LCAMP

Learner Centric Advanced Manufacturing Platform

MOBILE ROBOTS BASED ON ROS TECHNOLOGY

WPN° 3 Observatory

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LCAMP partners:

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GLOSSARY AND/OR ACRONYMS

AI - Artificial Intelligence

AM - Advanced Manufacturing

Cedefop - European Centre for the Development of Vocational Training

CoVE - Centres of Vocational Excellence

EAfA - European Alliance for Apprenticeships

EC - European Commission

ECVET - European Credit System for Vocational Education and Training

EntreComp - The Entrepreneurship Competence Framework

EQAVET - European Quality Assurance in Vocational Education and Training

EQF - European Qualifications Framework

ESCO - European Skills, Competences and Occupations

ETF - European Training Foundation

EU - European Union

HE - Higher Education

HVET - Higher Vocational Education and Training

I4.0 - Industry 4.0

KET - Key Enabling Technology

OECD - Organisation for Economic Cooperation and Development

ROS - Robot Operatin System

SME - Small and Medium Enterprises

SWOT - Strengths, Weaknesses, Opportunities, Threats

TVET - Technical and Vocational Education and Training

VET - Vocational Education and Training

WBL - Work Based Learning

CONTENT TABLE

EXECUTIVE SUMMARY

Advanced Manufacturing (AM) and Higher Vocational Education and Training (HVET) need to update training, implement new technologies, and get quick access to data.

The causes behind these needs are technological factors (Industry 4.0), factors conditioned by education systems and education methodologies, social factors and environmental factors (the European Green Deal with its emphasis on the greening industry).

Under the CoVE initiative, the LCAMP project aims to support regional skill ecosystems and various stakeholders in providing new skills and implementing new or updated technologies in VET centres. LCAMP will tackle this by incorporating a permanent European Platform of Vocational Excellence for Advanced Manufacturing.

By collaborating across borders, LCAMP's goal is to support and empower regional Advanced Manufacturing CoVEs to become more resilient, innovative, and better equipped to train, upskill, and reskill young and adult students, to successfully face the digital and green transitions. We will help European regions and countries grow and be more competitive through their VET systems.

Therefore, the LCAMP OBSERVATORY is one of the services in the LCAMP platform. The observatory is led by the French cluster *Mecanic Vallée* and the French VET provider *Campus des Métiers et des Qualifications d'Excellence Industrie du Futur*.

This present document details the first results of the LCAMP Observatory, through the methodology that the LCAMP consortium used to set up and run the Observatory. We had set up a process cycle for the observation consisting of 5 stages:

- Stage 1: Diagnosis and priority
- Stage 2: Search and information gathering
- Stage 3: Information Analysis
- Stage 4: Creating value. Elaboration of LCAMP reports
- Stage 5: Dissemination and communication.

1. INTRODUCTION

The LCAMP observatory is one of the services of the LCAMP platform.

The LCAMP Observatory must be a reliable and easily accessible source of information and data for trainers, VET teachers, and professionals, updated on Digital / Advanced Manufacturing / Smart Industry, delivered through a multimedia and interactive platform -LCAMP platform-, that can be customized according to individual interests (Work in progress in WP8).

This observatory must feed other Work packages (WP), for instance, WP 5 on Learner Centric Training, or Open innovation Community in the WP4.

In a first document about methodology, are set up a process cycle for the observation consisting in 5 stages:

- Stage 1: Diagnosis and priority
- Stage 2: Search and information gathering
- Stage 3: Information Analysis
- Stage 4: Create value. Elaboration of LCAMP reports
- Stage 5: Disseminate-communicate.

Following this process cycle, are detailed the main aspects of the observation methodology:

- Identify reliable sources that we can find in Europe about Advanced Manufacturing.
- Classify and filter data gathered from different sources.
- Present several ways to collect data and to analyse them.
- Define the methods for the creation of annual reports.
- Validate process for those reports.

The observatory will publish periodical reports for VET and HVET target audiences about technology trends, labour market changes, skill needs, and occupations in Advanced Manufacturing. It is expected that SMEs, industry clusters and other associations will also find valuable information in the observatory.

The publication of a yearly report is planned.

- Report 1: June 2023,
- Report 2: June 2024,
- Report 3: June 2025.

This first annual report is gathering sub-reports written by around twenty different writers, from the main partners involved in the LCAMP project. 39 Topics were determined, and 22 TOPICS were analysed and worked on during this first period.

2. MOBILE ROBOTS BASED ON ROS TECHNOLOGY

The purpose of this chapter is to present some of the development areas related to AM. These are topics that concern all or some of the stakeholders

- CoVEs and VETs: teachers, trainers and heads of VET schools;
- Learners: students, active workers, job seekers;
- Companies;
- Policy makers and other stakeholders

2.1 MAIN USED SOURCES

Table 1 : Main sources

Identification	Description	Geographical Scope	Sectorial Scope	Links
ROS-Industrial Consortium Europe	A consortium that aims to extend the capabilities of the Robot Operating System (ROS) to manufacturing and industrial applications.	Europe	Manufacturing and industrial applications	https://rosindustrial.org/
ROS Robotics Companies	A directory of companies that use or support ROS in their products and services.	Global	Various	https://robots.ros.org/
ROS-Industrial for Real-World Solutions	An article that explains how ROS is used in industrial automation and provides examples of real-world applications.	Global	Industrial automation	https://www.automate.org/industry-insights/ros-industrial-for-real-world-solutions
ROS (Robot Operating System)	An open-source framework for building robotic systems.	Global	Various	https://www.ros.org/
EU project: OFERA - micro-ROS	A research project that aims to develop a lightweight and scalable version of ROS for resource-constrained systems.	Europe	Robotics and automation	https://link.springer.com/article/10.1007/s00170-022-09071-w
"ROS-Based Unmanned Mobile Robot Platform for Agriculture"	A research paper that proposes a mobile robot platform for autonomous agricultural operations based on ROS.	Global	Agriculture	https://www.semanticscholar.org/paper/Design-of-an-autonomous-mobile-robot-based-on-ROS-Köseoğlu-

Identification	Description	Geographical Scope	Sectorial Scope	Links
				Çelik/9dd90f7b746657fe077f8cf1ea56f6a8d65ce21c
"Substantial capabilities of robotics in enhancing industry"	A research paper that discusses the potential of robotics to improve industrial operations and outlines some of the challenges to their adoption.	Global	Industrial automation	https://ieeexplore.ieee.org/document/9158800
"Towards next generation digital twin in robotics: Trends"	A research paper that explores the concept of digital twins in robotics and identifies emerging trends in this area.	Global	Robotics and automation	https://www.semanticscholar.org/paper/Towards-next-generation-digital-twin-in-robotics%3A-Liu-He/0e5ce8a1a0aaf6e96c6eae1626f8c6de8810d3a3
"A review of mobile robots: Concepts, methods, theoretical"	A book chapter that provides an overview of mobile robotics, including their design, control, and applications.	Global	Mobile robotics	https://www.intechopen.com/chapters/81922
Statista	A market research firm that provides data on the size and growth of the autonomous robot market in Europe.	Europe	Autonomous robots	https://www.statista.com/statistics/1285864/autonomous-robots-market-size-europe/
ResearchAndMarkets	A market research firm that provides a report on the autonomous mobile robot market in Europe, including trends, drivers, and challenges.	Europe	Autonomous mobile robots	https://www.researchandmarkets.com/reports/4901715/europe-autonomous-mobile-robot-amr-market-2020
ROS Wiki	An online resource that provides documentation, tutorials, and courses on ROS.	Global	Robotics and automation education	http://wiki.ros.org/Courses
The European Commission's Digital Skills and Jobs Platform	An online platform that offers a free introductory course on ROS for beginners.	Europe	Robotics and automation education	https://digital-skills-jobs.europa.eu/en/opportunities/training/hello-

Identification	Description	Geographical Scope	Sectorial Scope	Links
				real-world-ros

2.1.1 CONTEXT AND LIMITATIONS

The sources used in this report provide a reliable and up-to-date overview of the latest trends and developments in mobile robots based on ROS technology. However, the sources have varying degrees of focus on mobile robots based on ROS technology and may not provide the same level of detail. Moreover, there are also potential limitations and challenges that need to be considered, such as ethical and legal issues, safety and security concerns, and the potential impact on employment and social welfare. It is important for researchers, policymakers, and industry representatives to continue to explore these issues and work towards developing mobile robots based on ROS technology that is safe, reliable, and beneficial for society.

2.1.2 WHY RELEVANT?

Mobile robots based on ROS technology have become increasingly important in many different industries due to their numerous advantages. For example, they can significantly improve efficiency, reduce costs, and enhance safety. Understanding the latest trends and developments in mobile robots based on ROS technology is crucial for researchers, policymakers, and industry representatives.

2.2 MAIN DATA

The main data used in this report are as follows:

- Overview of ROS-based mobile robots develop
- Trends in ROS-based mobile robotics development
- Examples of applications of ROS-based mobile robots

2.2.1 CONTEXT AND PRESENTATION

The main data presented in this report provide an overview of the latest trends and developments in mobile robots based on ROS technology, as well as their applications in different industries. The data is presented in a clear and concise manner, using tables and figures where appropriate to enhance the presentation.

The main data used in this report are as follows:
ROS-Industrial Consortium Europe. (n.d.). The ROS-Industrial Consortium Europe is a consortium of industry, research, and academic institutions that promotes the use of ROS in industrial applications. They provide training and support for companies interested in developing ROS-based mobile robots for industrial use.

ROS Robotics Companies. ROS Robotics Companies provides a list of companies that use ROS in their products and services.

ROS-Industrial for Real-World Solutions. ROS-Industrial for Real-World Solutions is a program that aims to promote the use of ROS in real-world industrial applications. It provides support for companies interested in using ROS for industrial automation, including software development, training, and consulting.

ROS (Robot Operating System). ROS is an open-source software framework for developing robotics applications. It provides a comprehensive set of tools and libraries for developing mobile robots, including navigation, mapping, and localization algorithms.

EU project: OFERA - micro-ROS. The EU project OFERA (Open Framework for Embedded Robotics Applications) is a project that aims to develop a new generation of embedded robotic systems that are modular, adaptable, and scalable. One of the project's goals is to develop a micro-ROS platform for embedded systems.

"ROS-Based Unmanned Mobile Robot Platform for Agriculture". The paper presents a mobile robot platform based on ROS for agricultural applications. The platform is designed to perform tasks such as crop monitoring, harvesting, and spraying, and it has the potential to improve crop yields and reduce the use of pesticides, fertilizers, and water.

"Substantial capabilities of robotics in enhancing industry". The paper reviews the capabilities of robotics in enhancing industry, including mobile robots based on ROS technology. The paper highlights the potential of mobile robots based on ROS technology to improve efficiency, productivity, and safety in various industries.

"Towards next generation digital twin in robotics: Trends". The paper presents the latest trends in digital twin technologies for robotics, including mobile robots based on ROS technology. The paper highlights the potential of digital twins to improve the performance and reliability of mobile robots based on ROS technology.

"A review of mobile robots: Concepts, methods, theoretical". The paper provides a comprehensive review of mobile robots, including mobile robots based on ROS technology. The paper covers the concepts, methods, theoretical approaches, and future directions of mobile robots. [12345]

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[1] Statista. (2021). Autonomous robots - Market size in Europe 2020-2025. Retrieved from https://www.statista.com/statistics/1285864/autonomous-robots-market-size-europe/

[2] ResearchAndMarkets. (2020). Europe Autonomous Mobile Robot Market to 2026. Retrieved from https://www.researchandmarkets.com/reports/4901715/europe-autonomous-mobile-robot-amr-market-2020

[3] ROS Wiki. (n.d.). Courses. Retrieved from http://wiki.ros.org/Courses

[4] The European Commission's Digital Skills and Jobs Platform. (n.d.). Hello (Real) World with ROS - Robot Operating System. Retrieved from https://digital-skills-jobs.europa.eu/en/opportunities/training/hello-real-world-ros-robot-operating-system

[5] NobleProg. (n.d.). ROS Training Courses in Germany. Retrieved from https://www.nobleprog.de/en/ros-training

2.2.2 CONTEXT AND PRESENTATION

The main data presented in this report provide an overview of the latest trends and developments in mobile robots based on ROS technology, as well as their applications in different industries. The data is presented in a clear and concise manner, using tables and figures where appropriate to enhance the presentation.

2.2.3 SUMMARY AND SYNTHESIS

The data presented in this report highlight the importance of mobile robots based on ROS technology as a powerful and flexible platform for developing autonomous vehicles. Recent trends and developments in ROS-based mobile robotics have focused on improving their performance and reliability using techniques such as digital twins and deep learning. Mobile robots based on ROS technology have many different applications, ranging from inspection and surveillance to transportation and maintenance, and they have the potential to revolutionize these industries by improving efficiency, productivity, and safety. However, there are also potential limitations and challenges that need to be considered, such as ethical and legal issues, safety and security concerns, and the potential impact on employment and social welfare. It is important for researchers, policymakers, and industry representatives to continue to explore these issues and work towards developing mobile robots based on ROS technology that is safe, reliable, and beneficial for society.

2.3 DATA ANALYSIS

The data analysis presented in this report aims to provide a comprehensive overview of the latest trends and developments in mobile robots based on ROS technology.

2.3.1 INTRODUCTION

Mobile robots based on the Robot Operating System (ROS) technology have become increasingly popular and are now the preferred platform for developing autonomous vehicles. ROS provides a comprehensive set of tools and libraries for developing mobile robots, including navigation, mapping, and localization algorithms.

With the increasing demand for automation in various industries, mobile robots based on ROS technology have become increasingly important, as they can perform a wide range of tasks autonomously, such as inspection, surveillance, transportation, and maintenance. They have the potential to revolutionize these industries by improving efficiency, productivity, and safety.

The objective of this report is to provide a comprehensive overview of the latest trends and developments in mobile robots based on ROS technology as well as explore the trends, challenges, and opportunities of mobile robots based on ROS technology in advanced manufacturing. We will also identify the skills and competencies required for VETs and learners to integrate these robots into their operations.

2.3.2 CONTEXTUALISATION

Mobile robots based on ROS technology are becoming increasingly important in many different industries, as they can perform a wide range of tasks autonomously, such as AM, inspection, surveillance, transportation, and maintenance. ROS provides a comprehensive set of tools and libraries for developing mobile robots, including navigation, mapping, and localization algorithms. In advanced manufacturing, these robots are used to perform tasks that are dangerous, repetitive, or require precision. The integration of mobile robots based on ROS technology in advanced manufacturing can lead to significant improvements in efficiency, productivity, and safety.

The development of mobile robots based on ROS technology in advanced manufacturing covers various fields, including F1: Trends, F2: Impact on Jobs, F3: Skills & Qualif, and F4: Future Skills. The geographical scope of this report will focus mainly on European countries.

2.3.3 OBJECTIVES / RESEARCH QUESTION / PROBLEM STATEMENT:

Objectives

The objectives of this sub-report are:

- To understand the current and future trends of mobile robots based on ROS technology in advanced manufacturing. We will also identify the challenges and opportunities that these robots present to VETs, learners, and companies.
- To highlight the applications of mobile robots based on ROS technology.

- To analyse the potential benefits and limitations of mobile robots based on ROS technology

Research question

What are the trends, challenges, and opportunities of mobile robots based on ROS technology in advanced manufacturing, and what are the skills and competencies required for their integration?

Problem statement

Mobile robots based on ROS technology have the potential to revolutionize the manufacturing industry, but there are challenges and opportunities associated with using this technology. This report aims to analyse the current state of ROS technology in the manufacturing industry, identify the challenges and opportunities, and explore the future directions of ROS technology in the manufacturing industry.

2.3.4 FINDINGS

Mobile robots based on ROS (Robot Operating System) technology are transforming the field of advanced manufacturing. Integrating mobile robots based on ROS technology into advanced manufacturing operations requires specific skills and competencies, such as programming, data analysis, and maintenance[6]. Vocational Education and Training (VET) and learners need to develop these skills and competencies to integrate and maintain these robots.

Companies that employ mobile robots must provide their employees with training and resources to ensure they have the necessary knowledge and skills to work with ROS-based robots[7].

Mobile robots based on ROS technology offer several advantages in advanced manufacturing, including increased efficiency, accuracy, and safety[8]. They can perform hazardous or strenuous tasks that are challenging or dangerous for humans, such as working in hazardous environments or carrying heavy loads, and can operate 24/7 without fatigue or errors, which improves productivity.[9]

Advantages of Mobile Robots Based on ROS

Mobile robots based on ROS technology have been recognized for their positive impact on manufacturing. According to a report from the International Journal of Advanced Robotic

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[6] Markus D. Kobelrausch et al., « Skill Acquisition for Resource-Constrained Mobile Robots through Continuous Exploration », in *Cognitive Robotics and Adaptive Behaviors* (IntechOpen, 2022), https://doi.org/10.5772/intechopen.104996.

[7] Alex Owen-Hill, « 10 Essential Skills That All Good Roboticists Should Have », 2020, https://blog.robotiq.com/10-essential-skills-that-all-good-roboticists-have.

[8] Jeff Kerns, « 3 Trends in Mobile Industrial Robotics », Machine Design, octobre 2019, https://www.machinedesign.com/automation-iiot/article/21838201/3-trends-in-mobile-industrial-robotics.

[9] « ROS-Industrial », ROS-Industrial, 10 mai 2023, https://rosindustrial.org.

Systems, ROS-based mobile robots have been shown to improve productivity, reduce errors, and increase safety in manufacturing operations (Saha, Chowdhury, and Mamun, 2019). They can perform tasks more quickly and accurately than humans, leading to increased efficiency in the manufacturing process. These robots can be programmed to perform tasks with a high level of precision, reducing errors and improving product quality. They can also work around the clock without fatigue or errors, increasing efficiency and productivity.

Mobile robots based on ROS technology offer several advantages in advanced manufacturing, including improved efficiency, accuracy, and safety (ros.org, 2021). They can be used to perform tasks that are dangerous or difficult for humans, such as working in hazardous environments or carrying heavy loads, reducing the risk of accidents or injuries. Furthermore, according to a study by the Robotics Industries Association, the use of mobile robots in manufacturing can lead to significant improvements in efficiency and cost savings (Robotics Industries Association, 2019).

In short, the use of mobile robots based on ROS technology in manufacturing has been shown to have a positive impact on productivity, safety, and cost savings. These robots can perform tasks more quickly and accurately than humans, reducing errors and improving product quality. They can also work around the clock without fatigue or errors, increasing efficiency and productivity.

Mobile robots based on ROS technology offer several advantages in advanced manufacturing, including improved efficiency, accuracy, and safety. These robots can perform tasks more quickly and accurately than humans, leading to increased efficiency in the manufacturing process.

They can be programmed to perform tasks with a high level of precision, reducing errors and improving product quality. Mobile robots based on ROS technology can be used to perform tasks that are dangerous or difficult for humans, such as working in hazardous environments or carrying heavy loads, reducing the risk of accidents or injuries.

Furthermore, these robots can work around the clock without fatigue or errors, increasing efficiency and productivity.[10]

Challenges of Mobile Robots Based on ROS

The integration of mobile robots based on ROS technology into advanced manufacturing presents some challenges.

Companies must provide training and resources to ensure that their employees have the necessary knowledge and skills to work with mobile robots based on ROS technology[11]. The cost of implementing mobile robots based on ROS technology can be high, depending on the complexity of the manufacturing process and the number of robots required.

[10] « ROS-Industrial ».
[11] Owen-Hill, « 10 Essential Skills That All Good Roboticists Should Have ».

Moreover, the integration of mobile robots based on ROS technology into advanced manufacturing could lead to job displacement, as some tasks previously performed by humans could be automated.

In addition, the lack of standardization in mobile robot development and deployment can lead to interoperability issues and hinder their adoption[12].

Opportunities of Mobile Robots Based on ROS

Mobile robots based on ROS technology offer several advantages in advanced manufacturing, including increased efficiency, accuracy, and safety[13].

ROS-Industrial is an open-source project that extends the advanced capabilities of ROS software to industrial-relevant hardware and applications[14]. The ROS-Industrial Consortium provides technical support and training to facilitate the continued adoption of ROS-Industrial by industry.

The integration of mobile robots based on ROS technology into advanced manufacturing operations requires specific skills and competencies, such as programming, data analysis, and maintenance[15]. Companies that employ mobile robots must provide their employees with training and resources to ensure they have the necessary knowledge and skills to work with ROS-based robots[16].

The development of mobile robots based on ROS technology is an active area of research, with new applications and capabilities being developed[17]. The open-source nature of ROS technology allows for collaboration and innovation among developers and researchers, leading to the development of new applications and capabilities for mobile robots.[18] [19] [20]

Skills and Competencies Required

The integration of mobile robots based on ROS technology into advanced manufacturing requires a combination of skills and competencies.

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[12] Murat Koseoglu, Orkan Murat Celik, et Omer Pektas, « Design of an autonomous mobile robot based on ROS », *2017 International Artificial Intelligence and Data Processing Symposium (IDAP)*, septembre 2017, 1-5, https://doi.org/10.1109/IDAP.2017.8090199.
[13] Kerns, « 3 Trends in Mobile Industrial Robotics ».
[14] « ROS-Industrial ».
[15] Kobelrausch et al., « Skill Acquisition for Resource-Constrained Mobile Robots through Continuous Exploration ».
[16] Owen-Hill, « 10 Essential Skills That All Good Roboticists Should Have ».
[17] Luo et al., « Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications ».
[18] « ROS-Industrial ».
[19] « Robots.Ros.Org ».
[20] Luo et al., « Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications ».

ROS-Industrial is an open-source project that extends the advanced capabilities of ROS to manufacturing automation, providing a solid foundation for the integration of mobile robots in advanced manufacturing. Knowledge of ROS and related tools is important as it provides a wide range of tools for common tasks such as motion planning or visualization[21]. Learners can be guided to set up and plan paths and tasks for mobile robots, design Human Machine Interface (HMI), write robot motion programs, and have skills in automated task planning.

Programming is another critical skill required for mobile robot integration, as mobile robots based on ROS technology use a programming language such as C++ or Python to operate. VETs and learners must have a good understanding of these programming languages to integrate and maintain these robots. Data analysis is also essential for mobile robot integration, as these robots generate a large amount of data that needs to be analysed to optimize their performance. VETs and learners must have a good understanding of data analysis techniques to interpret and use this data. Maintenance is a crucial competency required for mobile robot integration, as these robots require regular maintenance to ensure their optimal operation. VETs and learners must have a good understanding of maintenance techniques to keep these robots in good condition.

In addition to technical skills, good communication, problem-solving, and teamwork skills are important for mobile robot integration. Companies must provide training and resources for VETs and learners to develop these skills. To become a good roboticist, a variety of skills are necessary such as programming, mechanical design, electrical engineering, and data analysis. These skills can be developed through formal education, online courses, or on-the-job training. Robotics engineers also need soft skills such as communication, problem-solving, and teamwork skills to collaborate with other team members effectively.

[21] « ROS-Industrial ».

Table 2 : Skills and Competencies Required for the Integration of Mobile Robots Based on ROS Technology in Advanced Manufacturing [22] [23] [24] [25] [26] [27] [28] [29] [30]

Skills	Description
ROS knowledge	A good understanding of ROS technology and related tools is important to integrate mobile robots in advanced manufacturing
Programming	Mobile robots based on ROS technology use a programming language, such as C++ or Python, to operate. VETs and learners must have a good understanding of these programming languages to integrate and maintain these robots.
Data analysis	Data generated by mobile robots needs to be analyzed to optimize their performance. VETs and learners must have a good understanding of data analysis techniques to interpret and use this data.
Maintenance	Mobile robots require regular maintenance to ensure their optimal operation. VETs and learners must have a good understanding of maintenance techniques to keep these robots in good condition.
Communication	Good communication skills are important for effective mobile robot integration.
Problem-solving	Problem-solving skills are important to overcome any issues encountered during mobile robot integration.
Teamwork	Good teamwork skills are important for effective mobile robot integration.
Path and task planning	Learners can be guided to set up and plan paths and tasks for mobile robots in advanced manufacturing.
HMI design	Learners can be guided to design Human Machine Interfaces (HMIs) for mobile robots in advanced manufacturing.
Robot motion programs	Learners can be guided to write robot motion programs for mobile robots in advanced manufacturing.

[22] Kobelrausch et al., « Skill Acquisition for Resource-Constrained Mobile Robots through Continuous Exploration ».
[23] Owen-Hill, « 10 Essential Skills That All Good Roboticists Should Have ».
[24] Kerns, « 3 Trends in Mobile Industrial Robotics ».
[25] « ROS-Industrial ».
[26] Luo et al., « Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications ».
[27] « Top 15 Robotics Engineer Skills », 1 octobre 2020, https://www.zippia.com/robotics-engineer-jobs/skills/.
[28] « ROS-Industrial for Real-World Solutions », Automate, s. d., https://www.automate.org/industry-insights/ros-industrial-for-real-world-solutions.
[29] Lisa Heuss, Clemens Gonnermann, et Gunther Reinhart, « An Extendable Framework for Intelligent and Easily Configurable Skills-Based Industrial Robot Applications », *The International Journal of Advanced Manufacturing Technology* 120, nº 9 (1 juin 2022): 6269-85, https://doi.org/10.1007/s00170-022-09071-w.
[30] « Autonomous Robotics in Advanced Manufacturing | Temasek Polytechnic », s. d., https://www.tp.edu.sg/schools-and-courses/adult-learners/all-courses/skillsfuture-series/autonomous-robotics-in-advanced-manufacturing.html.

Skills	Description
Automated task planning	Learners can have skills in automated task planning for mobile robots in advanced manufacturing.

Current and Future Trends

According to a report by MarketsandMarkets, the adoption of mobile robots based on ROS technology in advanced manufacturing is expected to increase significantly in the coming years.

The ROS-based robot market is projected to grow from USD 1.0 billion in 2020 to USD 3.4 billion by 2026, at a CAGR of 20.6% from 2020 to 2026.

The current trends in mobile robots based on ROS technology in advanced manufacturing are the development of more intelligent and autonomous robots and the development of mobile robots for agriculture.

Researchers are developing modular ROS-based autonomous mobile industrial robot systems for automated intelligent manufacturing applications. They are proposing finite state machine-based methods to integrate and manage various modular functions on mobile robots.

Autonomous Mobile Industrial Robots (AMIR) have been developed with a carefully designed mechanism and a fully modular ROS environment in robotics labs. Robots are designed to collect materials and deliver products from one location to another.

ROS-based unmanned mobile robot platforms are also being developed for agriculture. These robots are designed to perform tasks such as crop monitoring, spraying, and harvesting.

The robots are equipped with sensors and systems that enable them to navigate through the fields and perform their tasks autonomously.

The ROS-based mobile robot system is used to control the robots, and the robots are calibrated using cam-lidar calibration. The robots are also equipped with a virtual private network that enables them to communicate with each other and with the central control system.[31] [32] [33] [34]

The future trends in mobile robots based on ROS technology in advanced manufacturing are expected to include the increasing use of mobile robots, the integration of mobile robots with

[31] Luo et al., « Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications ».
[32] Eu-Tteum Baek et Dae-Yeong Im, « ROS-Based Unmanned Mobile Robot Platform for Agriculture », *Applied Sciences* 12, nº 9 (janvier 2022): 4335, https://doi.org/10.3390/app12094335.
[33] « Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications | 2020 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM) », s. d., https://dl.acm.org/doi/abs/10.1109/AIM43001.2020.9158800.
[34] Luo et al., « Modular ROS Based Autonomous Mobile Industrial Robot System for Automated Intelligent Manufacturing Applications ».

other technologies, the development of new applications and use cases for mobile robots, and the development of swarm robotics.

The adoption of mobile robots based on ROS technology in advanced manufacturing is expected to increase significantly in the coming years.

The integration of mobile robots based on ROS technology with other technologies, such as blockchain and edge computing, could lead to more efficient and flexible manufacturing processes.

The adoption of mobile robots based on ROS technology could lead to the development of new applications and use cases in advanced manufacturing, such as logistics, warehouse management, and quality control.

The integration of mobile robots based on ROS technology with swarm robotics could lead to the development of new applications in advanced manufacturing, such as decentralized manufacturing and collaborative assembly.

The ROS-Industrial project is an open-source initiative that extends the advanced capabilities of ROS software to industrial-relevant hardware and applications.

The project aims to accelerate the development of ROS-Industrial by managing a roadmap to identify and prioritize ROS-Industrial capabilities for industrial robotics and automation, instituting and enforcing code quality standards appropriate for an industrial software product, and providing a wide range of user services, including technical support and training, to facilitate the continued adoption of ROS-Industrial by industry.[35] [36] [37] [38]

Table 3 : ROS-based Robot Market Size and Growth Forecast (2023-2030)

Year	Market Size (USD billion)	CAGR
2023	0.44	9.2%
2024	0.48	9.2%
2025	0.53	9.2%
2026	0.58	9.2%
2027	0.63	9.2%
2028	0.69	9.2%
2029	0.75	9.2%
2030	0.81	9.2%

Source: Robot Operating System (ROS) Market Is Expected To Reach around USD 0.7 Billion by 2030, Grow at a CAGR Of 9.2% during Forecast Period 2023 To 2030 - Data By Contrive Datum Insights Pvt. Ltd.

[35] Ricardo Tellez, « Top 10 ROS-Based Robotics Companies to Know in 2019 », The Robot Report, 22 juillet 2019, https://www.therobotreport.com/top-10-ros-based-robotics-companies-2019/.
[36] « ROS-Industrial ».
[37] « Robots.Ros.Org ».
[38] Peng Guo et al., « An ROS Architecture for Autonomous Mobile Robots with UCAR Platforms in Smart Restaurants », *Machines* 10, nº 10 (octobre 2022): 844, https://doi.org/10.3390/machines10100844.

Table 4 : Autonomous Robots Market Size in Europe (2019-2023)

Year	Market Size (USD million)
2019	455.9
2020	498.2
2021	549.6
2022	603.2
2023	657.8

Source: Statista - Autonomous robots market size in Europe from 2019 to 2023 (in million U.S. dollars)

3. CONCLUSION

In conclusion, mobile robots based on ROS technology are a rapidly growing field with a wide range of applications. The open-source nature of ROS has enabled researchers and developers to collaborate and build upon each other's work, resulting in the development of many innovative robotics applications. The use of ROS-based mobile robots has the potential to improve safety, efficiency, and productivity in many industries, including manufacturing, healthcare, agriculture, and service industries. As the technology continues to advance, we can expect to see even more exciting developments in the field of mobile robotics based on ROS. However, there are also potential limitations and challenges that need to be considered, such as ethical and legal issues, safety and security concerns, and the potential impact on employment and social welfare. It is important for researchers, policymakers, and industry representatives to continue to explore these issues and work towards developing mobile robots based on ROS technology that are safe, reliable, and beneficial for society.

To realize the full potential of mobile robots based on ROS technology, VETs, learners, and companies need to develop the necessary skills and competencies to integrate and maintain these robots. The creation of new jobs that require skills and competencies related to mobile robot integration, programming, and maintenance is also an opportunity for VETs and learners. CoVEs can play a crucial role in the development of these skills and competencies. By providing focused training and resources, CoVEs can help VETs and learners integrate mobile robots based on ROS technology into their operations. Additionally, CoVEs can work with companies to develop customized training programs that address the specific needs of their operations.

Standardization efforts in mobile robot development and deployment can help overcome interoperability issues and accelerate the adoption of mobile robots based on ROS technology in advanced manufacturing. While there are some challenges associated with using ROS, its many advantages make it an essential tool for researchers and developers working in the field of robotics. The adoption of mobile robots based on ROS technology has the potential to create new job opportunities, but it also requires workers to acquire new skills and qualifications to remain competitive in the job market.

In conclusion, mobile robots based on ROS technology have become an increasingly important area of research and development in many different industries. Understanding the latest trends and developments in mobile robots based on ROS technology is crucial for researchers, policymakers, and industry representatives alike. Researchers, policymakers, and industry representatives must continue to explore issues such as ethical and legal concerns, safety and security concerns, and the potential impact on employment and social welfare. By addressing these issues and developing mobile robots based on ROS technology that is safe, reliable, and beneficial for society, we can harness the full potential of mobile robots based on ROS technology to improve safety, efficiency, and productivity in many industries.

Statements

- The demand for mobile robots based on ROS technology is increasing across various industries, due to their numerous advantages, such as increased efficiency, accuracy, and safety.
- The development of mobile robots based on ROS technology is an active area of research, with new applications and capabilities being developed, driven by the need for advanced automation in manufacturing, healthcare, and logistics.

- The lack of standardization in mobile robot development and deployment can lead to interoperability issues and hinder their adoption, which highlights the need for collaboration and cooperation among researchers, policymakers, and industry representatives.
- The integration of mobile robots based on ROS technology into advanced manufacturing presents both challenges and opportunities, such as job displacement, cost of implementation, and the need for specific skills and competencies, which need to be addressed by VETs and learners, policymakers, and industry representatives.
- CoVEs can play a crucial role in developing the necessary skills and competencies to integrate and maintain mobile robots based on ROS technology. By providing focused training and resources, CoVEs can help VETs and learners integrate mobile robots based on ROS technology into their operations and work with companies to develop customized training programs.

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5. INDEX OF TABLES

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