Deliverable 2.1 b

Design and assembly of the electronic system to control, collect and analyse data from the robot

MONTH 22 – submitted on 18 September 2018

Brief overview of the components that constitute the VineScout embedded platform.

SUN;UPV

Abstract

The VineScout project aims at deploying a ready-to-market (TRL9) robotic solution designed according to a user-centered approach, practically achieved by the permanent feedback from, and interaction with, end-users through intense field testing and the realization of Agronomy Days (Task 5.2). The VineScout advances beyond the State of Art by implementing real-time non-invasive monitoring technology in a concept robot adapted to field conditions (Vinescout, 2016). The strategic relationship between work packages and benchmarks is shown in ***Figure 1***.

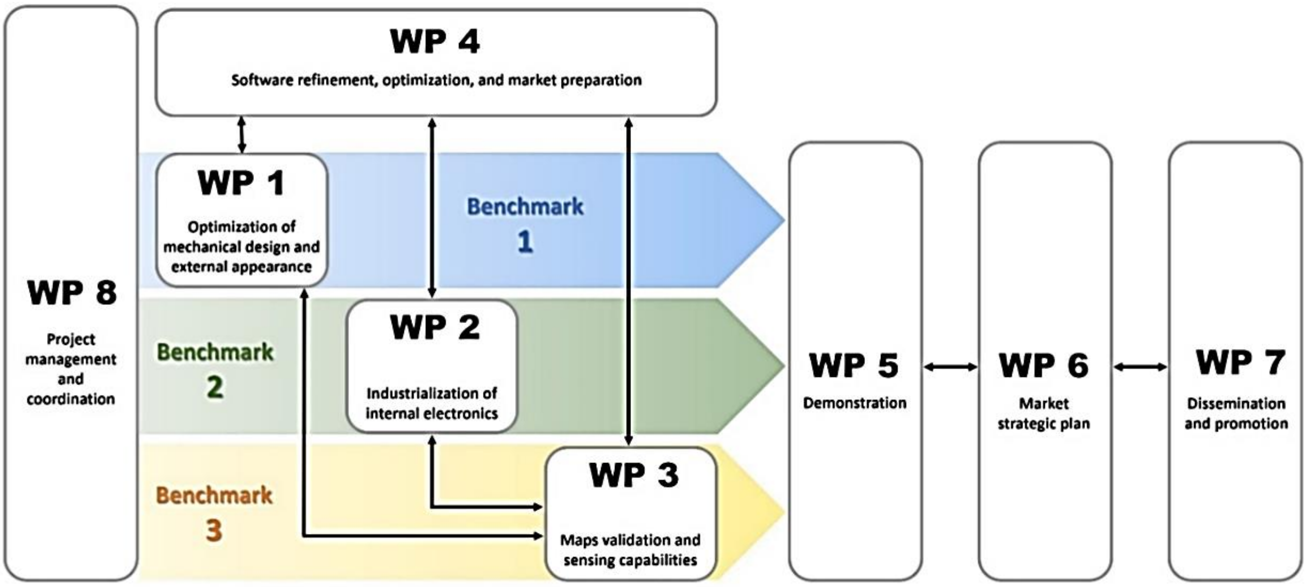

Figure 1: The strategic relationship between work packages and benchmarks.

The D2.1 is a brief overview of the components that constitute the Embedded Computing System proposed by SUN and gives background details of the choice of components.

Specific details regarding the project can be found at the VineScout project official website[1].

[1] The VineScout project http://VineScout.eu/web/

Version History

Date	Authors	Description
11/11/2017	Pedro MACHADO (SUN)	First draft
27/11/2017	Pedro MACHADO (SUN)	Apply changes
11/12/2017	Verónica SAIZ (UPV)	Apply changes
11/12/2017	Verónica SAIZ (UPV)	ECAS submission
14/07/2018	Pedro MACHADO (SUN)	Added details about the VS-2 prototype details
16/07/2018	Flemming CHRISTENSEN (SUN)	Internal revision
21/07/2018	Pedro MACHADO (SUN)	Apply changes
17/08/2018	Verónica SAIZ (UPV)	Final revision

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List of Abbreviations

Abbreviation	Definition
ADAS	Advanced driver-assistance systems
ARM	Advanced RISC Machine
ATX-PSU	Advanced Technology Extended – Power Supply
BLE	Bluetooth Low energy
CAN	Controller Area Network
COTS	Commercial off-the-shelf
CPU	Central Processing Unit
DDR	Double Data Rate
DoA	Description of the Action
FMC	FPGA Mezzanine Card
FMC-LPC	FMC Low Pin Count
FPGA	Field-Programmable Gate Array
GNSS	Global Navigation Satellite System
GPIO	General Proposed Input/Output
GPRS	General Packet Radio Service
GPS	Global Positioning System
GPU	Graphical Processing Unit
HDL	Hardware Description Language
HDMI	High-Definition Multimedia Interface
HSST	High-Speed Serial Transceiver
I/O	Input/Output
I2C	Inter-Integrated Circuit Bus
IC	Integrated Circuit
IMU	Inertial Measurement Unit
Industry 4.0	Current trend of automation and data exchange in manufacturing technologies
IoT	Internet of things
IP	Intellectual Property
MPSoC	Multi-Processor System on a Chip
OPC-UA	OPC Unified Architecture
OS	Operating System
PC	Personal Computer
PCIe	Peripheral Component Interconnect Express
PCIe/104	Embedded computer standard
PHY	Physical Layer
PL	Programmable Logic
PS	Processor System
RF	Radio Frequency
RISC	Reduced Instruction Set Computer
ROM	Read Only Memory
ROS	Robotic Operating System
RS232	Recommended Serial 232
RS485	Recommended Serial 485
RTPU	Real-Time Processing Unit
SATA	Serial Advanced Technology Attachment
SDRAM	Synchronous dynamic random-access memory
SerDes	Serialiser / Deserialiser
SoC	System on a Chip
SPI	Serial Peripheral Interface
SSD	Solid State Drive
TRL	Technology Readiness Level
UART	Universal Asynchronous Receiver/Transmitter
UAV	Unmanned aerial vehicle
USB	Universal Serial Bus
VHDL	VLSI Hardware Description Language
VLSI	Very Large-Scale Integration
WiFi	Wireless Fidelity
WP	Work Package

1. Introduction

In this section the following subjects are discussed:

a. Document structure.
b. Overview of WP2.
c. List of tasks.
d. Requirements and restrictions.
e. Assumptions and Limitations.

1.1. Deliverable structure

The deliverable D2.1 layout is as follows:

Section 1: Introduction – This section gives an overview of WP2, including the tasks carried out, the requirements set, and the restrictions found.
Section 2: Hardware platform – all the details of the Hardware platform are presented in this section.
Section 3: Conclusions and future work.

1.2. Work Package overview

The main objective for Work Package 2 (WP2) is to design, fabricate, install, and test the complete electronics network for each of the three robots deployed at the end of the action. It will assure the seamless integration of software and electromechanical devices. WP2 will also include an advantageous negotiation with component and software providers, very especially with the sensors that will comprise the navigation and monitoring engines of the robots. Previous prototypes with handcrafted electronics for the developing stages are difficult to replicate at a commercial level, and fail-safe capabilities plus environmental endurance must be granted for the long-life expectancy of the VineScout project [1].

1.3. List of tasks

The WP2 includes the following tasks [1]:
T2.1 – Electrical analysis for VS-1 (M1-M10)
T2.2 – Upgrade of electronic system for prototype VS-2 (M12-M22)
T2.3 – Commercially oriented modular design for VineScout (M18-M34)

1.4. Requirements and restrictions

The list of requirements and restrictions that have a direct or indirect impact on the development of the VS-1 Embedded Computing System (ECS) ***Table 1***.

Table 1: List of requirements and restrictions

Designation	Description	Type	Implications
R1	VineScout robot must be power sufficient	Functional	1. Use solar panels for charging the robot while is being used. 2. The User should be able to monitor the robot power consumption 3. The user should be able to monitor power being generated by the solar panel(s).
R2	The robot must be able to adapt to different types of landscapes and weather conditions	Functional	1. The robot design must take into consideration a wide range of landscapes. 2. The selection of enclosures with IP65. 3. Select components with Industrial/Automotive grade.
R3	Fail-safe electronics and response	Functional	1. Selection of high-quality devices/sensors. 2. Redundancy of sensors/actuators. 3. Each robot will have unique credentials and users cannot operate robots if the credentials are not valid.
R4	Improve the overall performance of the Embedded computer platform	Performance	1. Select a powerful Multi-Processor System-on-a-Chip (MPSoC). 2. The MPSoC must include a Processor System (PS), Graphical Processing Unit (GPU), Real-Time Unit (RTU) and freely Programmable Logic (PL).
R5	Increase the Runtime velocity	Performance	1. The Software must be reviewed for efficiency.
R6	Commercially-oriented solution	Functional	1. If time and resources allow, the Robot will have the possibility of CAN bus communication for facilitating the interface with automotive/sensors with ISOBUS certified.
R7	The robot will have to collect a wide range of data for a post-processing phase.	Functional	1. Provide 1TB SSD storage for storing the data collected.
R8	Provide flexibility to incorporate new sensors to the robot.	Functional	1. Provide different connections options following the industrial standards, including DisplayPort, SATA, HDMI, USB, 1000/100 Mbps Ethernet, WiFi, FMC-LPC, BLE, PCIe/104 ‘Type 3’, etc.
R9	Produce the robot at the best possible retail price	Non-functional	1. The price of the parts will be negotiated with suppliers to get the best possible quantity discounts. 2. The parts selection will be made based on the relation of the price and quality, as well as on the safety needs for standardization
R10	Platform must run Microsoft Windows	Functional	1. Development will be carried out in MS Windows due to the complexity of sensor integration. If time and resources allow, an attempt to develop a version running Linux will be proposed, but this will be second priority
R11	Provide FireWire connectivity	Functional	1. FireWire interfaces are required for stereo vision
R11	Budget	Operative	1. SUN has an overall of €431,834.38 for delivering a fully-functional solution.

1.5. Assumptions and Limitations

The following assumptions were made:

1) A wide range of sensors will be connected to the robot, including navigation and crop sensing
2) The typical users will be non-experts and therefore the robot must be highly flexible, robust and fail-safe.
3) One Terabyte of space will provide for storing data, nevertheless, the user can increase the space by upgrading the storage device.

4) A GNSS receiver will be necessary for real-time mapping. Internet will not be used and therefore coverage will not be necessary.
5) The robot will stop moving if any of the critical sensors or actuators stops working properly.
6) The user must have easy access to the stop buttons and the robot must stop if at least one emergency stop button is pressed.
7) The robot power consumption is still not estimated as field tests based on resistance are in progress, but preliminary results show that one day of mapping work is covered if slope is moderate. (check section 2.1 for further details)

The following updates of the preliminary specifications must be considered for upcoming versions:

1) The final version of the VineScout robot may not be ISOBUS[2] certified due to of the time it takes obtaining this standardization. Nevertheless, efforts will be made for making the robot compatible with ISOBUS. The final version of the VineScout Embedded Computer System is thought to have two CAN Buses interfaces. Further details about the CAN Bus and prototypes are given in section 2.
2) The VS-2 prototype will not be compatible with ROS because:
    a. It is not convenient at this level of development where new sensors are being added to the already-established network, which is complex and fully functional with MSW.
    b. ROS is not an industry standard for off-road farm equipment. It is a privilege to count on manufacturer leaders in the Advisory Board, and their assessment is being instrumental for moving from academic to market solutions.

2. Hardware platform

Details about the hardware platform are described in this section.

2.1. The VineScout Robot

The VineScout robot is the next generation of farming robots and it is being designed for providing high flexibility enabling users to decide when and where to map a vineyard. The VineScout robot will be equipped with a wide range of sensors and actuators. Some of the sensors and all the actuators will be used for navigation and are considered critical, while the remaining sensors will be used for collecting data used for inferring the evolution of the plantation (e.g. water stress and nutritional status). **¡Error! No se encuentra el origen de la referencia.** shows the VineScout robot sensors map.

Power consumption is an important feature of the VineScout project as we aim to deliver a robot solution with an autonomy of at least 6 hours of continuous working.. **¡Error! No se encuentra el origen de la referencia.** lists the sensors, and actuators and its power consumption, assuming the worst-case scenario (when all the parts are draining 100% of the required power):

We measured in the field both when the robot was idling and mapping up slope and down slope. The average power was 24 V x 6 A = 144 W. The point is not the energy consumption but the battery performance. At this point, with over 20 full days of testing with VS-2, we always had enough power each day, but tests should be conducted in fields with different slope degrees until we find the battery limitation. Also, the capacity for charging is lowering its performance with both temperature and time.

[2] ISOBUS seeks to establish and maintain transparency regarding the functionalities supported by specific products and their compatibility with others. Retrieved from http://www.aef-online.org/products/aef-isobus-database.html#/About on the 13/11/2017

2.2. First prototype (VS-1) of the Embedded Computer System (ECS)

The first prototype of the VineScout Embedded Computer System (ECS), also called EMC2-ZU3EG (Figure 2), is now being tested and comes equipped with a powerful Xilinx MPSoC ZU3EG device (Figure 3) as the main processing unit. This module will be soon installed and tested in the VineScout VS-1 prototype.

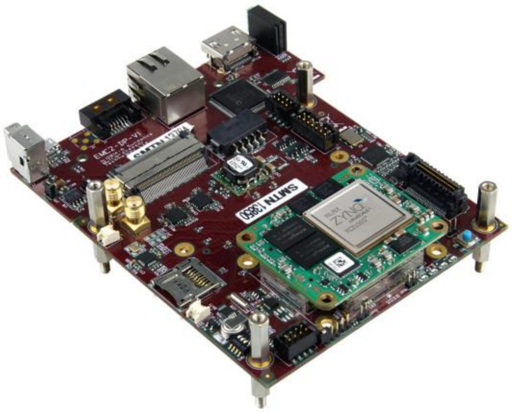

Figure 2: EMC2-ZU3EG computer board

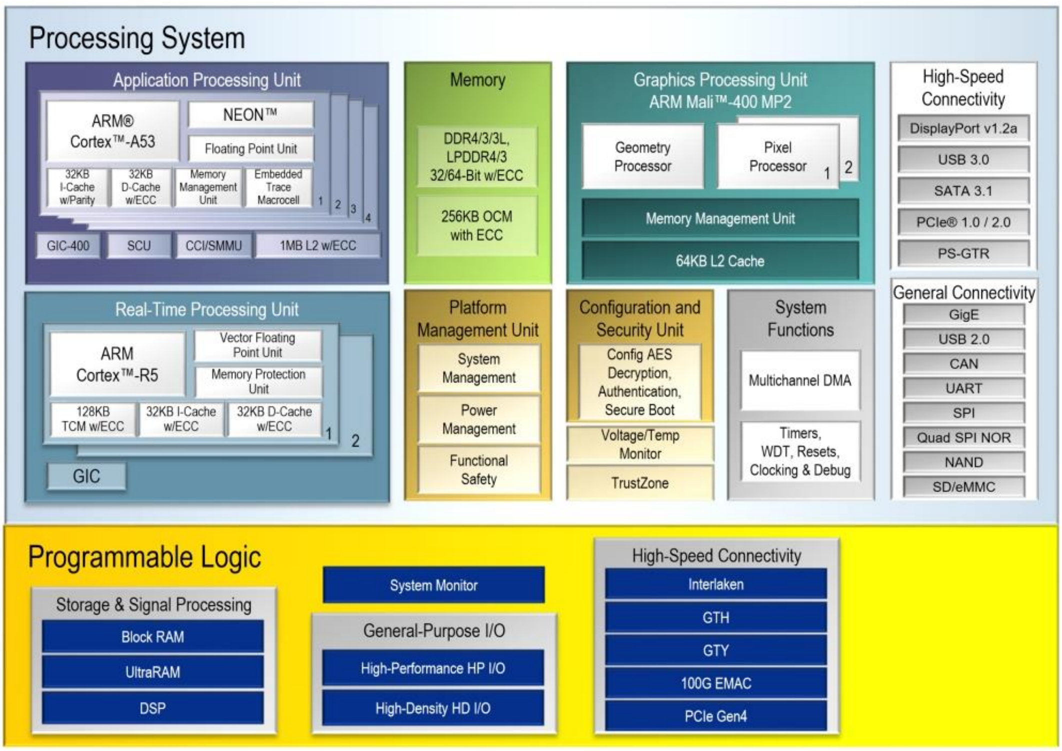

Figure 3: Xilinx ZU3EG block diagram

This EMC2-ZU3EG ECS was developed by SUN for the H2020 TULIPP Project, so is well supported with connectivity to standard interfaces, like USB, HDMI and Ethernet on the ARM CPU (Processing System = PS) of the Xilinx Zynq SoC and has flexibility to interface to specific vision interfaces (e.g. HMDI, CameraLink, etc) on the Zynq's FPGA side (Programmable Logic = PL). The EMC2-ZU3EG computer board (***Figure 1***) will be used for starting the migration/design/testing and updating of the support for the latest version of the Xilinx tools.

The EMC2-ZU3EG ECS was developed to work with Linux Operative System, and as WALL, UDLR, and UPV agreed to develop VineScout solutions in Windows, this computing card was never implemented, tried, or used in VineScout-I platform, which was field tested in the summer of 2017 and demonstrated over the first Agronomy Day (http://vinescout.eu/web/agronomy-days).

2.3. Second prototype (VS-2) of the ECS

From the beginning, UPV, WALL, and UDLR agreed on developing solutions in Windows, and work will continue with this operative system until reaching a satisfactory solution.

The windows stack is used to run the VineScout main software while the Linux stack is used to provide digital and analogue I/Os. UPV requested SUN to include a FireWire interface on the Windows stack to enable the possibility of connecting the BumbleBee camera. This stack is composed of 1x Dual Core Intel Atom 64-bit processor (TinyATOM board) processor 4x USB2.0 (TinyATOM board) , 4x USB3.0 (USB3000X card) , 9x UART (TinyATOM board and Serial2000 card), 2x Ethernet connections (TinyATOM board) and 4x FireWire ports (FireSpeed2000 card).

The Linux stack (see Figure 4) provides the Digital and Analogue I/Os connectivity. The Linux stack is composed of 2 main components, namely the MPSoC unit (and its carrier board) and the FMC expansion card that fans out the I/Os from the MPSoC to the outside world.

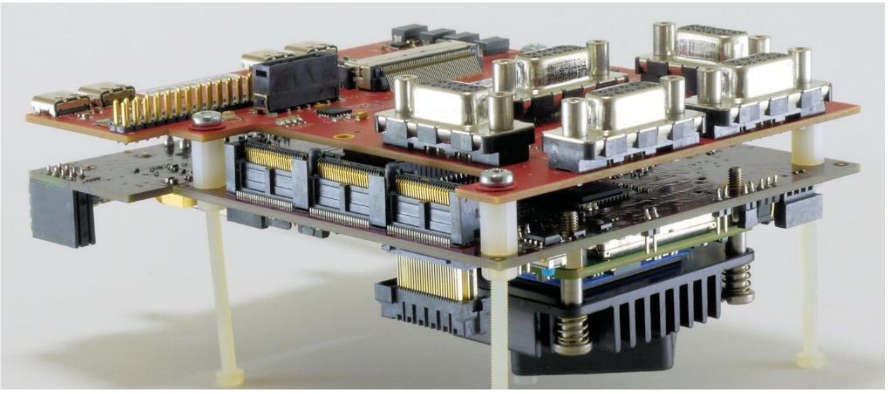

Figure 4: Linux stack

The selected MPSoc was the Xilinx Zynq 7 Series which provides standard connectivity (e.g. SPI, I2C, CAN, USB, GiGE, PCIe, etc), Dual Core ARM cortex A9 (used to run Ubuntu Linux OS), memory interfaces and Programmable Logic (used for Hardware acceleration).

The windows-based PC/104 assembled by SUN for VS-2 could not support the software required for development by UPV and UDLR, presenting unfixable issues with drivers and Windows updates. The computer was never stable, and as a result could never be used for running the robot VS-2. At the risk of being forced to cancel all 2018 testing season and the official steering week, which would have implied at least one year delay in the project objectives and development, UPV had to purchase an industrial computer and install all the development software in less than a month, from the Mid-project meeting at the end of May to the first field tests on 18 June 2018. The cost of this computer was approximately 1,800 €, and was covered by UPV.

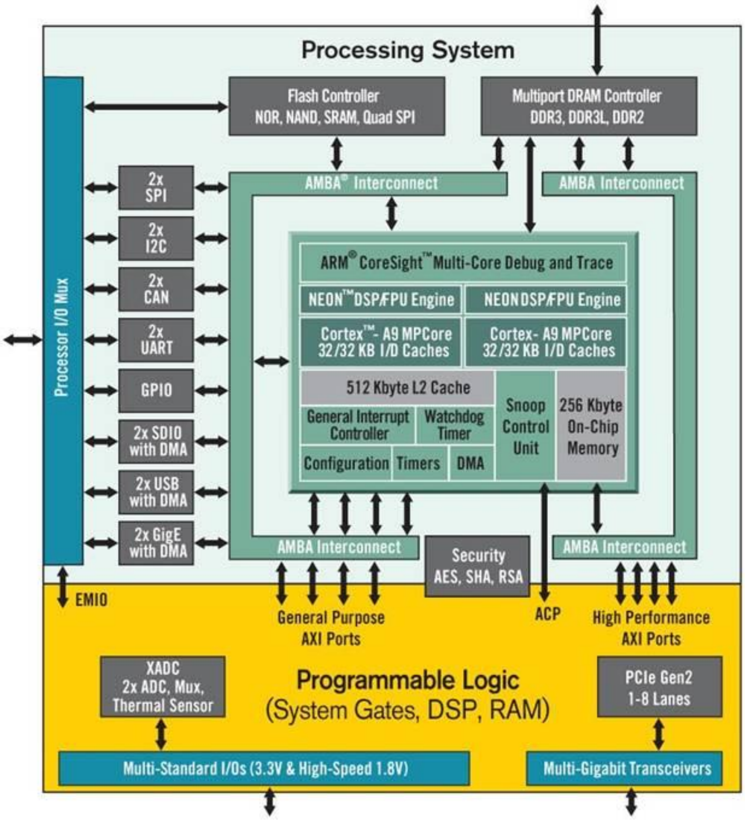

Figure 5: Xilinx Zynq 7 series block diagram.

A new module called FM191 module (Figure 6 and Figure 7) was specially designed to fan out the GPIO pins to the outside world via the FMC-LPC connector. The FM191 module provides 15x single-ended I/Os 5V TTL accessible via 3x DB9 connectors, 12x analogue Inputs 5V TLL (with a resolution of 24-bits@2kSPS) accessible via 2x DB9 connectors, 8x Analogue Outputs (with a resolution of 12-bits via 2x DB9) via 2x DB9 connectors, 4x USB3.0 via 4x USB-c connectors and a 40-pin GPIO (compatible with Raspberry Pi rev. B).

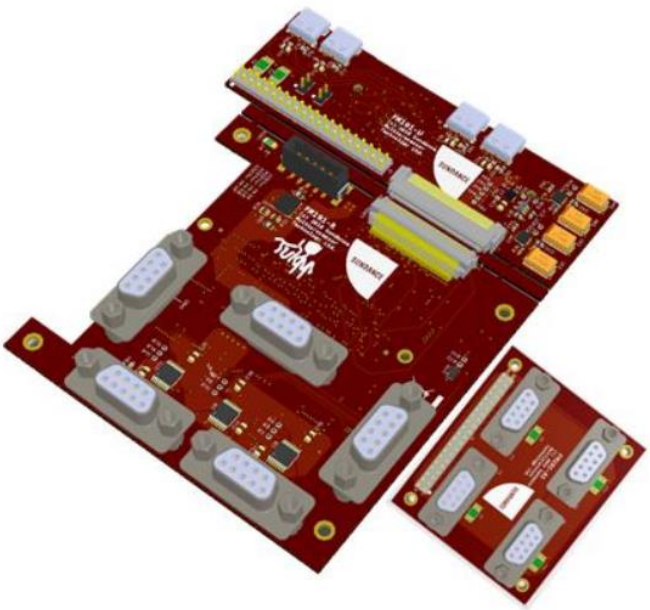

Figure 6: FM191 3D drawing

The FM191 daughter card was required for

1) simplify the connection of sensors (e.g. ultrasonic and switch buttons), lights and actuators.
2) Provide connectors with mechanical lock (DB9 connector) for improving the connectivity and therefore, reduce the vibration stress on the connector.
3) Increase the compatibility with COTS sensors and actuators.

The control, navigation and safety sensors/actuators are connected to the Linux stack which is interconnected to the Windows stack via the Ethernet. The Linux stack software was designed to work with a wide range of Internet-of-Things (IoT) and therefore the communication between the Linux and Windows stack is done using the MQTT machine-to-machine (M2M) protocol. The documentation and software was made available online and can be found in the Sundance GitHub repository.

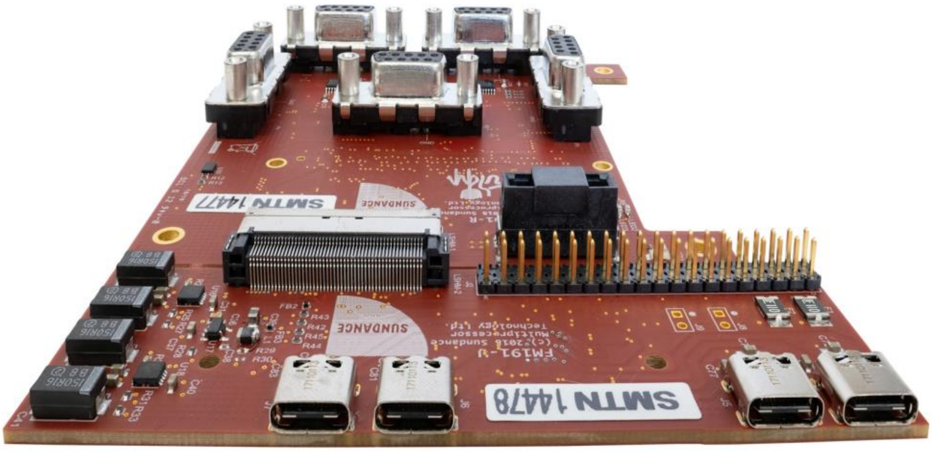

Figure 7: FM191 module

Both stacks are powered by the Opus DCX6.360W (Figure 8)which is high efficiency power source unit that converts the 24V from the battery into the AT, ATX, uATX and mini ATX motherboards. The DCX6.360W delivers the standard voltages of 3.3V (15A@12V or 12A@24V maximum ratings), 5V (17A@12V or 15A@24V maximum ratings), +12V (12A@12V or 10A@24V maximum ratings) and -12V (0.5A@12V or 0.35A@24V maximum ratings) via standard connectors, prevents rebooting the both stack during the robot power up, provides a delayed shut down timer, a stand-by power control for low battery drain and automatic shutdown at low battery voltage to protect the battery. The use of the DCX6.360W as main power supply system prevents the noise propagation, power dips to the VS-2 system/sensors which reduces undesirable faulty responses of these systems. The DCx6.360W will also supply power to all the actuators and sensors used on the VineScout robot which is desirable for avoiding undesirable faulty responses as consequence of having multiple power sources.

Figure 8: Opus DCX6.360W

The FM191 daughter card was not ready by the time of 2018 field testing season. At the time of the tests, it could turn on led lights but had not interacted with the rest of sensors. At the risk of cancelling the entire 2018 testing season with the official Agronomy Day, UPV had to borrow a commercial input-output board to conduct the field tests and purchase a new board for the robot (there was no time to install the recently-bought card as it took several weeks to arrive in Valencia, and the experiments were already in progress). The card bought had a cost of 2,450 €, which again had to be supported by UPV budget.

2.4. Final prototype (VS-3) of the ECS

The work on the final platform is progressing and the release date will be available by end of 2018. SUN platform for the VS-2 ECS could never be implemented in VS-2 platform, and therefore significant changes are expected in the use of MPSoC devices. The VS-3 prototype (see **¡Error! No se encuentra el origen de la referencia.**) aims to work first in Windows until the robot mapping and navigation system is fully developed. When this occurs, SUN and UPV will study the possibilities to build a Linux-based working solution if resources are available and both partners agree on the distribution of work for this task. If this happens within a reasonable timeframe, there will be a chance to use a Xilinx Zynq Ultrascale ZU4EV MPSoC device. The Xilinx Ultrascale Zynq ZU4EV device was highly optimised for automotive/ADAS (further details about this device are given below in this section).

The ZU4EV device will allow high performance because it includes a Quad 64-bit CPUs, GPU, RTU and an FPGA on the same chip. The CPUs are required for running a standard operating system (OS) for delivering the specific services (e.g. Ethernet standard services, Databases, etc), the GPU will be used for accelerating the Graphics processing, the RTU will be used for handling Real Time event and execute real-time tasks (e.g. Emergency stop) and the FPGA will be used for accelerating the image processing (e.g. autonomous navigation) and control the critical sensors/actuators (e.g. ultrasonic sensors and control the motor drivers).

A Two CAN channels are available for making the VinesScout Robot compatible with other automotive such as farming tractors. These features will make the VineScout robot a highly compatible, reliable and easy to use robotic platform to work side-by-side with humans and other collaborative robots.

The VS-3 prototype will be composed of 2 main computer-processing components, namely the MPSoC component (and its carrier board) and the FMC expansion card that fans out the I/Os from the MPSoC to the outside world.

The Zynq ZU4-EV MPSoC has the same I/O resources as the current Zynq Z7030 and a few more. The main addition is four extra SerDes to allow high-speed connection (Figure 9), Upgrade to ARM Quad Core A53 64-bit with SEIC board directly between FPGA (PL) section and/or used for USB3. It has extra I/O pins that will allow a Dual GigE interface for high-speed cameras, etc.

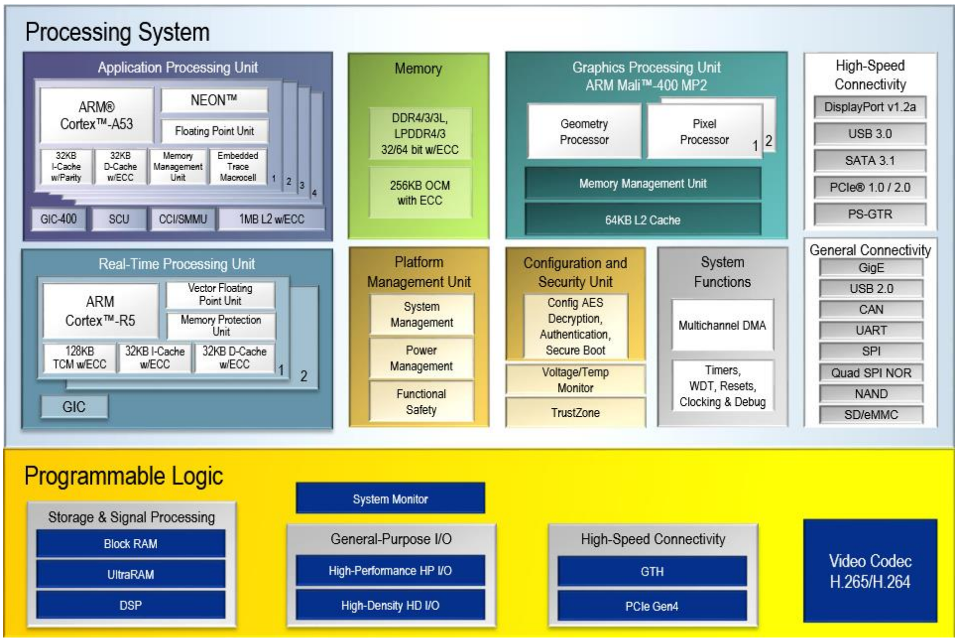

Figure 9: The Zynq EV family with integrated Video CODEC

The Video CODECs [bottom right corner] are what really makes a difference as will provide compression of video instantly and without the use of PS (ARM CPU resources) or PL (FPGA resources) and should not interfere significantly with the overall power consumption.

The second component is the FM191 module (Figure 7) which wasnever used in VS-2 prototype. Again, the FM191 module provides 15x single-ended I/Os 5V TTL accessible via 3x DB9 connectors, 12x analogue Inputs 5V TLL (with a resolution of 24-bits@2kSPS) accessible via 2x DB9 connectors, 8x Analogue Outputs (with a resolution of 12-bits via 2x DB9) via 2x DB9 connectors, 4x USB3.0 via 4x USB-c connectors and a 40-pin GPIO.

A CTI PCIe/104 Quad Mini PCIe/mSATA expansion board will be added via PCI/104 expansion bus (Figure 10). The CTI expansion board will be used for installing 1x CAN module (PCAN-miniPCIe dual channel), 1x UP AI Core (Movidius Myriad 2 CPU 2450), 4G module (ME909U-521P 4G Mini-PCIe) and 1x WiFi 802.11 b/g/n module (Intel Wireless WIFI Link 4965AGN Mini PCI). The CAN module will be used to make the VS-3 compatible with several automotive sensors and actuators, and the UP AI Core will be used to accelerate state-of-the-art Artificial Intelligence algorithms.

Figure 10: CTI PCIe/104 Quad Mini PCIe/mSATA expansion board

Finally, the VS-3 prototype will be installed on costume IP65 enclosure (Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15) which will allow to remove the fan of the MPSoC.

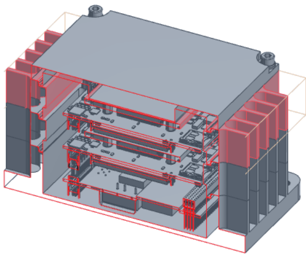

Figure 11: Enclosure drawing. Vertical cross-section view

Figure 12: Enclosure drawing. Top view

Figure 13: First layer of the enclosure.

Figure 14: Second layer of the enclosure

Figure 15: Enclosure overview

3. Conclusions and Future Work

The first 12 months of the project were used for capturing and analysing the requirements and restrictions of the prototype, and for testing the first version of the VineScout robot. The results obtained from the field tests helped SUN in designing the final version of SUN VS-1 ECS, which was never implemented in the robot. This version is an improvement of the EMC2-ZU3EG platform currently being tested (by SUN) in another ongoing European project, namely, the Tulipp European Project.

The VS-2 prototype suffered major design revisions as consequence of the initial requirement of having a system compatible with Microsoft Windows for development. The VS-2 prototype has proven to be challenging because it was also required to re-design the overall communications paradigm between two systems running different operating systems. Nevertheless, all those issues are still not solved and, as a result, the SUN boards were never implemented in the second version of the robot, which was tested and demonstrated in 2018. In the VS-3, we aim to provide a reliable solution in Windows. Preliminary power tests show that the Linux stack is an excellent option because it delivers high performance and low power. The Linux stack consumes and average of 14.26Wh and the full system an average of 24.43Wh. However, it is not certain that the Linux-based solution will be operational within the project timeframe.