutions which can not easily be assessed by third parties without revealing secrets.

An open-source library of space-craft components could lead to a project which could be called "One Satellite Per Country" or OSPC in the style of the OLPC project. Key features and goals of such a project would be the acceleration of university satellite projects, standardization of key components and interfaces, the bridging of the "space divide" by acceleration of technology transfer, the creation of a international community of space-craft developing engineers, and the creation of business opportunities for hardware manufacturers, leading to a decrease of overall satellite building costs.

First step of such a project could be the consolidation and integration of available open-source software tools into a open-source "Satellite Development Kit" OpenSatDK in order to simulate and test proposed hardware designs and implementations. This would allow to create a virtual satellite basic implementation which allows starting a satellite project without the need of purchasing expensive special hardware and in contrary allows to spend available funding on human resources. In a second step the validated and verified hardware designs then could be manufactured and tested in real small-satellite projects in order to be proven to be space qualified. Key requirements on these designs should be the availability and low cost of parts and the possibility to manufacture the designs without expensive special equipment rather then the performance.

To wrap up the argumentation the following key benefits and chances of an open-source satellite project can be stated:

- Spendings can bee focused on human resources and research rather then on hardware purchase.
- Double spendings on researching technologies independently from others can be avoided.
- Technology transfer can be accelerated. Peer-review is eased.
- De facto standards can be established.
- Businesses opportunities can be created for hardware manufacturers and consultants.
- Technology development can be accelerated.
- Community building is implied.
- Hardware cost and thus overall mission cost can be reduced.
- Overall space awareness can be increased.

II. ANALYSIS OF CURRENT SITUATION

The digital divide

The term digital divide was coined in the mid-1990s, appearing in several news articles and political speeches. The original meaning of the term was the differences in the accessibility to personal computers in the different parts of the world. Nowadays the term digital divide is used for the differences in the access to information technologies as a whole, including personal computers, mobile phones and internet. Or basically the differences in access to digital information.

The digital divide leads to a significant disadvantage of the developing nations in the field of economical and industrial competition with the developed nations because most industries nowadays are reliant on access to the internet [6].

Brain-drain

The disadvantage in competition together with the low standard of living in the developing nations leads to the so called brain drain. This term means that the few well educated people in the country tend to leave the country because of their great mobility and the lack of adequate jobs in the developing nations.

The brain-drain is a considerable problem for the industry of the developing nations, because even if adequate jobs for highly educated people are created, most of the time the possible employees already left the country or might have better job opportunities in the developed world. This fact leads to the importance of bridging the digital divide and to deal with the brain drain for the developing nations. While the digital divide can not be bridged easily the brain-drain can be coped with by offering well paid jobs for highly educated people that at the same time provide a challenging working environment with a perspective for further development of the country [7].

Projects to bridge the digital divide

To cope with the digital divide numerous projects have been proposed a number of them include open-source technology. One of the most prominent examples of such projects is the aforementioned OLPC project but also numerous e-governance and e-learning projects as well as projects to establish communication networks in rural areas are in existence [1].

Another example of open-source software to bridge the digital divide is the Republic of Macedonia. It is using Edubuntu in all primary and secondary schools. The program, called Computer for every child, was started in 2008 [8].

III. TECHNOLOGY TRANSFER THROUGH OPEN-SOURCE PROJECTS

The adoption of FOS concepts in developing countries promotes local research and development, rather than external suppliers or importing technological products. Also, FOS can provide the leverage for locally developed skills, increase local talents participation, minimize investment risks, and increase cost saving. The cost advantages concern three areas:

- low adoption costs
- low technology acquisition costs
- low technology development costs

Frequently, intellectual property rights inhibit developing countries from receiving technologies to develop similar technologies or new products, based on existing ones. However, FOS technologies have no such transfer or development problems. Moreover, developing countries will be in direct contact with global knowledge holders without any legal or political restrictions.

The brain drain and free movement of skilled people problems in developing countries can be minimized, since FOS participants cooperate remotely. The knowledge is distributed in the host country and participants will have the freedom of movement. The FOS also allows technology users to customize it according to their needs. Now, users can play active roles in technology transfer and open new sources of innovation.

The wide use of FOS increases the utility of the technology with the increase in the network size. This concept is known as the network effect where users provide feedback and standardize the use of the technology which in turn is evident for the usefulness of the technology. From the industry and business point of view, FOS is a boost in the establishment of start-up firms, offering new business models for existing products.

In developing countries, not only is the technology development weak, but also the technology development and adoption planning. Within the FOS community, plans can be derived by the developers themselves without political or external intervention or support. Governments have only to define policies and plans to support the introduction of FOS concepts to the academic and research institutes and the industry to sponsor the use and development of FOS products and show their advantages [9].

IV. EMERGING SPACE FARING NATIONS

Capabilities

The capabilities of a nation with a space policy can be divided in five categories [10]:

- Category 0: No space capability.
- Category 1: Limited capability in the field of satellite operations and manufacturing.
- Category 2: Advanced capability in the field of satellite operations and manufacturing.
- Category 3: Capability of manufacturing a satellite and operating it.
- Category 4: Capability of manufacturing, operating and launching satellites.

Most of the developing nations are in category zero because they do not have any capabilities in building or operating satellites. In contrary most of the developed nations are in category four. Either they have direct access to space launch via domestic developed launchers or they are in a cooperation like for example the ESA member states. This fact constitutes the "space divide". The categories one to three are called "emerging space powers" in this context. These nations have already have limited capabilities in satellite manufacturing or operations on a level which enables a limited amount of domestic value creation. Prominent examples of these categories are:

- Category 1: Nigeria with NigeriaSat-1 and -2 manufactured in UK [11].
- Category 2: South Africa with SUNSAT and SumbandilaSat manufactured in South Africa [12].
- Category 3: Brazil with the SCD and CBERS series of satellites manufactured in Brazil [13].

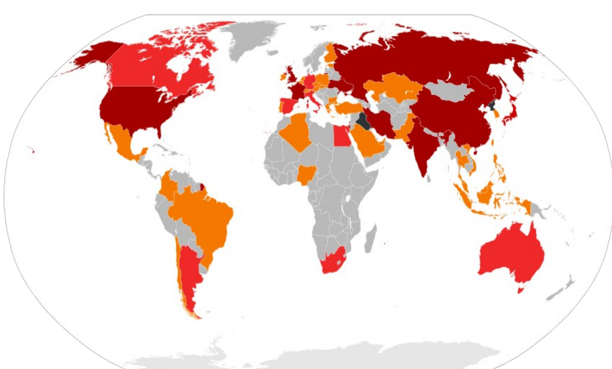

Fig. II: Satellite operating nations [26]

Satellite operation capabilities

Being able to operate a satellite is considered to be the first step in building up space capabilities. The operation of a satellite requires knowledge and resources that can enable the later step towards a manufacturing industry. The access to a domestic ground station increases overall space awareness in the country and can serve as a incubator for further projects.

Satellite manufacturing capabilities

The actual manufacturing of satellites and satellite components is the key of building a space infrastructure in a country. In order to manufacture a satellite a huge amount of manpower and knowledge is needed. This makes satellite manufacturing ideal to cope with brain-drain. Also the manufacturing of a satellite is the most value adding part of the process so that money spent domestically in manufacturing is very efficiently spent.

Satellite launching capabilities

The capability to independently launch a satellite into earth's orbit is the final step in becoming a real "space faring nation". Currently only ten different space agencies have the capability of launching a satellite. Nevertheless the launching capability is not very important for a developing space-faring nation because there already is a quite diverse commercial launch service market and the development of an own launcher capability is extremely costly.

Bridging the "space divide"

Bridging the "space divide" is desirable for countries dealing with a brain-drain. A well functioning domestic space industry not only can attract highly educated workers but also constitute a nucleus for other high-tech industries. Furthermore the space industry can benefit the country's economy by means of geospatial data and other space related services such as communication, navigation, disaster management and so forth.

In order to get from Category 0 to Category 3, bridging the "space divide", a number of capabilities have to be built up in the country. Typically for this purpose a national space agency is founded. The space agency is responsible for selecting a space policy and to coordinate the efforts in the different institutions. Nevertheless space agencies are typically not founded before a nation reaches Category 1, so in order to get there different means have to be taken into account.

As mentioned above, one of these means of bridging the "space divide" can be the usage of open-source software and hardware.

V. THE OSPC PROJECT

In the following sections a brief outline of the proposed "One satellite per country" project is given. The name of the project as already mentioned is derived from the "One laptop per child" project. The aim of the project is to create a community of space engineers which are building a tool-kit for building small satellites and to distribute this knowledge to all interested persons. All software used for this purpose should be open-source in order to mitigate licence fees and royalties. All hardware used in order to build the satellite shall be commercial of the shelf wherever possible.

Step one: Creating a community

The first and maybe most important step in this project is the creation of a community of engineers willing to contribute their ideas and efforts to the project. Since already a lot of space relevant software is open-source it should nevertheless possible to find engineers who are willing to contribute. Tasks in this stage of the project include public relations, technology assessment, community building, creation of on-line documentation and space relevant e-learning materials and so on. Already in this stage of the project learning as well as contributing opportunities exist for partners in developing nations.

Step two: Building OpenSatDK

The second stage of the project is the integration of relevant open-source engineering programs into an "OpenSatDK". The OpenSatDK is a loosely coupled set of programs required to build a satellite in all its aspects. These are:

- Mission planning,
- computer aided design of structures,
- computer aided design of electronic circuits,
- programs for thermal and structural analysis,
- system simulation including on-board computers
- and a development environment for on-board software

All these programs shall be backed by a database which serves as a central point of storing information about the system. Even by "only" contributing to open-source computer programs a great deal of capacity building can be achieved because the implementation of the described architecture requires deep insight in satellite engineering.

Step three: Building the OpenSat library

The third step is the implementation of a library of satellite components. The first and maybe most important step in this part of the project is the definition of a set of standard interfaces both electrical and mechanical as well as a communication protocol if needed. In this stage of the project it also is possible to convince universities or other third parties to open-source specific satellite parts if they are not intended for commercial use or if they are deemed to be outdated. The alternative is to start with every part from scratch. Both alternatives have distinct advantages and disadvantages. The output of this stage of the project shall be at least mechanical drawings of the parts, functional models for the system simulation environment and structural and thermal analysis of the developed parts.

In this stage of the project the actual collaboration between developed and developing space programs can start. Developing nations can truly benefit from the previous work of others and start to alter the designs in a way that fits their needs the most while being constantly peer-reviewed by the projects partners. Also the different developing countries can specialize in specific parts of the library so that a collaboration between developing nations can easily be achieved and double spendings can be avoided.

Step four: Building the reference designs

The last step is the implementation of the OpenSat library parts in real satellite missions. At this point there will be countless business opportunities for both the developed and developing space nations. Building of space grade parts and assemblies require specific quality assurance methods and practices.

If the developed parts are performing as designed and proof to be reliable in space applications the manufacturing of a small satellite can be done even in countries where there is no heritage in building satellites. All which is needed is a certain amount of well trained engineers and the help of the OSPC project's community.

Since only commercial of the shelf parts shall be used in the project the satellite's hardware will be very cheap compared to commercial satellites so that the available budget can be spent on domestic research and manpower. This again helps to bridge the "space divide" and to further advance the project itself. Variants of the reference designs can be developed and tailored to the needs of specific missions. Even a whole satellite bus can be developed in this manner.

VI. POSSIBLE CANDIDATES FOR OSPC PROJECT

In the following section a short overview of the possible candidates for an integration in the OSPC project is given. The mentioned projects are all either open-source software or open hardware platforms. This list is not exhaustive and only is meant to serve as an example of how many space relevant open-source projects already are existent.

Software

Space Trajectory Analysis

Space Trajectory Analysis (STA) is able to visualize a wide range of space trajectories. These include among others orbits around planets and moons, interplanetary trajectories, rendezvous trajectories. STA was started in 2005 to provide a framework in astrodynamics research at University level. As research and education software applicable to Academia, a number of Universities support this development by joining ESA in leading the development. STA provides calculations in the fields of spacecraft tracking, attitude analysis, coverage and visibility analysis, orbit determination, position and velocity of solar system bodies, etc. STA implements the concept of "space scenario" composed of Solar system bodies, spacecraft, ground stations, pads, and so on. STA is able to compute communication links between objects of a scenario (coverage, line of sight). STA development is open-source and it is programmed using the C++ language. Software integration and overall validation is performed by ESA [14].

gEDA

gEDA is an electronic design automation application suite released under the GPL. gEDA is mostly oriented towards printed circuit board design. The gEDA applications are often referred to collectively as "the gEDA Suite". The gEDA Suite is composed from the following parts [15]:

- PCB: A PCB layout program
- Gerbv: A gerber file viewer
- ngspice: A port of Berkeley SPICE
- GnuCap: A modern electronic circuit simulator
- gspiceui: A GUI front end for ngspice/GnuCap
- gwave: An analogue waveform analyser
- gaw: A rewrite of gwave. Works with gspiceui.
- Icarus Verilog: A Verilog simulator
- GTKWave: A digital waveform analyser
- wcalc: Transmission line and electromagnetic structure analysis

QEMU

QEMU is a machine emulator. It can run an unmodified target operating system and all its applications in a virtual machine. QEMU runs on several host operating systems. The host and target CPUs can be different. The primary usage is to run one operating system on top of another and to provide simulation capabilities for development boards which are not available or to expensive for software developers. For example QEMU is used as back-end for Google's Android software development kit. QEMU also can be used for debugging because the virtual machine can be easily stopped, its state can be inspected, saved and restored [16].

QEMU can either be used for a pure processor emulation or as a whole computer-system simulation. In this case the peripherals are modelled in C, but those models only represent the hardware in a functional manner and the behaviour of the hardware can be different from the real hardware. To avoid this, and because SystemC models are reusable in other contexts, in the proposed system simulator the processor peripherals are modelled in SystemC. This approach also makes the processor peripherals partly independent from the used processor architecture [17].

OpenSimKit

OpenSimKit provides the functionality to simulate complex systems by modelling their system topology. Additionally the OpenSimKit kernel has the ability to solve differential equation systems on system level, both solving initial value problems as well as boundary value problems. OpenSimKit is a modular service-oriented framework and is programmed in Java. It is divided into the simulation kernel which is responsible for solving the differential equation system and a model library. Inside OpenSimKit every part of the satellite and the environment is represented by such a dedicated model object [18].

Currently OpenSimKit provides a complete rocket upper stage simulation including propellant and oxider tanks, high-pressure blow-out tanks, pipes, pressure regulators, valves a rocket engine and so on. Furthermore a gravitational model and a structural model is available to provide a coarse orbit propagation. A simple graphical user interface can be used to command the simulator. The simulator is configured via XML-files. This approach is identical to commercial system simulators and has the advantage that the system topology of the simulation can be changed independently from the model implementations [19].

Hardware

LEON IP Library

LEON is a 32-bit CPU microprocessor core, based on the SPARC-V8 RISC architecture and instruction set. It was originally designed by the European Space Research and Technology Centre, part of the ESA, and after that by Gaisler Research. LEON has a dual license model: A LGPL/GPL FLOSS, or a proprietary license that can be purchased for integration in a proprietary product. The core is configurable through VHDL generics, and is used in system-on-a-chip (SOC) designs.

The LEON CPU family has become a de facto standard in the European space industry and is used in a number of successful space missions. The LEON CPU family is a great example how the availability of the design as VHDL files and the availability of open-source tool-chains for the development of corresponding software can lead to a fast adoption of a technology in the market [20].

OpenRISC

OpenRISC is the original flagship project of the OpenCores community. This project aims to develop a series of general purpose open source RISC CPU architectures. A team from OpenCores provided the first implementation, the OpenRISC 1200, written in the Verilog hardware description language. The hardware design was released under the GNU Lesser General Public License, while the models and firmware were released under the GNU General Public License. A reference SoC implementation based on the OpenRISC 1200 was developed, known as ORPSoC (the OpenRISC Reference Platform System-on-Chip). A number of groups demonstrated ORPSoC and other OR1200 based designs running on FPGA [21].

BeagleBoard

The BeagleBoard is an open-hardware, low-cost, fan-less single board computer equipped with a powerful microprocessor giving a laptop-like performance. The BeagleBoard comes with a full set of open-source tools. Development costs decrease as there are open-source compilers and programming tools available. The main features of BeagleBoard are listed below:

- OMAP3530 Microprocessor – 1200 DMIPS, based on ARM Cortex-A8 running at 600Mhz
- TMS320C64x+ DSP for signal processing at up to 430MHz
- Memories: 256MB of NAND Flash, 256MB of SDRAM
- SD/MMC Card slot, can be used as OS file system, file storage and more
- Multiplexable expansion header: I2C, SPI, UART, GPIO, SD/MMC

All those features have to managed by an operating system in order to use them in an efficient way. The best option for BeagleBoard is Linux, mainly because there is an active project supporting BeagleBoard which includes working drivers for the features listed above, a tool-chain and many common packages ready to build and install into BeagleBoard [22].

Universal Software Radio Peripheral

The Universal Software Radio Peripheral (USRP) products are a family of computer-hosted hardware offered by Ettus Research LLC for making software radios. The USRP product is intended to be a comparatively inexpensive hardware device for software radio. The USRP hardware connects to a host computer through a high-speed USB or Gigabit Ethernet link. The connection enables host-based software to control the USRP hardware and prepare signals for transmission or reception. The USRP family was designed for flexibility, allowing developers to make their own daughter-boards for specific needs with regard to connectors, different frequency bands, etc. The board schematics for the USRP family hardware are freely available for download. Open source drivers and free software to integrate with GNU Radio are also available [23].

Elphel 353/363 series camera

Elphel is an open hardware and open source camera designed by Elphel Inc. primarily for scientific applications, though due to its open hardware and open -source camera software, it can easily be customised for many different applications. Elphel Inc. was founded in 2001 by the Russian physicist Andrey Filippov. The Elphel cameras are widely used in industrial and scientific environments.

Elphel cameras are being used to capture images for Google Street View and the Google Books project and are used in a Global Hawk UAV operated by NASA. The Moss Landing Marine Laboratories use Elphel cameras in their project called Submersible Capable of Under Ice Navigation and Imaging, a project for robotic surveying and exploration in Antarctica [24].

VI. DISCUSSION

The application of open-source and open-hardware technology in the field of satellite development will enable a fast technology transfer between developed and developing space-faring nations. This will lead to a win-win situation because the developing nations can gain knowledge and build up capacities while the industry in developed nations can offer consultancy and hardware manufacturing.

While there are already a lot of open-source software and hardware projects available that might be used in such a project, most of these projects have to be adopted to the specific needs of the space sector. Where this is not deemed feasible alternative implementations have to be found and validated in the course of this project. The adoption of pre-existing technologies to the needs of the space industry is challenging but also a promising way to develop more cost efficient commercial of the shelf solutions.

Most important for the success of such an undertaking nevertheless will be sufficient funding and contribution by mayor industrial companies and governmental and non governmental organisations. A motivation to contribute to the project for industrial companies could be the possibility of establishing reference designs incorporating specific hardware parts such as high-reliability FPGAs, public relations, the possibility of creating new markets and offering consultancy services. Governmental organizations such as space agencies can benefit from contributing to the project by establishing standards and by new collaborations with developing space-faring nations.

Because the OSPC project shall focus on commercial off the shelf products, the project also can be a viable testing environment for these commercial off the shelf components. These verified products later can be spun-in into the developed nations space programs. This division of labour will be beneficial for both the developing and developed space-faring nations.

To conclude the benefits and chances of an open-source satellite project are:

- Spendings can bee focused on human resources
- Double spendings can be avoided
- Technology transfer can be accelerated
- Technology development can be accelerated
- De facto standards can be established.
- Businesses opportunities can be created
- Hardware cost can be reduced
- Overall space awareness can be increased

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