7.10

Exploitation plan - Initial

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Abstract	The micro-ROS project aims to bring resource-constrained devices, such as microcontrollers, as first-class participants of the robot ecosystem. In particular, it aims to offer support to the Robot Operating System (ROS) on its second version: ROS 2. In an attempt to maximize the impact of our work, to concentrate and align our efforts, this report will discuss our initial exploitation plan.

1 Introduction

1.1 Executive summary

In this document, we will introduce the OFERA exploitation plan which is intended to stimulate and guide activities supporting the exploitation of the main findings and outputs arising from the project. Specifically, the partners aim to obtain sustainable, profitable and wide-scale exploitation of the project results both at a general and particular levels.

To provide context, the OFERA project aims to bring resource-constrained devices, such as microcontrollers, as first-class participants in the robot ecosystem. In particular, it aims to offer support to the Robot Operating System (ROS) on its second version: ROS 2. In an attempt to maximize the impact of our work, the document will start describing the general exploitation plan for the overall project. Such section will be split in 6 parts:

1. **project's mission and vision**
2. **target customers**
3. **strategic approach to materialize the vision**
4. **competition and SWOT analysis**
5. **unique selling propositions (USPs)**
6. **relationship to Communication, Dissemination, Collaboration and Standardization plans**

The general exploitation strategy will be followed by partner-specific activities related to their interests and the corresponding indicators to track their sucess. Each partner will describe such activities and commit resources to execute them.

Finally, a discussion about future exploitation-related work will be introduced. Follow up deliverables should indicate what would be the commitments for the long-term maintenance and evolution of micro-ROS after the end of this project and who developed such tasks.

1.2 Purpose of Document

The document aims to introduce our exploitation plan. This includes a general exploitation strategy for the overall project leaving for the future each partner's individual exploitation plan and the long term maintenance and evolution strategy.

The general exploitation plan for micro-ROS should provide details about how the project results will be positioned in the market. Such details will be discussed through: a) project's vision, b) strategic approach to materialize the vision, c) target customers, d) competition and SWOT analysis, e) unique selling propositions (USPs) and f) relationship to Communication, Dissemination, Collaboration and Standardization plans.

1.3 Partners Involved

Short Name	Full Name	Contribution
ALR	Acutronic Link Robotics AG	Leading author

Short Name	Full Name	Contribution
Bosch	Robert Bosch GmbH	Co-writing
eProsima	Proyectos y Sistemas de Mantenimiento S.L.	Support
PIAP	Industrial Institute for Automation and Measurements	Support
FIWARE	FIWARE Foundation	Support

2 Acronyms and keywords

- ROS: Robot Operating System
- QA: Quality Assurance
- RTOS: Real-Time Operating System
- TSC: Technical Steering Committee
- OEM: Original Equipment Manufacturer

3 General Exploitation Plan

3.1 Project's Mission and Vision

Robots today are networks of mixed devices which include general purpose microprocessors and microcontrollers. Often, these networks are summarized as the interconnection of all networks into a (robot) global one, the *robot network*. Most often, microcontrollers within the *robot network* are used within sensors or actuators, coupled with additional electronics to interface appropriately.

micro-ROS vision is to enable European companies to rapidly deliver robotic products integrating highly resource constrained devices (microcontrollers). micro-ROS aims to bridge the technological gap between the established robotic software platform for high performance computational devices and the low level libraries for microcontrollers. To do so, the project's mission is to bring microcontrollers as first class participants of the Robot Operating System (ROS) 2 robot ecosystem, the *de facto* standard for robot application development.

3.2 Target Customers and Stakeholders

Target customers include:

- robot hardware/component vendors
- robot OEMs
- general hardware vendors
- microcontroller OEMs
- embedded engineers
- researchers

Although we do not foresee other stakeholders at the time of writing, we acknowledge the strong interest that the project has received from the community and expect further additions to this section in future exploitation reports.

Also see the dissemination report for stakeholder-targeted dissemination activities.

3.3 Strategic Approach to Materialize the Vision

To materialize a reality where microprocessors and microcontrollers could be mixed together seamlessly in any robotic system, the project aims to expand the ROS 2 robot ecosystem to such devices, preferably through modifying ROS 2, where possible, but also through supplying complementary pieces where the current ROS 2 approach is unsuitable or non-existent. This strategy reduces the sustainability burden, and eases adoption.

In addition, the growth of the resulting, larger ecosystem is supported through standardization and community building efforts. Through these efforts in particular, the project also achieves enhanced visibility and influence of European actors in the world-wide ROS 2 community.

Specifically, the project's key results, as currently known (i.e. existing or planned), contribute to this as follows:

Key result	Type	Contribution
DDS-XRCE	OMG Standard	Ensures vendor-independent interoperability for deeply embedded devices.
Micro XRCE-DDS	Open Source	The reference implementation for DDS-XRCE, available for use and enhancement by the community. Also already provides message-level compatibility with ROS 2.
HRIM	Community Standard	Ensures discoverability and interoperability through self-description of devices.
ROS 2 Embedded Client Library	Open Source	Optimal performance for embedded devices in the ROS 2 eco-system through a small runtime, and specialized scheduling support.
ROS 2 Embedded Building Blocks	Open Source	Useful building blocks for embedded applications, e.g., embedded TF
micro-ROS	Brand	A unifying brand name for ROS 2 efforts targeted at deeply embedded devices

All of the corresponding activities are based upon the following core principles:

- Commercial exploitation - with a particular focus on Europe
- Alignment with ongoing initiatives
- International community acceptance

In the following, we will discuss each one of the key results.

3.3.1 DDS-XRCE & Micro XRCE-DDS

This result of the project has already been available in beta-form early on, and has meanwhile been adopted by several organizations, such as Robotis, Auterion, Renesas, and others, based on a clear unique selling point: Easy (if not yet seamless) integration with the existing ROS 2 ecosystem through the agent.

This is an example of a mutually beneficial cycle: The project drives awareness of the DDS-XRCE standard, and the Micro XRCE-DDS implementation drives demand for, and adoption of additional layers of the stack.

To further increase ease-of-use, an integration with the standard ROS 2 middleware interface, rmw, has also been provided.

3.3.1.1 DDS-XRCE Barriers and Risks Right now, resource (particularly RAM) use is still an issue when targeting low-end small devices.

Beyond the current ad hoc benchmarks, more usage data will be collected in the benchmarking activity and used to further improve the current implementation.

Apart from that, real-world experience with performance of the DDS-XRCE protocol is currently limited. Initial indications are promising but challenging use cases will need more evidence. Again, this is being collected as part of the project already.

3.3.1.2 Input from users The project already includes users (Bosch, ALR, PIAP), and a number of external users are providing feedback directly to partner eProsima.

3.3.1.3 Roles of the partners Partner eProsima is leading standardization, development and productization, partners Bosch and ALR are exploring use cases in their products, and partner PIAP is exploring a research use case as well as performing benchmarking.

3.3.2 ROS 2 Embedded Client Library and Building Blocks

The client library represents the default entry-point for developers using ROS 2.

Modifying the existing client libraries, particularly for reduced resource usage, will greatly improve performance and enhance the user experience of newcomers to embedded devices.

Supplying embedded-specific building blocks, such as specialized executors with domain-specific scheduling APIs, improved system composition concepts and an embedded TF are all crucial to realize the potential of micro-controllers.

Therefore, both use within their own products, as well as the development of supporting products are natural exploitation pathways.

To control this development, the consortium has initiated a ROS 2 Embedded Special Interest Group.

3.3.2.1 Barriers and Risks With regard to the client libraries itself, the most important barrier is cultural: rcl, rmw and rclcp are not written in the way of most embedded libraries. On the other hand, newcomers to embedded devices expect something Linux-like. Striking a balance between these two worlds could be characterized as the basic problem of the overall project, and a great deal of analysis and planning has been carried out in the first year to understand the situation fully.

The project has now committed to modifying the existing client libraries, rather than coding it from scratch. While this carries the risks of not being able to address the smallest use cases, it greatly increases the chances of keeping, and growing, the existing community and thus prevent the risk of a fork.

A second barrier is the use of the C++ standard library in the primary client library, rclcpp. The C++ standard library is not available on all platforms and only limited testing on its resource use could be carried out, yet, so there is also the risk of increased resource use. This will be addressed using more benchmarking and the exploration of greater modularization, to selectively use only what's necessary.

Last, but not least, there is also the risk of organizations "just" integrating Micro XRCE-DDS in their existing client code, and foregoing the full ROS2 implementation. We consider this risk minor – firstly, it would still represent use of a key project result, and secondly, over time, we expect that as people come to realize that many of the features they require are already provided by ROS 2, they would migrate.

3.3.2.2 Input from users As the consortium includes several users already, concrete feedback is always present.

Moreover, the project consortium has engaged the community in the ROS 2 Embedded Interest Group, where it will carry out regular interactions, as outlined in the dissemination and collaboration reports.

3.3.2.3 Roles of the partners Partner eProsima has performed the porting of the basic client libraries, partner Bosch is assisting with the basic libraries and working on the embedded building blocks, partner ALR is working on the information model, the drivers and the RTOS abstractions. Partner PIAP provides benchmarking, crucial both for improvement and for promotion. Partners eProsima, Bosch and ALR currently organize the ROS 2 Embedded interactions. All partners contribute to the SIG's design papers.

3.3.3 Hardware Robot Information Model (HRIM)

HRIM is an information model for robots that aims to facilitate interoperability among modules from different vendors of robot hardware. Offering a common interface, pursues the simplification of reconfigurability and flexibility, an innovation the robotics industry strongly could benefit of. Although born as part of the H-ROS infrastructure, HRIM is independent and contains rules/specifications that standardize interactions between different robot components from different vendors.

3.3.3.1 Barriers and Risks HRIM is still in its early stages and is still under development. As a young technology, it needs to show matureness and usefulness for the target audience. Even that, it is a solution that is already integrated under H-ROS, ensuring its feasibility and existence.

Many industrial players could see such an information model as a thread to its technology, as it breaks the vendor lock-in. This parties that could be not interested in having a technology that threatens their sales market and business model. In consequence, they could refuse it, marginalizing this initiative.

Another of the task to perform is to explain the usefulness of HRIM to robot developers. Specially to ROS users, which normally are more keen on adopting novel tools. ALR needs to perform communication and dissemination actions to ensure developers notifies its existence.

One of the technical issues HRIM could face is that could have difficulties integrating some devices. This could happen because the technical implementation provided by different manufacturers could be too diverse to gather together.

3.3.3.2 Inputs from users Even that is early to have a direct input of the users of HRIM, as ALR has been sharing and presenting it in many conferences and groups, it has received direct input from roboticists and technical people. These experts consider that there is need in the usage of such an information model. This helps ALR forecasting that HRIM should be adopted gradually in different areas linked to robotics.

3.3.3.3 Roles of the partners ALR develops HRIM and make use of it in H-ROS for creating modular robots, such as MARA. Additionally, as pointed out in the project proposal, ALR aims to integrate micro-ROS enabled devices in within H-ROS, using a micro-ROS to H-ROS Agent as bridging system between both worlds.

3.3.4 micro-ROS brand

In its first year, the project has already established the name "micro-ROS" to stand for a deeply embedded version of ROS. While other activities exist, most notably Robotis' XEL network, these are far more limited in scope and tied to single companies. In contrast, "micro-ROS" has already become known as the *community effort*, due to the consortium's dissemination activities, the formation of a ROS Embedded SIG, and our push for a joint effort that is in keeping with the spirit – and the code – of the ROS community.

This situation represents an opportunity to establish this name as a conduit for the interests embedded community as a whole, thus increasing Europe's influence on the overall ROS 2 eco-system.

To pursue this, consortium will strive to further establish the "micro-ROS" name as something akin to a brand name, increasing its prominence and focus. A first step in this direction has been to distinguish "micro-ROS" from the name of the European project, to clearly mark is as something which is supposed to live on after the project. Such a vision of future sustainability is important to increase trust.

It is also already clear that to pursue this strategy, the wider community needs to be involved. The ROS community has already been engaged through the ROS 2 Embedded SIG, but the wider embedded community is an important stakeholder as well.

3.3.4.1 Barriers and Risks A barrier to pursue this strategy is that to target the embedded community more broadly, i.e. beyond the parts already present within the ROS community, would require additional resources. Moreover, in its current stage, the project results represent a different cultural approach than that typically followed by the embedded community. Therefore, there is a risk that addressing the community right now could have adverse effects that are difficult to counter afterwards. Arguably, this has already happened to some extent with ROS in general.

To address this, hard data, such as benchmarks, could be leveraged. Also, current pain points in the embedded community that micro-ROS could address would be important to find out. There is already some corresponding knowledge within the consortium, but it would need to be distilled further.

A further risk is that the overall ROS community will not accept the consortium's leadership in this regard. So far, this does not appear to be the case, but new players can always emerge. Moreover, due to the activity being funded as a fixed term project, questions of sustainability have already arisen.

Therefore, it appears prudent to involve an organization which is perceived as having a long-term mandate and which is at the same neutral so as not to invite competition. It should ideally be one in which the consortium has a strong representation.

3.3.4.2 Inputs from users Input from parts of the target audience has already been sought and is continued to be sought within the ROS 2 Embedded SIG. Bosch is also pursuing this internally, to gather inputs from its core embedded development business units. Similar input can likely be provided by all partners.

3.3.4.3 Roles of the partners Each of the partners is using the "micro-ROS" name in its dissemination activities related to the project, and all of them have taken steps to publicize its activities, as outlined in the dissemination report. On behalf of the whole consortium, eProsima, Bosch and ALR are currently organizing the meetings of the ROS 2 Embedded SIG. All partners have contributed to the SIG's first pull request, and continue to contribute to further documents. ALR has registered a trademark "micro-ROS" and all partners are currently engaged in discussing how to further handle the brand name.

3.4 Competition and SWOT analysis

Opposed to micro-ROS, several contenders aim to become the reference approach for microcontrollers in robotics. The most relevant are:

- **rosserial**: rosserial is a protocol for wrapping standard ROS serialized messages and multiplexing multiple topics and services over a character device such as a serial port or network socket. It's available at http://wiki.ros.org/rosserial. rosserial is focused in ROS 1 and has been an interesting and useful source of inspiration for the OFERA project.
- **mROS**: Presented as a light-weighted runtime environment for ROS nodes onto embedded micro-controller. This work seems to be still on its early stages and the code is available at https://github.com/tlk-emb/mROS/.

At the proposal-development time, the SWOT analysis was presented as follows:

- **Strenghts**:
  - Cooperation with industry and SMEs
  - Experienced partners
  - ROS 2 compatibility
  - Big community

  - Based on standards
  - Good channels for dissemination and exploitation
  - Open source license

- **Weaknesses**

  - New concept/product
  - Lack of adoption and use of DDS in the deep embedded world
  - Mixture of patterns: pub/sub and client/server
  - No friendly development environments

- **Opportunities**

  - Emerging market
  - No big competitors
  - Digitising European Industry as flagship initiative of EU Digital Single Market Strategy
  - FIWARE involvement
  - Good platform for researchers

- **Threats**

  - Reduced number of developers
  - Slow adoption
  - Overall implementation is too heavy for certain micro-controllers
  - Tradeoff between capabilities/performance
  - Final performance unsatisfactory over wireless or serial mediums

The partners can already appreciate some changes. In contrast with the previously described competing initiatives, currently and according to the partners and the insight and reactions received from the community, the SWOT analysis looks as follows (text in **bold** indicates additions while ~~crossed-over~~ text, removal):

- **Strenghts**:

  - Cooperation with industry and SMEs
  - Experienced partners
  - ROS 2 compatibility (**through a bridged device**)
  - Big community
  - Based on standards (**particularly including DDS-XRCE**)
  - Good channels for dissemination and exploitation
  - Open source license
  - **Captivating new concept/product**

- **Weaknesses**

  - ~~New concept/product~~
  - Lack of adoption and use of DDS in the deep embedded world
  - Mixture of patterns: pub/sub and client/server
  - ~~No friendly development environments~~

- **Opportunities**

  - Emerging market
  - No big competitors
  - Digitising European Industry as flagship initiative of EU Digital Single Market Strategy
  - FIWARE involvement
  - Good platform for researchers
  - **Novel development environment for deep embedded devices based on containers**
  - **OEM players adopting micro-ROS**
  - **Strong positive response from selected ROS community members**

- **Threats**
  - Reduced number of developers
  - Slow adoption
  - Overall implementation is too heavy for certain microcontrollers (**alternatives have been considered**)
  - Tradeoff between capabilities/performance
  - Final performance unsatisfactory over wireless or serial mediums
  - **Appropriate governance is critical for the sustainability of the project**

Upcoming exploitation reports would keep analyzing the SWOT based on the community response and the identified commercial activities.

3.5 Unique Selling Propositions (USPs)

micro-ROS offer a unique proposition in the areas of embedding ROS 2 on resource-constrained devices and get tiny computation devices as first class participants of the ROS ecosystem. The project, pushed by experienced partners in the area of robotics, include all the necessary competences to release a worldwide technical trend. The partners are committed to drive results towards the interest of commercial entities and most, will themselves launch products based on micro-ROS. Moreover, the consortium members have relevant experience in Open Source and are committed to satisfy community needs for further growth of the project.

Thanks to the European leadership and strong precense in the area of microcontrollers, micro-ROS aims to become the de facto framework for deep embedded (microcontroller-based) robot application development.

3.6 Revision of Actions and Priorities regarding Communication and Dissemination Activities

In addition to the above listed collaboration and standardization activities, the exploitation strategies also materializes in communication and dissemination activities.

Target communities and working groups. The following table provides a revised list of the communities identified as targets for raising awareness of the project results. For each of them, partners already involved in the community which will be responsible of raising such awareness are listed. Added entries are in **bold** while discarded communities or responsibilities are ~~strikethrough~~.

Target community	Partners responsible of raising awareness
ROS, **ROS 2 Embedded SIG**, **ROS 2 TSC** and Open Robotics Foundation	BOSCH, EPROS, ALR, PIAP
HROS	ALR
OPC Foundation	ALR, BOSCH
FIWARE	FF, EPROS
Internet Industrial Consortium	FF, ~~BOSCH~~[1]
International Data Spaces Association	FF, ~~BOSCH~~[1]
OMG	EPROS
Advanced Robotics for Manufacturing (ARM) Institute	~~ALR~~[2]
DroneCode.org	EPROS
ISO 299	ALR

[1] There are no further plans to push OFERA results in the Internet Industrial Consortium and the International Data Spaces Association on the part of BOSCH as the OFERA partner. The membership of the Robert Bosch GmbH or subsidiaries in these organizations and the involvement by business units remains untouched.

[2] There are no further plans to push OFERA results in the Advanced Robotics for Manufacturing (ARM) Institute on the part of ALR as the OFERA partner.

Project-wide activities. The following table provides a revised list of communication and dissemination activities defined for the whole project consortium. Updated activities are in **bold** while canceled activities are ~~strikethrough~~.

Communication and dissemination activity	**Target Goal**	**Defined Actions**	**Target KPIs**
micro-ROS Website	General information	Frequent updates of the micro-ROS website and Search Engine Optimization (SEO)	micro-ROS website within the 5 first SERPs (Search Engine Results Pages)
Publication of project results in relevant target community websites and forums	Gain visibility within target communities	Publication on ROS Community Forum. Publication on Dronecode.org Presence on H-ROS website	>5 posts/year

Communication and dissemination activity	Target Goal	Defined Actions	Target KPIs
Participation in technical conferences and workshops	Raise awareness on technical and scientific community, particularly the ROS Community	Presence at ROSCON Presence at FIWARE Summit Presence at relevant ROS-Industrial conferences and workshops	>5/15/20 (year 1/year 2/year 3) technical presentations (uploaded on slideshare) by end of first/second/third year of the project >125/375/500 attendees in total by end of first/second/third year of the project >12/37/50 downloads from slideshare by end of first/second/third year of the project
On-site demonstrations and presentations	Attract customers Raise awareness	Presentations and or demonstrations to target customers/users	50 proposed 35 responded 35 performed
Scientific publications	Scientific dissemination	Publication to journals and magazines	> 10 publications
Presence at major trade fairs	Market awareness, Go-To market	Presence with dedicated space within FIWARE's or some partner's booth	>=2 large trade fairs (Hannover-Messe Industry Fair, some other)
Active presence on social networks	Raise awareness on Social Media	Regular posts through FIWARE channels	>3 posts/month (Twitter, LinkedIn, Facebook) 1 video/year on YouTube >10 average likes /share per post
Featured blog posts	Social awareness	Blog posts or articles within FIWARE website or other websites	> 10 posts/year > 1000 visits/year
Production of marketing material	Promotion	Flyers, brochures, promotional material	1 flyer 1 brochure 1 poster 1 infographic
Press releases	Awareness among decision and	Official communications policy makers	>=2 / year
One-to-one communication	Awareness on target audiences	Newsletters Mailings	Featured article every two FIWARE monthly newsletters >1 featured mailings/year

Partners dissemination plans. In the following revised lists of the individual communication and dissemination activities of each partner are provided. Again, updated activities are in **bold** while canceled activities are ~~strikethrough~~.

EPROS:

- Presentation of the project on the Project and EPROS website, Press Release
  - All the project results
- Concept Demos to eProsima Customers
- Promotion within ROS as ROS contributor
  - micro-ROS Website inside ROS.org, as a module of ROS
  - Presentations at the next ROS Conferences 2017-2020 [ROSCON]
  - Articles, Blog posts.
- Promotion within FIWARE as FIWARE Foundation Chapter leader for Robotics and Middleware (Presentations, Articles, Examples, Web content, etc)
  - Presentations and workshops at FIWARE summits
  - micro-ROS demos using FIWARE stands in important fairs (Iot Congress, Hannover Messe, etc)
  - Web content for a new FIWARE website area devoted to robotics.
- Promotion within Dronecode.org (Presentations, Articles, Examples, Web content, etc)
- Presentations as success case at OMG meetings

ALR:

- Presentation of the project in the H-ROS website.
- Promotion and demonstrations to existing customers of H-ROS
- Promotion within the ROS 2 community and collaboration with community projects.
- Promotion within several robotic conferences and forums. In particular, promotion at ROSCon 2018 with several mentions and a talk dedicated to micro-ROS results.
- Promotion within OPC Foundation through direct actions that aim to align efforts.
- Promotion within ISO 299 for the proposal of specific text that would allow micro-ROS products to be considered as part of the service robots modularity ecosystem.
- Promotion and collaboration with other EU projects. In particular, participation in RobMoSys as part of their expert's sessions, facilitating bridges between both projects and connecting together future activities in a joint manner.
- Promotion at ROS-Industrial meetings/conferences (ALR together with its subsidiaries is a full member of ROS-I Consortium Europe)
- Promotion within the Advanced Robotics for Manufacturing (ARM) Institute

PIAP:

- Promotion within several robotic conferences and forums, including showcasing of demonstration platform.
- Presentation of the micro-ROS benchmarking results at the ROS Conference (ROSCon), joint with EPROS.
- Publication of at least two papers in peer-reviewed robotic journals.

BOSCH:

- Promotion at ROS-Industrial meetings/conferences (Bosch is full member of ROS-I Consortium Europe)
- Promotion within the ROS 2 community, **in ROS 2 TSC** and at ROSCon
- **Presentation at relevant non-robotic conferences from the Cyber-Physical-Systems and Real-Time Community (e.g., CPS-Week and DATE)**
- Presentation within Bosch in annual reports and on the Wiki of the internal project that will back the micro-ROS activities of Bosch

FF:

- Promotion within FIWARE, as part of the regular activities of the FF:
  - FIWARE Summits, Sessions, workshops, hackathons, etc.
  - Web content: Press Releases, Blog posts, new Robotic area, etc.
  - Global Fairs (Hannover Messe, Iot Congress, Mobile World congress, etc)

4 Future Exploitation Work

Future exploitation work will cover each partner's individual exploitation plans and the long term maintenance and evolution strategy of the project. As per the application, the OFERA project and its partners are committed to maintain and favor the leadership of Europe in some strategic areas of the robotics area. The long term maintenance and evolution strategy of the project will take this in consideration.