A Product Line Approach to Pico/Nanosatellite On-Board Software

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Abstract: *The main purpose of this paper is to demonstrate the feasibility of Software Product Line (SPL) as a development concept to the On-Board Computer Software in Picosatellites. The scenario considers the demand for a serialized production motivated by industrial and academic needs. The SPL concept supports and organizes the implementation of a wide of projects with common set of software assets classified by features that fulfills each customer mission. It is expected the solution will be applied to two separate computer subsystems which basically differs on the target processor, namely a Tubesat platform using BX-24 and a Cubesat with an arduino solution. The approach taken is general and maybe suitable to other domains where improvements on productivity and reliability are necessary.*

Keywords: *Picosatellites, Software Product Line, Systems Engineering, Software Engineering*

1 Introduction

One of the main problems encountered in the design of embedded systems is how to handle the reuse of software, because it plays an important leading role in the industrial competition considering reduction on engineering efforts and guarantee the quality, productivity and time-to-market at the same time.

Considering the lack of engineering Human Resources for the space market, this paper seeks to demonstrate the feasibility of applying the concept of SPL (Software Product Line) to meet emerging demand pico/nanosatellites breaking the paradigm of "each product is completely different from the others" and considering being faster than competitors in time-to-market of new products with competitiveness in all instances as cost, added value, shape and compatibility with other systems with the reuse of engineering effort from previous developments of the same family of products.

SPL is a set of applications with similar functionality and specialized to a particular area sharing a common base in order to address the variability in end platforms, that is, a EPL can be assumed as a group of products that are closely associated in the functionality, that are sold to the same group of customers, that are promoted through the same kind of dissemination (Garcia *et al*., 2002).

For a case study, it is proposed the application of the SPL targeting both BX-24 and Arduino, for tubesats and cubesats respectively. The BX-24 and Arduino are different processors largely used for academic ends as robotics, automation and prototyping projects.

2 The Pico/Nanosatellites

The picosatellites and nanosatellites are artificial satellites classes from a very small category, as shown in Figure2, which is determined by size, weight and shape. The Tubesats are classified as Picosatellites and Cubesats as Nanosatellites in accordance to Figure 2 which shows the classification in view of wet mass.

Figure 1 - Tubesat and Cubesat

Group name	Wet Mass	
Large satellite	>1000kg	
Medium sized satellite	500-1000kg	
Mini satellite	**100-500kg**	
Micro satellite	**10-100kg**	
Nano satellite	**1-10kg**	**Small Satellites**
Pico satellite	**0.1-1kg**	
Femto satellite	**<100g**	

Figure 2 - Satellites Classification (SSTL, 2012)

Considering the low cost of these satellites in contrast with conventional large sized, industry and universities are turning their attention to this new opportunity to both expand the market space and the scientific researches.
Some expected uses of these pico/nanosatellites are:

- Earth-from-space video imaging;
- Earth magnetic field measurement;
- Satellite orientation detection (horizon sensor, gyros, accelerometers, etc.);
- Orbital environment measurements (temperature, pressure, radiation, etc.);
- On-orbit hardware and software component testing (microprocessors, etc.);
- Tracking migratory animals from orbit;
- Testing satellite stabilization methods;
- Biological experiments;
- On-orbit advertising;
- Space art;
- Space burials.

3 Processors BX-24 and Arduino

Both BX-24 and Arduino are processors kits which can be easily programmed from a simpler and friendlier IDE (Interface of Development Environment) if compared with traditional ones.
The kits are mostly composed by:

- Microcontroller;
- PCB (Printed Circuit Board);
- communication cable and power supply;
- Sample Codes;
- Forums and Communities sharing the knowledge and helping when needed;

Table 1 - Comparative between BX-24 and Arduino

	BX24	Arduino
Speed	83,000 Basic instructions per second	22,000,000 instructions per second
EEPROM	32K bytes (User program and data storage)	Flash 32K bytes + EEPROM 1K byte
RAM	400 bytes	2 KB
Available I/O pins	21 (16 standard + 2 serial only + 3 accessed outside standard dip pin area)	22 (14 digital + 6 analog + 2 serial)
Analog Inputs (ADCs)	8 (8 of the 16 standard I/O pins can individually function as 10bit ADCs or standard digital I/Os or a mixture of both)	6 analog
Serial I/O speed	1200 - 460.8K Baud	1200 - 460.8K Baud
Programming interface	High speed Serial	USB
Physical Package	24 pin DIP module	24 pin DIP module

The Table 1 shows the basic differences between BX-24 and Arduino which can help to choose the best model for each application. These kits are normally used to sense the atmosphere by getting input from a diversity of instruments and to touch its surroundings by managing battery use, turning on antenna amplifier, and other tasks.

These processors environment has been designed to be friendly for beginners without programming initial knowledge. The idea is users can construct prototypes that can answer to control external devices as servo-motors, multiplexers and read values from sensors, data-receivers and others. Some examples are musical instruments, robots, light sculptures, games, interactive furniture (Margolis, 2011), even interactive clothing and now Satellites.

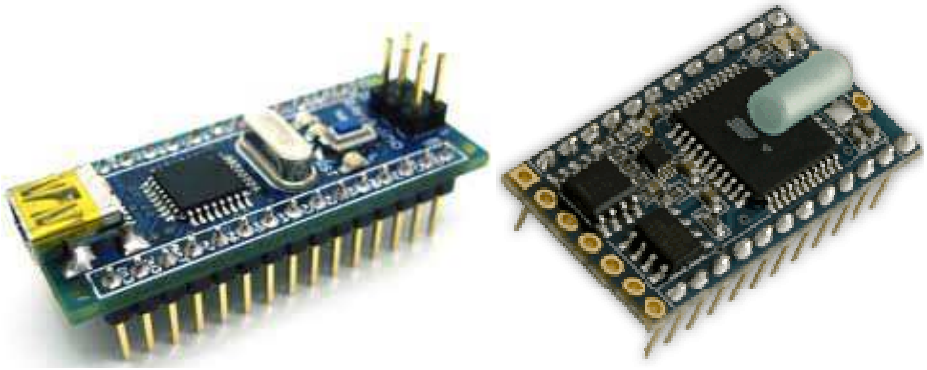


Figure 3 - Arduino and BX-24 Processors

The Figure 3 shows the Arduino and BX-24 processor board which are, complete control system on a chip, combined with a software development environment on a PC-compatible computer. A BX-24 system combines a BasicX chip with additional devices to make it a standalone computer. In the same way, Arduino is composed by a Arduino IDE, the chip and additional components as communication cable, power supply and others.

4 The demand for a Serialized Production for pico/nanosatellites

Producing satellites in series is not a basic issue because of the particularity of each mission and the great launching costs involved. In other hand, the idea of using a standard framework and change only the payload are motivating the space researching institutes as INPE, ITA, NASA and others because of the possibility to reduce the global costs, make possible a faster Human Resources training and the possibility of implement a flying formation of satellites.

The expectative is the pico/nanosatellites can drive the expansion of industrial market considering the space devices exploration because of the possibilities of addresses the solutions to science, exploration, technology development, education and operations, making the business economically attractive.

5 Software Product Line Concept

Software product lines are emerging as a viable and important development paradigm allowing companies to realize order-of-magnitude improvements in time to market, cost, productivity, quality, and other business drivers. Software product line engineering can also enable rapid market entry and flexible response, and provide a capability for mass customization (SEI, 2012).

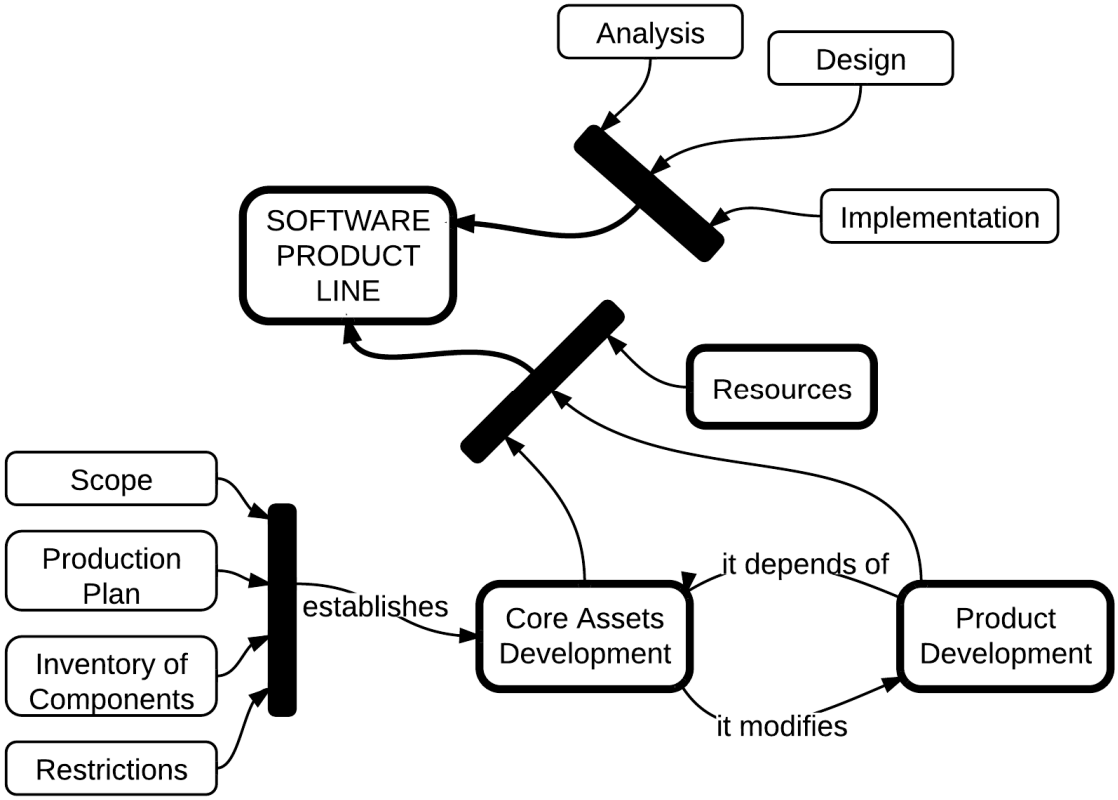


Figure 4 - SPL Organization

Adopting this concept as shown in the Figure 4, it is necessary to separate the Product Development from Core Assets Development but both shall be managed by the same technical manager:

- **Core Assets Development:** This team is responsible for the development of generic resources, which can be used on any product of the same Family;
- **Product Development**: Mainly consists of assembling the assets developed or stored by Core Assets Team, creating products allowing the best fit to the market requirements;
- **Resources:** Is responsible for the coordination and overseeing providing the achievement of the EPL including all technical and organizational necessities.

6 SPL applied to pico/nanosatellites

The objective in the initial specification of a mission is to align software requirements with specific requirements without taking care with the processors. Seeing this premise, the Figure 5 demonstrates a generic OBC's state machine for pico/nanosatellites:

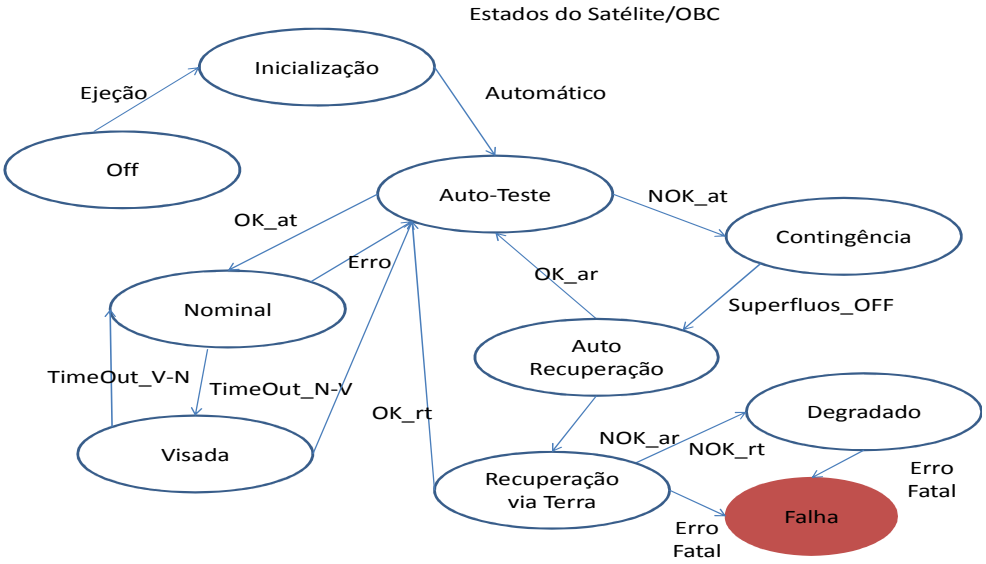


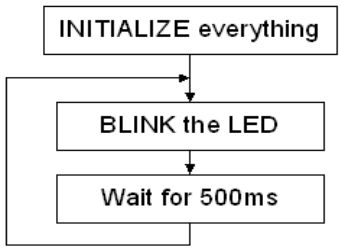
Figure 5 - OBC's state machine

This state machine does not specify software strategies or specific microcontrollers, on contrary it opens possibilities to work with different types of processors according to the necessities.

Following this concept, the state machine presented at Figure 5 can be implemented with freedom to choose between BX-24, Arduino or any other processor that can meet the requirements.

The function of the OBC's codes can be seeing as SPL Assets, which are specified with modeling languages, as UML, and be implemented in different languages.

In order to exemplify the application, below in the Figure 6 is demonstrated a top level flow chart and implementation in C++ and Basic:



Arduino (C++)	**BX-24 (Basic)**

public blink() {
digitalWrite(ledPin, HIGH);
delay(500);
digitalWrite(ledPin, LOW);
delay(500);
}
	Public Sub Blink()
	Call pin(ledpin, 1)
	Call Delay (0.5)
	Call pin(ledpin, 0)
	Call Delay (0.5)
	EndSub

Figure 6 - SPL Example

The example can demonstrate that the engineering effort to specify the LED-blinking algorithm is fully reused in two different processor platforms as Arduino and BX-24.

The SPL approach taken is general and maybe suitable to other domains where improvements on productivity and reliability are necessary thru the orderly and efficient reuse of software assets.

7 Conclusion

The SPL concept can contribute to the opportunity to reach economical and technical improvements, considering as an approach to make the engineering knowledge organized, reusable and keeping lessons learned from previous developments.

This approach provides contributions to improve Embedded Systems Developments, building an effective and well-structured process that can provide a powerful combination of suitable infrastructures, features, and managerial guidelines.

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