



H2020-ICT-25-2016-2017



HYbrid FLying rollIng with-snake-aRm robot for contact inSpection

HYFLIERS

D7.5

HYFLIERS Dissemination and Exploitation Final Report

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Abstract:

This deliverable reports about the dissemination and exploitation activities of the consortium partners during period P3.

Keywords:

Conference. Dissemination. Exploitation. Horizon 2020. HYFLIERS. Innovation. IPR management. Journal. Magazine. Workshop. Risk mitigation. Value Chain.

Executive summary

This deliverable reports about the dissemination and exploitation activities of the consortium partners for the third and final reporting period P3 (from 1 January 2021 to 30 September 2022). The exploitation activities include risk mitigation for successful deployment in an operational scenario. A look towards the exploitation of HYFLIERS outcomes beyond the project's lifetime is also included in the deliverable.

Abbreviations and symbols

AIRPHARO	Aerial Robotic Systems Physically Interacting with the Environment
ANSA	Agenzia Nazionale Stampa Associata (National Associated Press Agency)
ATEX	atmosphères explosives
CTQ	critical to quality
CUI	corrosion under insulation
EC	European Commission
ECNDT	European Conference of Non-Destructive Testing
EMAT	electromagnetic acoustic transducer
ERF	European Robotics Forum
HYFLIERS	Hybrid flying rolling with-snake-arm robot for contact inspection
ICRA	International Conference on Robotics and Automation
ICUAS	International Conference on Unmanned Aircraft Systems
IEEE	Institute of Electrical and Electronics Engineers
IP	intellectual property
IROS	International Conference on Intelligent Robots and Systems
LIDAR	light detection and ranging
MATINE	Maanpuolustuksen tieteellinen neuvottelukunta (Scientific Advisory Board for Defence)
MGPP	multi-generation-product-plan
MVP	minimum viable product
NDT	non-destructive testing
SMI	stress magnetic investigation
UAV	unmanned aerial vehicle
UT	ultrasound transducer, ultrasonic testing

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1. Dissemination

The HYFLIERS research results are targeted to reach:

- Scientific community,
- Industry and end users,
- Educational community,
- General public.

All HYFLIERS project outputs include a project acknowledgement statement, or otherwise suitable identification means, to help to identify them as originating from the project.

Publications are written on both the methods and technologies developed during the project and the applications. Scientific publications are made primarily through high-level international conferences and journals, favouring open-access models. Dissemination also exploits social networks (including LinkedIn, Twitter, etc.), national and local newspapers and television, as relevant. In addition to publications, the consortium also aims at organising international workshops on the research areas related to the project, summer schools, academic courses, seminars and events including communications and seminars within the end user companies

1.1. Dissemination Actions

The following contains the dissemination actions of each individual partner in the consortium.

1.1.1. Academic Partners

University of Oulu

During P3, University of Oulu disseminated HYFLIERS results at conferences as follows (more are under preparation):

- Celentano U, Kauppinen M, Rönning J (2021) Ground support for drone-based industrial inspections. Aerial Robotic Systems Physically Interacting with the Environment (AIRPHARO). <https://doi.org/10.1109/AIRPHARO52252.2021.9571042>.
- Rönning J, Celentano U (2022) Hybrid robots for safe and effective oil and gas pipe inspection. International Conference on Intelligent Robots and Systems (IROS). 23-27 October. Kyoto, Japan.

HYFLIERS project was also advertised at the following events:

- Juha Rönning at MATINE (Maanpuolustuksen tieteellinen neuvottelukunta, Scientific Advisory Board for Defence), Arctic and Space thematic group, 7 May 2021.
- Juha Rönning at MATINE (Maanpuolustuksen tieteellinen neuvottelukunta, Scientific Advisory Board for Defence), 20 September 2022.

The following academic these have been produced (more are under preparation):

- Miika Sikala (2022) Data management system for wireless sensor ground station. Bachelor's Thesis. Degree Programme in Computer Science and Engineering. University of Oulu. June.

The project's web-site (<http://hyfliers-project.eu/>) is maintained up-to-date with the progress.

University of Seville

USE disseminated HYFLIERS results through the publication of scientific papers in journals and at international conferences and workshops. In the third period seven papers in journals have been published and one more is under review, and another three papers have been published in international conferences:

- F.J. Garcia Rubiales, P. Ramon Soria, B.C. Arrue and A. Ollero, "Soft-Tentacle Gripper for Pipe Crawling to Inspect Industrial Facilities Using UAVs". *Sensors* **2021**, *21*, 4142. <https://doi.org/10.3390/s21124142>
 - S. R. Nekoo, J. Á. Acosta, G. Heredia and A. Ollero, "A benchmark mechatronics platform to assess the inspection around pipes with variable pitch quadrotor for industrial sites", *Mechatronics*, Vol. 79, 2021, Article 102641, <https://doi.org/10.1016/j.mechatronics.2021.102641>.
 - S. R. Nekoo, P. J. Sanchez Cuevas, J. Á. Acosta, G. Heredia and A. Ollero, "Experimental Investigation of Soft-Landing of Quadrotors via Induced Wind Modeling Approach," 2021 Aerial Robotic Systems Physically Interacting with the Environment (AIRPHARO), 2021, pp. 1-6, <https://doi.org/10.1109/AIRPHARO52252.2021.9571054>.
 - S. R. Nekoo, J. Á. Acosta, G. Heredia and A. Ollero, "Soft-Landing of Multi-Rotor Drones using a Robust Nonlinear Control and Wind Modeling," 2021 International Conference on Unmanned Aircraft Systems (ICUAS), 2021, pp. 1070-1079, <https://doi.org/10.1109/ICUAS51884.2021.9476763>.
 - F. Ruiz, B. Arrue and A. Ollero, "A flexible propelled arm: Mechanical considerations for the use in UAVs," 2022 International Conference on Unmanned Aircraft Systems (ICUAS), 2022, pp. 1047-1055, <https://doi.org/10.1109/ICUAS54217.2022.9836149> . <https://arxiv.org/pdf/2204.13987>
 - S. R. Nekoo, J. Á. Acosta and A. Ollero, "Geometric control using the state-dependent Riccati equation: application to aerial-acrobatic maneuvers", *International Journal of Control*, 95:7, 1875-1887, 2022. <https://doi.org/10.1080/00207179.2021.1881165>.
 - S. R. Nekoo, J. Á. Acosta and A. Ollero, "Quaternion-based state-dependent differential Riccati equation for quadrotor drones: Regulation control problem in aerobatic flight", *Robotica*, 40(9), 3120-3135, 2022. <https://doi.org/10.1017/S0263574722000091>.
 - S. R. Nekoo, J. Á. Acosta and A. Ollero, "Gravity compensation and optimal control of actuated multibody system dynamics", *IET Control Theory Appl.*, Vol. 16, pp. 79-93, 2022, <https://doi.org/10.1049/cth2.12206>, <https://zenodo.org/record/6135692>.
 - S. R. Nekoo, J. Á. Acosta, G. Heredia and A. Ollero, "A PD-Type State-Dependent Riccati Equation with Iterative Learning Augmentation for Mechanical Systems," in *IEEE/CAA Journal of Automatica Sinica*, vol. 9, no. 8, pp. 1499-1511, 2022, <https://doi.org/10.1109/JAS.2022.105533> , <https://zenodo.org/record/6523679>.
 - F. Ruiz, B. C. Arrue and A. Ollero, "SOPHIE: Soft and Flexible Aerial Vehicle for Physical Interaction with the Environment," *IEEE Robotics and Automation Letters*, vol. 7, no. 4, pp. 11086-11093, Oct. 2022, <https://doi.org/10.1109/LRA.2022.3196768> . <https://arxiv.org/pdf/2205.12883>
- A. Caballero, M. Bejar, G. Heredia and A. Ollero, "Hybrid motion planning with dynamics awareness for aerial-ground robots in industrial inspection and maintenance", *Robotics and Autonomous Systems*, Submitted.

HYFLIERS results have been presented in the following:

- [TV Interview with Anibal Ollero](#) in Canal Sur, Andalusian regional TC channel. HYFLIERS prototypes are presented in the interview.
- HYFLIERS results have been presented in the workshop “[Resilient and Long-Term Autonomy for Aerial Robotic Systems](#)”, with HYFLIERS prototypes shown in the [workshop head video](#), co-organized by A. Ollero at the 2021 International Conference on Robotics and Automation (ICRA 2021, May 2021). HYFLIERS results have been also showcased in the following presentation:
 - “Resilience in Infrastructure Contact Inspection with Aerial Robots”, G. Heredia.
- HYFLIERS results have been presented at the AIRPHARO Workshop on Aerial Robotic Systems Physically Interacting with the Environment (November 2021), in the keynote presentation:
 - “[Intelligent and bioinspired aerial manipulators](#)” by A. Ollero.
- Workshop “[Autonomy in Aerial Robotics for Inspection and Maintenance](#)”, co-organized by A. Ollero and J. Röning at the 2021 European Robotics Forum (13-15 April 2021). HYFLIERS results presented in talks by:
 - A. Ollero, “Research and Development in Aerial Robotics”.

1.1.2. Research and Technological Centres

CREATE

CREATE is disseminating the achievements of the third period HYFLIERS project through scientific publications, workshops and exhibitions.

Workshops

- Presentations at the School of Mechatronical Engineering, Beijing Institute of Technology, Beijing, China, 11/06/2021 and 22/10/2021.

Video and Social

- [HYFLIERS](#) – University of Naples Federico II – February 2021
- [HYFLIERS](#) post on UniNa Facebook – February 2021
- [HYFLIERS](#) tweet on PRISMA Lab Twitter – February 2021
- [HYFLIERS for University of Naples Federico II](#) – PRISMA Lab YouTube channel – February 2021
- [HYFLIERS flight test](#) – PRISMA Lab YouTube channel – 21 June 2021
- <https://youtu.be/sr8Xmgzlt3E>
- <https://youtu.be/0dApTFFP8WM>
- https://youtu.be/59dA_u0MrE4

Booth @ Maker Faire Rome – The European Edition

- [Hyfliers @ Maker Faire Rome -The European Edition](#) post on PRISMA Lab Facebook – October 2021

Press and Social

- [Campania NewSteel presenta Neabotics](#) – Campania New Steel – January 2021
- [Campania NewSteel presenta Neabotics](#) post on Campania New Steel Facebook – January 2021
- [Campania NewSteel presenta Neabotics](#) – PRISMA Lab Press Club – January 2021
- [Il meglio della ricerca si incontra per dare vita ai robot aerei](#) – post on ANSA Scienza e Tecnica Facebook – June 2021
- [Il meglio della ricerca si incontra per dare vita ai robot aerei](#) – post on PRISMA Lab Facebook – June 2021
- [Podcast al via la seconda stagione di Dreambot](#) – PRISMA Lab Press Club – June 2021
- [Il meglio della ricerca si incontra per dar vita ai robot aerei](#) – ANSA Scienza e Tecnica – July 2021

Podcast

- [Robot per l'impresa](#) – Dreambot – June 2021
- [Robot per l'impresa](#) – Spreaker – June 2021
- [Robot per l'impresa](#) – I Tunes – June 2021
- [Robot per l'impresa](#) – Google podcasts – June 2021

Web

- [An industrialized version of a drone able to land and move on a pipe to perform ultrasonic thickness measurements](#) – The EU Innovation Radar Platform
- [An industrialized version of a drone able to land and move on a pipe to perform ultrasonic thickness measurements](#) – post on PRISMA Lab LinkedIn – September 2022
- [An industrialized version of a drone able to land and move on a pipe to perform ultrasonic thickness measurements](#) – post on PRISMA Lab Facebook – September 2022
- [HYFLIERS, il primo robot al mondo dalla mobilità ibrida](#) – University of Naples Federico II – Sep 2022

Papers

- [A hierarchical control scheme for multiple aerial vehicle transportation systems with uncertainties and state/input constraints.](#) Yu, Y.; Shi, C.; Shan, D.; Lippiello, V.; and Yang, Y. *Applied Mathematical Modelling*, 109: 651-678. 2022.
- **Robust Visual Localization of a UAV Over a Pipe-Rack Based on the Lie Group SE(3).** Lippiello, V.; and Cacace, J. *IEEE Robotics and Automation Letters*, 7(1): 295-302. 2022.
- [A framework to design interaction control of aerial slung load systems: transfer from existing flight control of under-actuated aerial vehicles.](#) Yu, Y.; Wang, K.; Guo, R.; Lippiello, V.; and Yi, X. *International Journal of Systems Science*, 1-13. 2021.
- **A Novel Hybrid Aerial-Ground Manipulator for Pipeline Inspection tasks.** Cacace, J.; Fontanelli, G. A.; and Lippiello, V. In *2021 Aerial Robotic Systems Physically Interacting with the Environment (AIRPHARO)*, pages 1-6, 2021.
- **A Novel Articulated Rover for Industrial Pipes Inspection Tasks.** Cacace, J.; Silva, M. D.; Fontanelli, G. A.; and Lippiello, V. In *2021 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*, pages 1027-1032, 2021.

FADA-CATEC

CREATE has disseminated the achievements of the third-period HYFLIERS project through scientific publications, workshops and exhibitions.

Papers

- Salvago, M., Pérez-Gran, F. J., Parra, J., Trujillo, M. A., & Viguria, A. (2021, October). Robust and Efficient Pose Estimation of Pipes for Contact Inspection using Aerial Robots. In 2021 Aerial Robotic Systems Physically Interacting with the Environment (AIRPHARO) (pp. 1-6). IEEE.
- Montes-Grova, M. A., Pérez-Grau, F. J., & Viguria, A. (2022, June). Multi-Sensor System for Pipe Inspection using an Autonomous Hybrid Aerial Robot. In 2022 International Conference on Unmanned Aircraft Systems (ICUAS) (pp. 1367-1374). IEEE.

Workshops

- European Robotics Forum, ERF2021. Autonomy in Aerial Robotics for inspection and maintenance, 13/04/2021.
- JORNADA 'Sistemas no Tripulados en el Sector Naval y Offshore', 12/05/2021
- European Robotics & AI workshop applied to Inspection and Maintenance, 29/06/2021
- International Symposium on Unmanned Systems and the Defense Industry, ISUDEF 2022, 30/05/2022

Exhibitions

- European Robotics Forum, ERF2021, 13/04/2021-15/04/2021
- UNVEX 2021, 7/07/2021-9/07/2021
- Expodronica 2021, 27/10/2021
- Amsterdam Drone Week, ADM, 29/03/2022-31/03/2022

1.1.3. Industrial Partners

Chevron Oronite

The results of the HYFLIERS project are disseminated in P3 on the following platforms:

- Internal Chevron Forums:
 - Chevron Fellows Technology Showcase, San Ramon, California, USA. October 2022
 - Chevron Facilities Engineering Forum, Houston, Texas, USA, June 2022
- Conferences
 - Sprint Robotics World Conference for Inspection and Maintenance Robotics, Amsterdam, Netherlands. 27/28th September 2022

TotalEnergies

The results of the HYFLIERS project have been disseminated in P3 as follows:

- TotalEnergies – ATCO internal seminar – (Nov. 2021) – Audience 30 persons
- TotalEnergies - Technological Innovation Platform – Annual Report 2021 (Jan. 2022)
- TotalEnergies - Technological Innovation Platform – Internal conference for field operations (Feb. 2022) – Audience 50 persons

WTR

The results of the HYFLIERS project are disseminated in P3 on the following platforms:

- Sprint Robotic Days, Zürich, Switzerland, 31th August / 1st September 2022
- Sprint Robotics World Conference for Inspection and Maintenance Robotics, Amsterdam, Netherlands. 27/28th September 2022
- Waygate Technologies – Advanced Inspection Services Technology Preview, January 2022
- OTC Asia, Kuala Lumpur, 21st – 25th March 2022

DASEL

During the execution of the third period of the HYFLIERS project, DASEL participated with the limitations of its structure in different diffusion acts such as: papers, web news and promotion in NDT congresses.

Papers

- HYFLIERS: Drones inteligentes para automatizar la inspección por Ultrasonido de infraestructuras de petróleo y gas. Roberto C. Giacchetta, Jorge Fernández Cruza, Jose D. Brizuela, Francisco Alarcón Romero. 14^o Congreso Nacional de END - Vitoria Junio 2019
- Control de corrosión por ultrasonido de infraestructuras de petróleo y gas utilizando drones inteligentes Roberto C. Giacchetta, José Brizuela, Jorge Fernández Cruza, Francisco Alarcón. **XII Congreso Regional De Ensayos No Destructivos y Estructurales (CORENDE)**, el 6 al 8 de noviembre 2019 Universidad de Lanús Bs As Argentina

Exhibitions

- ECNDT 2023 3- European Non Destructive Testing Congress 7 July 2023

Web

- [www.daselsistemas.com](https://www.daselsistemas.com/es/blog-y-eventos/496-hyflilers) <https://www.daselsistemas.com/es/blog-y-eventos/496-hyflilers>

1.2. Dissemination plan update.

An updated dissemination plan of the project was presented in deliverable D7.4 [D7.4]. The dissemination plan includes actions targeted to the scientific, industrial/end users and educational communities and the general public. The actions implemented by the consortium in the P3 period of the project have been presented in the previous section. The update of the dissemination plan for the rest of the duration of the project is presented in the following subsections for the four different target groups.

1.2.1. Dissemination to the Scientific Community

The dissemination of the HYFLIERS results is being done through publication of scientific and technical articles in journals and at international conferences and workshops. This task is being undertaken mostly by the research partners (Universities and Technology Centres) and the publications cover several areas of the work performed within the project.

HYFLIERS honours the H2020 Mandate on open access to publications, and therefore provides 'green' or 'gold' open access to peer-reviewed journal and conference publications. The open access will be provided through the Zenodo repository when possible, and linked to OpenAIRE.

In the P3 period, the consortium has published papers in the following *journals*:

- Mechatronics
- IEEE Robotics and Automation Letters
- Sensors
- International Journal of Control
- Robotica
- IET Control Theory and Applications
- IEEE/CAA Journal of Automatica Sinica
- Applied Mathematical Modelling
- International Journal of Systems Science

In the P2 period, the consortium has published research papers and delivered project presentations at these *international conferences*:

- 2021 Aerial Robotic Systems Physically Interacting with the Environment (AIRPHARO)
- 2021 International Conference on Unmanned Aircraft Systems (ICUAS)
- 2022 International Conference on Unmanned Aircraft Systems (ICUAS)
- 2021 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)

The P3 period has been still partly marked by the mobility restrictions due to COVID starting March 2020. The consortium members had the opportunity of presenting HYFLIERS results in the following workshops:

- Workshop “Resilient and Long-Term Autonomy for Aerial Robotic Systems”, in 2021 International Conference on Robotics and Automation (ICRA).
- Workshop "Autonomy in Aerial Robotics for Inspection and Maintenance", at the 2021 European Robotics Forum (ERF).
- European Robotics & AI workshop applied to Inspection and Maintenance, 2021
- International Symposium on Unmanned Systems and the Defense Industry, ISUDEF 2022
- European Robotics Forum, ERF2021
UNVEX 2021

1.2.2. Dissemination to the Industry and End Users

Dissemination of HYFLIERS to the Industry and End-Users is being done through public presentations at industrial conferences and workshops, and industrial seminars. This task is being undertaken mostly by the industrial partners, and also by the other partners.

In the P3 period, the consortium has delivered the following public presentations in industrial seminars, workshops and conferences:

- Conferences
 - Sprint Robotics World Conference for Inspection and Maintenance Robotics, Amsterdam, Netherlands. 27/28th September 2022

1.2.3. Dissemination to the Educational Community

The dissemination actions intended for the educational community consist of presentations to MSc and PhD students of robotics-related topics linked to HYFLIERS results, and also in summer schools. Actions in school and youth outreach programs are also included in this section. These actions are

mostly accomplished by the academic partners, and also the rest of the partners for the outreach actions.

In this third period, HYFLIERS partners have done the following actions to disseminate the project to the educational community:

- Training School on “Unmanned Aerial Systems for Inspection and Maintenance”, Seville, Spain, 7-11 March 2022.
- Presentation to students of the Electrical Engineering MSc program (U. Seville) 2022.
- Presentation to students of the Automation, Electronics and Telecommunication Engineering PhD program (U. Seville) 2022.

1.2.4. Dissemination to the General Public

Dissemination of HYFLIERS results to the general public is done through the project website (<https://hyfliers-project.eu>) and the partners’ own websites, the social media, appearance in the media, and presentations and presence in events intended for the general public.

In the P3 period, HYFLIERS partners have done the following actions to disseminate the project to the general public:

- Project website (<https://hyfliers-project.eu>);
- Individual partners’ websites;
- Twitter accounts;
- LinkedIn accounts.

2. Exploitation

With the aim to strengthen the position of Europe in the field, the HYFLIERS exploitation priorities are the following:

- Provision of HYFLIERS technology to the project’s end user;
- Direct commercial exploitation and licensing of HYFLIERS technology to third parties;
- Generation of spin-off companies;
- Inspiration of new research in robotics;
- Further improvement of academic teaching offer in the field.

A strong focus on the end user needs has been kept throughout P3 to continue strengthen the exploitation of the HYFLIERS project.

2.1. Exploitation activities

2.1.1. Industrial Partners

TotalEnergies / Chevron

The exploitation goal of the end users is to collaborate with the developers through the entire value chain of the project to ensure the system meets the required specifications including design considerations to satisfy the intended use case a live industrial oil and gas environment. The end users identified early in the project that the two proposed prototypes were too complex to certify for use in a potentially explosive atmosphere (ATEX). Instead, the approach decided for successful deployment

of the HYFLIERS prototypes in an industrial oil and gas environment is to mitigate risk to a level that is as low as reasonably practicable.

To achieve this, TotalEnergies and Chevron stated that a gas sensor must be included in the sensor payload of each prototype. Switching the power off is not enough as a residual current will exist in the batteries which are not designed to contain an ignition source (because of the non ATEX design). In this way, upon confirmed gas, each prototype is able to detect and fly away before reaching critical explosive limits.

The main issue that remains is in the event of a gas release once each prototype has landed, stabilised on a pipe and is clamped by some means, how to achieve the prototypes disconnecting from the pipe and taking off quickly enough.

To this end, USE has developed a mechanical bridge for the HRA prototype which acts as a quick release mechanism modular in design for various clamping methods. See Section 2.1.2.

During the live site testing to further enhance the validity of the test program, the end users ensured that a full range of global subject matter experts from both Chevron and TotalEnergies were present to witness testing. Additionally, a third-party certified inspector (Company: APPLUS, Netherlands) was present during the test program to give an independent opinion.

Chevron global subject matter experts included personnel from Houston, USA who are responsible for determining inspection programs and techniques for Chevron assets globally.

Chevron and TotalEnergies have offered the HYFLIERS consortium access to their industrial sites in 2023 to perform further industrial site validation tests once further development has been completed and validated in an outside non-industrial environment, on the HRA and HMR flying platforms.

Chevron and TotalEnergies are particularly interested in pursuing the use of satellite UT crawler on a stick (See Figure 3.) and are open to working with WTR to conduct further testing at our industrial sites.

WTR

The exploitation goal of WTR in HYFLIERS is to expand its product and technology portfolio as an inspection systems provider. The system will be fully industrialized and validated in cooperation with Waygate Technologies Advanced Inspection Services (AIS). The execution of commercial inspections by AIS will help to establish the technology on the market.

The patent application for ‘Vehicle Suspension with Coupled, Pivoting, Opposing Legs’ covering the kinematics of the HMR satellite has been approved (Number 11345201 (31/03/2021)). It will also further extend to additional countries to cover the IP aspects of the exploitation plan.

The localization system based on accelerometer, inclinometer, odometry and geometry data, but without the use of a LIDAR developed for the HYFLIERS satellite has been successfully implemented in a localization system for an underwater robot.

Following the conclusion of HYFLIERS, Waygate will focus on bringing a product to market that can fulfil the use-case and address the market as it was outlined at the outset of the project. According to the exploitation outlined in Section 2.2.

DASEL

Dasel will focus on further development of their ultrasound technology. The main objective is to develop the necessary elements to have a small UT unit.

DASEL continues advancing in the integration of ultra-low weight ultrasound systems, concentrated in the following technologies:

- EMAT,
- Roller probes,
- Guided wave technology,
- Multichannel system > 4 channels.

Dasel has a particular interest in using this type of technology in the field of aerospace inspection. The objective of DASEL is not to exploit the complete solution of HYFLIERS, but to market UT's software and electronics.

2.1.2. Academic Partners

University of Oulu

The HYFLIERS technologies will be exploited in further research activities as well as teaching. More in particular, the University of Oulu exploits its participation to the HYFLIERS project through their widened knowledge base:

- Activating related academic thesis topics (first theses have been already finalised while more are under preparation);
- Strengthening and expanding their teaching offer in specialised courses;
- Raising the University of Oulu's academic profile (the staff of UOULU HYFLIERS research team is active in strategic planning at the University);
- Sparkling new research in the field.

Moreover, the University of Oulu will promote HYFLIERS results through the presence of its coordinator in national and international communities, in particular, in euRobotics and SPARC, and thus feed them to the EC for possible use in future framework programmes.

University of Seville

The University of Seville has developed in HYFLIERS different technologies related to design, control, perception and localization of aerial robots for pipe inspection. The exploitation goals of USE include taking advantage of these technologies in new research lines as well as the development of the modular concept for a hybrid robot that can fly, land on insulated and non-insulated pipes, and move over them to reach the different points that need inspection. The concept was presented in a patent with reference ES2823073 that has been finally approved on March 2022, with also PCT extension requested with reference WO2021089896.

2.1.3. Research and Technological Centres

CREATE

The NEABOTICS spin-off, which has been founded by prof. Vincenzo Lippiello to exploit the outputs of the HYFLIERS project, under the stipulated scientific collaboration agreement with CREATE and a specific agreement signed for the exploitation of the results of the HYFLIERS project, has deposited 4 national patent requests:

- number 102019000006875 (15/05/2019): Accepted
- number 102019000016133 (12/09/2019): Accepted
- number 102020000020644 (31/08/2020): Accepted

FADA-CATEC

The main objective of FADA-CATEC is the transfer of technology to companies for commercialization. Since some of the technologies developed in this project have been demonstrated in a realistic scenario, it will be easier to attract the interest of the UAS/robotics industry. Then, the exploitation scheme is based on licensing the technology for industrialization and production.

The patent application sent by CATEC (application number P202130238) to the Spanish patent and trademark office is still pending approval. The patent presents a novel mechanism that provides any aerial robot with the ability to land safely on metallic pipes without the need for any active balancing system. Currently, this solution does not exist in the market but a previous study has been carried out by a specialized company to ensure the viability of the patent, so it is expected to be accepted during the next project period.

2.2. Exploitation Plan

2.2.1. Hybrid mobile robot

Summary

The section aims to outline an exploitation plan for the HYFLIERS systems as a product that could be sold by a system integrator and used by an inspection service provider to offer an inspection service to asset owners. Due to the differing TRL levels of the various HYFLIERS components, a generational approach is proposed. The Satellite is an already mature system that has performed well during the validation testing and was well received by the end users. With another iteration of the crawler design and development of a suitable portable remote-control system, an MVP (minimum viable product) prototype for extended onsite use could be created within a short time frame. Meanwhile the accompanying HMR flyer is already being iterated on as part of the PILOTING EU project, which will culminate in another site validation at Chevron Oronite in Q4 of 2023, where a successful combination of the flying, landing, and inspecting combination would be first demonstrated in a live refinery environment. Following that, a first MVP system could be derived. Learnings from the HRA development are already being integrated into the newest iteration of the HMR, particularly regarding the landing gear to provide a smoother and safer landing. In the long run a commercialized HYFLIERS system could also be equipped with the tools developed for the HRA robot to inspect nonmagnetic or insulated piping, where the magnetic crawler cannot be used. This could again significantly increase the targetable use-cases and further strengthen the business case by using common system components.

Multi generation product plan

1. Initial launch as satellite on a stick
 - a. Build service provider customer base with affordable product
 - b. Establish acceptance of inspection method adaption of procedures
 - c. Start establishing data for digital twin over lifecycle
2. Secondary launch of drone carrier for satellite
 - a. Expand addressable market
 - b. Improve value proposition

- c. Utilize and populate digital twin
- 3. Thirdly the rollout of additional inspection tools
 - a. Extension of use-cases to nonmagnetic assets and insulated piping

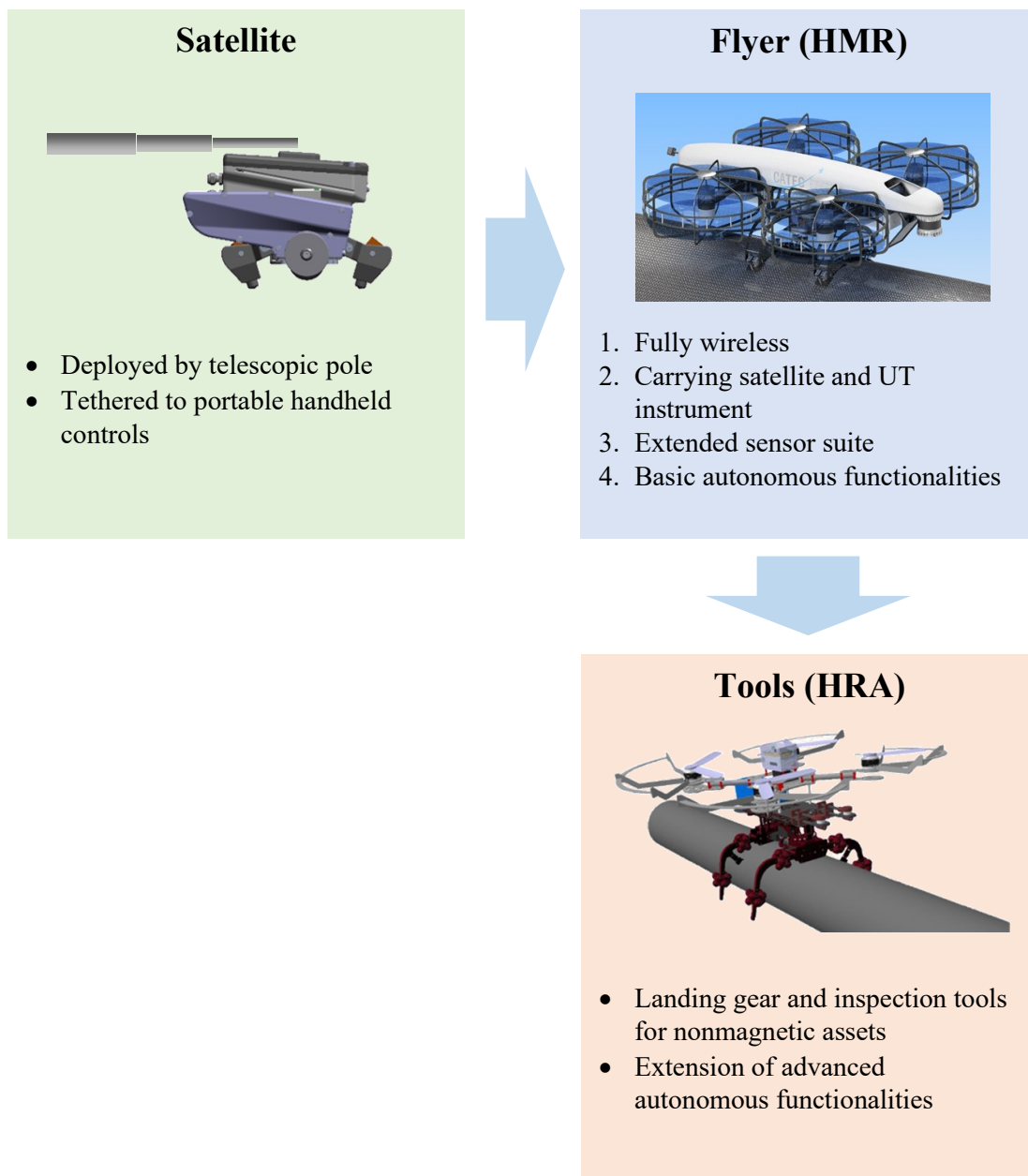


Figure 1. Multi generation product plan

Value chain

The value chain of Figure 2 was previously identified in deliverable D7.3.

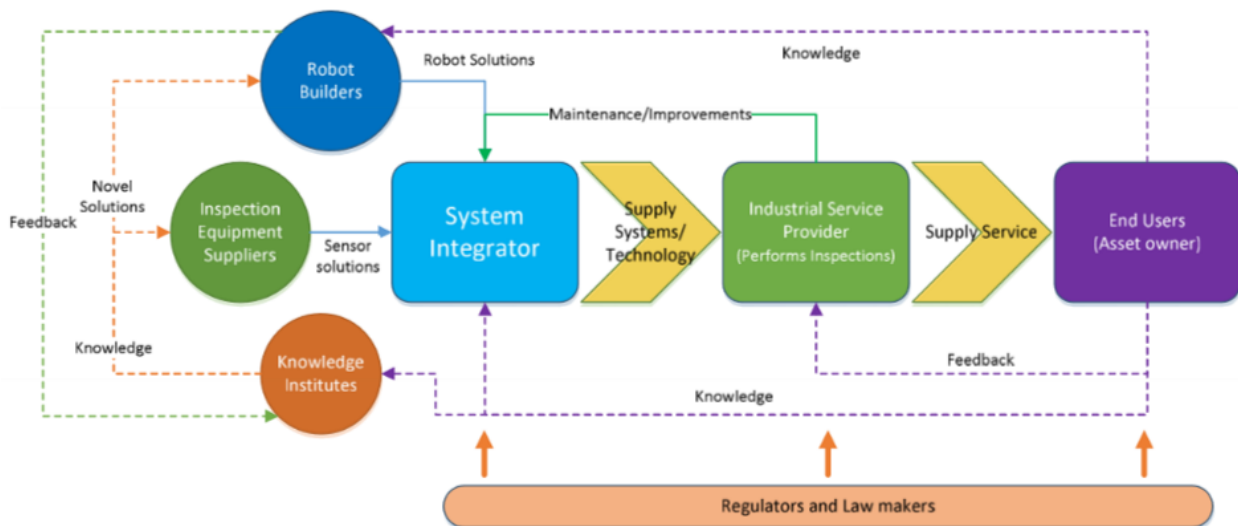


Figure 2. Value chain.

For Satellite

System integrator: Waygate Technologies Robotics

Industrial service provider: third-party industrial service providers in Oil&Gas market

End user (Asset owner): TotalEnergies, Chevron

Note: this satellite product would be easy to operate and therefore could also be purchased by end users for in house operation.

For HMR

System integrator: Waygate Technologies Robotics & CATEC

Industrial service provider: third-party system operator (industrial service provider) to be identified

End user (Asset owner): TotalEnergies, Chevron

For HRA

System integrator: Consortium partner or third-party system integrator to be defined

Industrial service provider: third-party system operator (industrial service provider) to be identified

End user (Asset Owner): TotalEnergies, Chevron

Market assessment

A top down-market assessment had been discussed in deliverable D7.3.

The addressable market for piping inspection services was estimated at around 0.5 – 0.75 USD billion per year. The addressable market volume for system sales and system-related support and maintenance (HYFLIERS technology-related systems) is estimated to around 100 – 150 USD million per year (ca. 20% of the inspection service business).

Additional potential markets to be approached are power generation, pharmaceutical or basic chemistry.

CTQs

CTQ (critical-to-quality) characteristics aim to break down the complex customer requirements into more easily quantifiable elements. Later analysis will use these to assess and compare the proposed product(s). Each of these is assigned with a priority to represent its importance to the customer. They were judged both based on the chief aim of the HYFLIERS project to provide remote controlled inspection solution with easy access in hard-to-reach places, as well as experience of the involved partners with their customer base that would consist a target market.

Table 1: CTQs

CTQ	Short Name	Priority
CTQ 01	Access capability Ease of access to various inspection locations. Range to remotely deploy. Need for direct line of sight. Remote deployment into hazardous areas.	High
CTQ 02	Deployment time Transport to inspection location. Relocation to next pipe. Powered from battery or mains. Need for scaffolding, cherrypicker or rope access and time required to set these up.	High
CTQ 03	Pipe types Range of diameters and geometries that can be inspected using the robot. Elevated pipe temperature for inspection during use. Capability to inspect piping of different (non-magnetic) materials or covered in insulation.	High
CTQ 04	NDT technique Inspection capability: Visual, wall thickness point measurement, Grid measurement, B-Scan, C-Scan.	Medium
CTQ 05	Operating time Time between recharging batteries or replenishing other consumable or wear parts.	Medium
CTQ 06	Cost Acquisition cost. Maintenance cost. Cost of trained personnel to operate.	Medium
CTQ 07	Environment Air temperature, Humidity, Rain. Temperature of pipes.	Medium
CTQ 08	Versatility Range of additional asset types and sizes that can be inspected using this device. Pipe material, coatings, and insulation.	Low
CTQ 09	Data acquisition Capability to store inspection data including thickness value, A-Scans and measurement location	Low
CTQ 10	Operation Control interface ease of use. Time to prepare, deploy, measure, retrieve, report.	Low

Competitive positioning

Table 2 shows an analysis of the competitive positioning of both the HYFLIERS standalone Satellite and full flying HMR system compared to other solutions in the market. This is a subjective analysis that aims to define suitable value propositions for the product. The scoring from 1 to 5 is assigned for the process piping inspection use-case outlined in the HYFLIERS project. For the purpose of this comparison, handheld equipment is considered as a complete product in conjunction with necessary

scaffolding, rope access or cherry picker equipment needed to address the targeted market that is assumed to include a significant amount of elevated piping.

Table 2: Competitive positioning analysis

CTQs		Hyfliers Satellite	Hyfliers HMR	Hyfliers HMR + HRA	Handheld spot probe & Scaffold	Phased array probe & Scaffold	Larger magnetic crawlers	Spot probe on a long pole (25m)	Spot probe on aerial drone	Large multi-segmented manipulator
1	Accessibility	4	5	5	2	2	2	3	3	3
2	Deployment time	4	4	4	1	1	3	4	4	3
3	Piping types	4	4	5	5	4	1	1	4	5
4	NDT technique	3	3	4	3	5	3	2	2	3
5	Operating time	4	3	3	4	3	5	4	2	5
6	Cost	4	2	2	4	3	3	4	2	2
7	Environment	4	3	3	5	4	4	4	3	5
8	Versatility	3	3	4	5	2	5	3	4	4
9	Data logging	4	5	5	2	5	5	2	4	4
10	Ease of use	5	3	3	5	3	3	4	3	3

Value propositions

Based on the competitive positioning discussed in the previous chapter, focus on the following value proposition allows the product to be differentiated from other solutions.

HYFLIERS satellite:

- No scaffolding, cherry pickers, ladders or rope access required for manual systems
- High portability of equipment without need for setting up control stations or deployment tools
- Quick deployment and redeployment with telescopic pole (e.g. jumping flanges)
- Obstructed spots can be access by crawler, e.g. between piping racks, where even elaborate scaffolds might be a challenge
- Reasonably priced addition to a conventional handheld UT instrument that eliminates the needs for scaffolding
- Main limitations to consider: Range of telescopic pole 5 m for deployment and range of tether 10 m.

HYFLIERS HMR:

- No need for personnel to walk the plant anymore
- Drone flies from a safe and centrally located landing site and control room to each spot
- Access to even the highest and least accessible locations with a combination of wireless drone and mobile satellite
- Additional data gathering with sensor suite on drone
- Drone landed on pipe consumes very little power, allowing complex measurements within reach of satellite
- Main limitations to consider: Range of satellite tether maximum 3 meter from closest available landing spot on horizontal straight pipe with sufficient overhead clearance for flyer.

HYFLIERS HRA:

- Inspection of all types of piping including insulated and other nonmagnetic
- Additional system versatility for other use-cases from the modular system design
- Main limitations to consider: Horizontal and straight piping with sufficient overhead clearance. Elbows and T-Sections accessible as far as actuated arm can reach.

Customer requirements

The deliverable D1.1 has already outlined a very detailed set of requirements for the systems. There are however potential additional requirements from the following sources to be considered:

- To achieve desired value propositions
- Results from the project conclusions that can be translated into additional requirements
- Additional consideration for the daily operation of an industrialized system
- Differing or additional requirements from Inspection Service Provider role identified in the value chain but not directly participating in the consortium
- Regulatory requirements, functional and non-functional standards

And likewise, the consideration of removing requirements with a high cost but limited immediate market impact.

For the UT Satellite on a Stick as a standalone unit:

Requirement	Value	Reasoning
Crawler		
Pipe OD	6 inch to flat	6 inch has been a wish requirement. Should be expanded to Must
Pipe Temperature	Up to 60 °C	100°C has been a Should/Could requirement. Current component selection has a critical ceiling of 80°C. Overheating issues of the motors also had to be addressed during the project. Some capability to address assets with elevated temperatures could however enable an additional value proposition in inspecting online piping and very hot and sunny locations.
IP Protection	IP65	As a standalone product, the satellite should be able to cope with use in light rain or on wet assets.
Cable Length	10 m	Short enough to limit impact of cable weight on small crawler, long enough for a person with mobile controls to reach any spot from ground or permanent platforms.
Deployment	Via Telescopic deployment pole	Means of quick deployment and redeployment that can circumvent otherwise impassable obstacles such as flanges or collars.
Remote deployment distance	5 m (possibly 7 m)	Maximum distance from ground or permanent platform to first possible deployment location from where the crawler can be driven to the inspection location. Keeping with portability of commercially available telescopic poles and manageable weight of satellite at full extension. Some

		use-cases like offshore platforms may have piping at 7 meter height from scaffolding.
Operating Environmental conditions	-10 C to 40 C air temperature	Typical temperature range of applicable safety standards with 10°C added to lower limit for use in winter.
Cameras	Front and rear navigation cameras (720p)	Was shown to be important for navigation, umbilical handling, recognition of reference features and assessment of driving surface condition.
Controls		
Portability	Deployable and managed by a single person	High mobility is key. It should ideally be as simple to transport and operate as a handheld probe.
Battery operation (typical load)	3.5 hrs	Battery lifetime should cover at least one shift without swapping.
Battery hot swapping	Yes	To extend operating time to a full day before recharging.
Hardware control for steering of crawler	Yes	Manual fine control is crucial when using cameras and encoder-based distance measurement to find inspection locations.
Camera viewing	Single camera at a time	
Camera recording	Record camera stream	
Operating Environmental conditions	-10 C to 40 C air temperature	To match satellite
Commercial		
Price	20 kEUR (excl. UT instrument)	System needs to be reasonably priced versus the cost of working at height (cherry picker, scaffold, climber) and as a reasonable addition to/with a basic handheld UT instrument.
Target countries	EU, UK, NA	Initial market to define compliance requirements.
Target market	Oil&Gas, Basic chemistry	Current use-cases identified and existing market access.

For the HMR:

The requirements pertaining to the flying part of the system shall be further reviewed upon completion of the PILOTING project and the accompanying onsite test at Chevron Oronite at the end of 2023.

Requirement	Value	Reasoning
Landing	Can be aborted at any time during and immediately after the landing process.	During the system integration testing and preparations for the onsite test, it had become apparent that the proposed “abrupt” landing approach would have difficulties to be accepted by end-users.

For the HRA:

The requirements pertaining to the different modular HRA systems shall be further reviewed upon completion of outdoor tests in Seville followed by site tests in Dunkerque TotalEnergies Oleum as described in D6.2.

Thanks to the modular concept of the HRA system, different landing gears and different arms could be qualified through the outdoor and site tests program.

Schedule

As outlined in the multi-generation-product-plan (MGPP), the approach is to first launch the satellite as a standalone system. Followed by the complete Hybrid platform being developed in parallel.

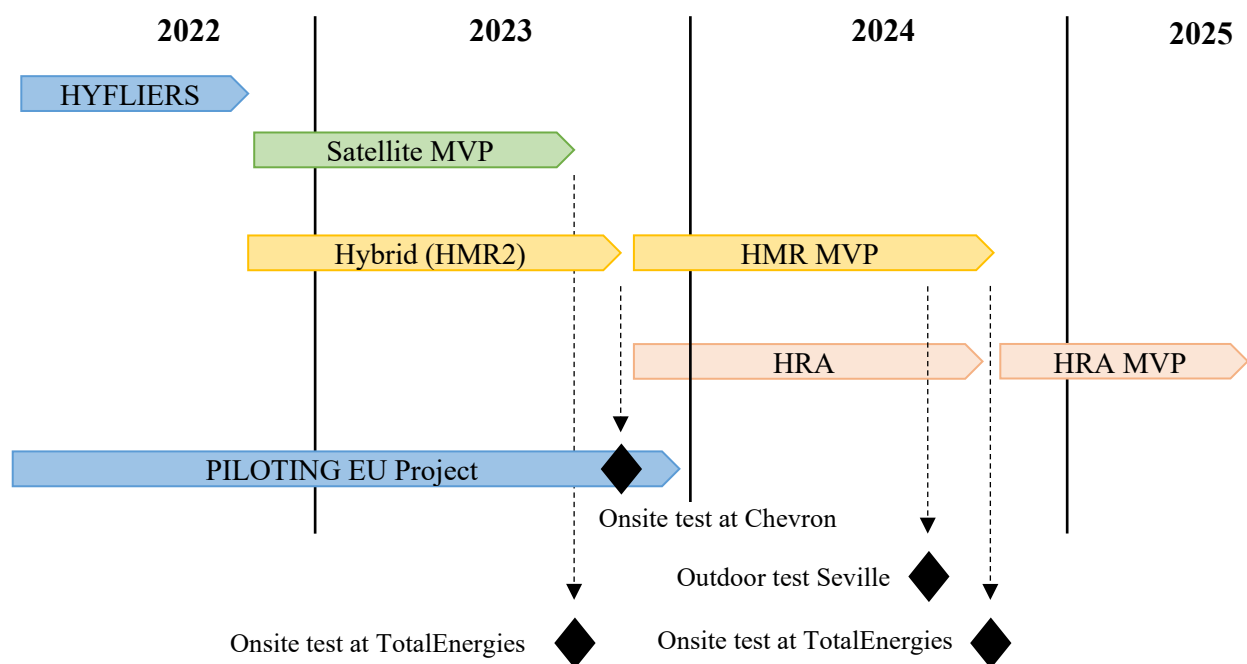


Figure 3. Exploitation project plan schedule.

2.2.2. Hybrid drone with an omnidirectional mobile base

Thanks to the achieved patents, NEABOTICS has developed of a special drone for the inspection of the corrosion under insulation (CUI), which is shown in the following video:

- <https://www.linkedin.com/feed/update/urn:li:activity:6961373107597000704>
- <https://youtu.be/prW1zCkO56s>
- <https://fb.watch/fJziIZF2WK>

NEABOTICS has also attracted further private investments from ENI SpA, which is investing in the development of this innovative systems to finalize an industrialized version of a hybrid drone equipped with an omnidirectional base able to stabilize and move over a pipe. The plan is to reach a stable fully industrialized version of such prototype in two years after the end of the project.

Figure 4 shows the pre-industrialized version of such a drone equipped with a SMI (Stress Magnetic Investigation) sensor during joined test with ENI and the owner of the SMI technology.



Figure 4. Pre-industrialized prototype of the drone with a mobile base developed during the HYFLIERS project (patent 102019000006875).

Moreover, the circular tool (Figure 5) is also considered for the development of an advanced version of this drone for the positioning of a multi antenna version of a SMI measurement system.



Figure 5. C-Tool (patent 102019000016133).

2.2.3. Other

In addition to the spin-off set up to exploit the HYFLIERS solution, several partners have been pursuing exploitation activities using HYFLIERS development results both for inspection of assets at elevated heights or in other applications. Multiple partners have held workshops with potential customers outside the consortium to pursue further exploitations opportunities.

References

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