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Harmony
Assistive robots for healthcare

# Enhancing Healthcare with Assistive Robotic Mobile Manipulation

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# 1. Introduction

The HARMONY project is a groundbreaking initiative aimed at advancing autonomous mobile manipulation technology for human-centred environments. This report encapsulates the extensive work and collaboration among the various partners involved in the project, including six academic institutions, a leading European robot manufacturer, a small-to-medium enterprise (SME), and two end-user organisations. The consortium's objective is to develop robust, flexible, and safe robotic solutions tailored for real-world applications in hospital settings.

HARMONY's vision is to revolutionise the automation of on-demand delivery tasks and bioassay sample flows within hospital environments. The project focuses on creating mobile robots that can seamlessly navigate and interact within these settings, addressing the limitations of current automation systems that often operate in isolation and lack flexibility. By integrating advanced mobile manipulation capabilities, the project aims to relieve overqualified staff from mundane and repetitive tasks, thereby optimising operational efficiency and enhancing the quality of healthcare services.

The project's methodology involves leveraging the strengths of each consortium partner. Academic partners contribute cutting-edge research in robotics, covering areas such as perception, localization, navigation, manipulation, and human-robot interaction. Industrial partners bring practical insights and experience in developing and deploying robotic solutions. The end-users provide critical feedback based on real-world needs and usability, ensuring that the developed solutions are practical and beneficial in operational settings.

The HARMONY project employs two primary robotic platforms provided by ABB and IDM. These platforms are used to explore and address the challenges associated with mobile manipulation in dynamic and unstructured environments. By focusing on ABB's dual-arm YuMi robot and IDM's customizable Harmony robot, the project combines high-precision manipulation capabilities with intuitive human-robot interaction features, making these robots suitable for complex tasks in hospital environments.

The expected outcomes of the HARMONY project are multifaceted. The project aims to deliver integrated robotic solutions and transferable components that can be utilised in various applications beyond the initial scope. These outcomes include advances in object pose estimation, motion planning, multi-robot task assignment, and immersive multimodal interfaces. Additionally, the project seeks to develop a robust and customizable robotic platform for indoor healthcare environments, providing a ready-to-market product for research and development purposes.

The exploitation of these results is planned through both individual partner efforts and collaborative initiatives. Academic partners will continue to build on the research outcomes, while industrial partners will integrate the findings into their products and services, fostering new business opportunities. The end-users, primarily hospitals, will benefit from enhanced robotic solutions that improve operational efficiency and patient care.

# 2. Harmony Exploitation Context

## 2.1. Market Opportunity

The market opportunities for a healthcare service robot are significant, as the healthcare industry faces several challenges that can be addressed by robotics:

1. **Ageing population**. As the global population ages, there is an increasing demand for healthcare services. This trend is particularly pronounced in developed countries, where the elderly population is growing faster than the general population. Healthcare service robots can help to alleviate the burden on healthcare providers by assisting with tasks such as on-demand deliveries, process automation, and monitoring.
2. **Shortage of healthcare workers**. Many countries currently face a shortage of healthcare workers. Healthcare service robots can help fill this gap by performing repetitive tasks, freeing up healthcare workers to focus on patient care and more complex tasks.
3. **COVID-19 pandemic**. The COVID-19 pandemic has highlighted the need for technologies that can reduce the risk of infection transmission. Service robots can help minimise human-to-human contact while maintaining some of the workflows.
4. **Technological advancements**. Recent advancements in robotics and artificial intelligence have made it possible to expand the range of tasks that can be performed and problems that can be solved by robots, within a healthcare setting.
5. **Cost savings**. Service robots can provide cost savings for healthcare providers by automating certain tasks that are repetitive and physically demanding for the staff, optimising the workflow, and improving efficiency. In addition, robots can help reduce the risk of errors, increase staff job satisfaction, and thus improve patient outcomes, leading to further cost savings in the long run.

## 2.2. Value Proposition

The vision of Harmony is to enable robust, flexible, and safe autonomous mobile manipulation technology for use in human-centred environments.

The project development targets two use cases: 1) the automation of on-demand delivery tasks around the hospital, and 2) the automation of bioassay sample flow. These use cases highlight existing processes where there is a need for fast, reliable, and flexible automation that offers mobility and object interaction in human spaces to undertake the dull and repetitive tasks that are currently performed by overqualified staff. While existing systems can automate parts of these processes, e.g. specialised bioassay machines, they form “islands of automation” that are limited in scope, rigid to changing demands, and still rely on staff to manually distribute goods and samples across the “islands”. Mobile manipulation technology is a suitable solution to this problem since it bridges these gaps while maintaining a high degree of flexibility to adjust to varying service demands and adapt to different user requirements and preferences.

A mobile manipulation robot that can be applied to a variety of use cases demands a degree of flexibility that is currently beyond the state of the art. The goal of Harmony is to develop a system that is capable of acting across a wide operational spectrum, from the (sub)millimetre precision required for fine object manipulation to autonomously navigating safely across building- and campus-scale human-populated spaces.

Given the different levels of sophistication of the research involved in the project, it is expected that an important part of the project's impact will be translated into long-term exploitable products or services. Nevertheless, it is also expected that subsets of the methods developed in Harmony can be, in the short-term, integrated into exploitable products or services. The following section summarises the main expected outcomes, with the potential of exploitation, at an academic or commercial level.

## 2.3. Experience and Synergies

The Harmony Consortium is formed by the following partners:

- Six academic partners with strong expertise in different fields of Robotics that cover the main scientific challenges of the project: perception, localization and mapping, navigation, planning, scheduling, manipulation, grasping and whole-body control, and human-robot interaction (ETHZ, BONN, TUD, UT, UEDIN, CREATE).
- A leading European robot manufacturer with a long track record in developing and bringing industrial-grade robots to the market (ABB).
- An SME experienced in developing custom solutions and bringing innovation to the market (IDM).
- Two hospitals (end users), that provide input based on their expertise on the market needs and usability of the developed solutions (KUH, USZ).

Because of the complexity of the scenarios and the general requirements of the project regarding human-robot interaction, the collaboration between the partners had different dynamics during the project. The existence of two different platforms, one provided by ABB and one provided by IDM, allowed for development and exploration, but also to identify the challenges that were being faced and the limitations regarding the implementation of technology.

At a certain point, it made sense that the partners working on manipulation and mobility, focused their efforts on ABB’s dual-arm YuMi, as it responds better to the manipulation requirements of the project. Since it is a robotic platform used for research, it has some limitations regarding HRI, but it is a great base for the development of capabilities and functionality that in the future can be extrapolated to the IDM Harmony robot, as it has the same hardware and sensors.

The IDM Harmony robot was designed with implementation as a goal, targeting a balance between functionality and HRI. Although it has a mobile platform and the same hardware and sensors as the ABB platform, it only has a single robotic arm, for simpler manipulation tasks, limiting the manipulation functionalities. On the other hand, its physical appearance, social behaviour, communication capabilities, and interface maximises its potential for acceptance from the users and a natural integration in an hospital environment. This work has been developed closely between IDM and UT, always considering the end-user partners feedback, and in the future can be applied to the ABB platform.

## 2.4. Expected Exploitable Outcomes

This section describes the project's main outcomes to be exploited by the Harmony partners. These outcomes are the result of work undertaken individually or in partnership during the project duration. Two main routes should be used for the exploitation of results:

- Components (software modules and knowledge) transferable to other applications. This can be done on an individual basis by each of the partners.
- Integrated robotic solutions. This should be seen as long-term exploitation as it will involve extra engineering efforts and finding appropriate stakeholders with commercial backgrounds in the field (and investors).

Based on these two main routes, the exploitable outcomes identified by the different project partners are presented below.

**ETHZ**

- **Object pose estimation.** Efficiently estimating the pose of known objects is a key requirement for tasks such as manipulation and path planning. A challenge lies in acquiring the necessary object models for these processes. ETH developed a method utilising recent learning-based object reconstruction methods to obtain object models in a time-efficient manner.
- **Object database.** A service robot will encounter various objects while performing its tasks. Rather than modelling these from scratch each time we want to give the robot a memory, or database, of objects it has seen that can be updated over time.
- **Object affordances.** Knowing what an object looks like, and estimating its pose are only the bare minimum of information one can have about objects. Many other properties relating to the functionality of objects or their relationships with each other are of interest when manipulating them. To this end, we develop learning

methods to predict how one can open and close objects or how pairs of objects interact. This information will be integrated into the object database to build a complete picture of known objects.

**TUD**

- Motion planning method and software for the base to navigate in human-populated environments.
- Online multi-robot task assignment method and software.
- Tools for multi-objective fleet design.

**UEDIN**

- Immersive multimodal interface for demonstrating in-situ operations.
- Metrics for 3D Object Pointing and Manipulation.
- An open-source ROS-PyBullet interface for reliable contact simulation.
- Design, modelling, and control of an extensible flexible finger for robotic manipulation.
- Data-efficient non-parametric modelling and control of an extensible soft manipulator based on Neural-ODE.
- An open-source optimization-based task specification (OpTas) library for task and motion planning.
- Developing a framework for learning fine pinch grasp from a demonstration.
- A novel formulation of a Behaviour Cloning network that uses tactile information and the robot’s proprioceptive data to learn contact-aware bimanual grasping skills from few-shot demonstrations.
- A formulation of convolutional AutoEncoder network which extracts representative contact features in the low-dimensional latent space and reconstructs the tactile images using the encoded latent vector with small reconstruction loss.

**UT**

- A Novel design for adaptive robot appearance that can be used for communicative purposes.
- Robot communicative behaviour designs to resolve interaction in hospital hallways.

**BONN**

- **Object-based localisation.** The plan is to further investigate the developed object-based localisation in the context of semi-static changes, i.e., objects (e.g., tables, chairs, etc.) stay in the environment but change their location, where not only 3D object detectors are used but also integrate novel view synthesis models for generating object appearances for objective re-identification.
- **Autonomous model acquisition.** A key task in surveying is the generation of so-called building information models (BIM), which provide a full 3D model of a building often referred to as a digital twin. Acquiring, maintaining, and updating a BIM is a labour-intensive task and is often performed by domain experts. The developments in Harmony could provide a starting point to investigate the usage of the developed autonomous model acquisition to bootstrap the generation of a BIM.
- **Change detection and map update.** The developed solution for change detection can identify persistent, added, and removed objects, but these changes are currently not exploited to experimentally verify the effectiveness in terms of localization performance. Therefore, the plan is to thoroughly evaluate the localization performance in environments with larger structural changes.

**USZ**

The exploitation of the Harmony outcomes involves a distinct approach compared to that of our research partners. For end-users, it is crucial to consider all the components as a cohesive whole. Our outcome is the newly gained knowledge and expertise we can use to support the exploitation regarding the usability and opportunities of the developed solutions and translate them into market needs.

**ABB**

The exploitation of HARMONY results is at present an ongoing discussion within ABB. ABB's "own" scientific results in the project are focused on whole-body motion control. For this part, it is already decided that ABB will continue its research after the HARMONY project ends, to increase technical readiness level and thereby prepare to be part of a future product. The productization of whole-body motion technology is however dependent on a decision to create a mobile manipulator product that has a unified controller architecture for both mobility and the articulated arm. Concerning this, it can also be noted that ABB is currently developing a research robot platform "proof-of-concept" mobile GoFa with a unified real-time controller, which is very suitable for whole-body impedance control research.

Another major ABB activity in HARMONY is the system integration of partner technology and deployment of these into the mobile YuMi research platform. The opportunity to work closely with competent partners in the integration process has led to ABB now considering productizing an improved and generic SW-interface to ABB robots for researchers as well as commercial partners that can extend ABB robot capabilities.

Regarding commercial exploitation of partner results, there is a need for further discussions both within ABB (e.g. TRL) and with partners. It is clear to ABB that to be able to deploy mobile robots in existing "brown-field" hospital labs and analysis labs in general, all aspects of the robot capabilities addressed within HARMONY must be improved compared to today's state-of-art, so in that sense, the technologies are attractive to ABB.

**IDM**

- **Customizable robot platform**. A robust and customisable robotic platform for indoor healthcare environments. The stand-alone Harmony IDM platform is a ready-to-market product that IDM can sell for R&D purposes. The platform includes ROS2 drivers. This result can begin to be explored in the short term.
- **Customizable service robot for a specific scenario**. IDM will offer an integrated solution, including the robot platform and software packages, customised to perform a specific service related to the Harmony use case scenarios. This result is expected to begin to be explored in the medium term. Nevertheless, the company will look for opportunities to start some pilot experiments in the short term, which will serve as input for the full exploitation of this solution.
- **Robot platform for third-party integrators**. Harmony IDM platform is provided to third-party integrators, based on a Business to Business (B2B) model, where the target clients will be companies developing service robotics applications. The platform must be provided with software packages for easy deployment and configuration of the mission. This result is expected to begin to be explored in the medium term.

# 3. Individual Exploitation Strategies

The projected plans for the exploitation of the outcomes are now presented. The two main strategies preferred by the partners are naturally dependent on their nature: academic partners will look to capitalise on the knowledge acquired during the project activities by developing further research in their respective fields of expertise; the industrial partners intend to integrate Harmony results enhancing their product and services, and/or to develop new business opportunities based on the project concept.

As agreed by the project consortium, the Intellectual Property Rights (IPR) of the foreground developed within the project belong to the partners that took part in its development. Therefore, before the start of the exploitation of the results, it is important to clarify which partner owns the right over which exploitable result.

## 3.1. Individual Exploitation Plans

This section presents the efforts and plans adopted by the Harmony partners for the exploitation of the project results.

### 3.1.1. ETHZ

We are in the process of open-sourcing the research outcomes to allow the research community to benefit from the work. We also utilise the components as part of other research and in showcases for the general public during visits and showcases that happen regularly at ETH.

### 3.1.2. TUD

We are in the process of open-sourcing the research outcomes to allow the research community to benefit from the work. We also utilise the components as part of other research and in showcases for the general public during visits and showcases that happen regularly at TU Delft. Follow up research projects, e.g., ERC Starting Grant "Intuitive Interaction for Robots among Humans (INTERACT)".

### 3.1.3. UEDIN

We are currently deploying the open-source libraries developed in the context of the Harmony project, namely the ROS-Pybullet interface for reliable contact simulation within the ROS framework and the OpTaS library for task and motion planning, on a **Joint Industrial Project** (JIP) between **Kawada Robotics** and The University of Edinburgh.

The project aim is to develop enhanced, robust capabilities on the Nextage Research Platform, such as enabling robust non-prehensile force interactions and manipulation under varying conditions, with the vision of developing the next generation of robots for reconfigurable factories, i.e. production lines that change frequently due to new batches of products requiring increased flexibility and autonomy.

Additionally, we are currently exploring the further improvement of the whole-body planning methods developed for the Harmony’s manipulation hospital scenarios in a follow-up project that aims to enable long-term horizon robotic tasks in the context of household environments.

Finally, we also used, and are planning to keep using, the robotic demos developed in the context of Harmony for educational purposes, such as the Edinburgh Science Festival, where we opened our laboratory to the general public to showcase some of the cutting-edge research platforms to inform and engage the visitors about the best ways to deliver human-centric assistance and effective human-robot collaboration.

### 3.1.4. UT

We aim to show the robot's adaptive appearance to the general public and healthcare professionals. For instance, through a television program, or at dissemination events for healthcare professionals. The robot's behaviours will be disseminated primarily through publications.

### 3.1.5. BONN

For the quantitative evaluation of the localization performance, i.e., generation of ground truth poses, we augmented our offices with AprilTags that can be seen from an upward-facing camera on our Dingo platform. This sensor setup was already exploited for our scientific publications and allowed us to provide dense ground truth poses over the whole environment and compute pose errors over the full trajectory. We plan to exploit this ground truth system and our robotic platform to provide a benchmark dataset for evaluating localization performance.

Using the ground truth pose, we are currently investigating the usage of novel view synthesis approaches for localisation to further exploit the Harmony multi-sensor setup on our Dingo platform for localization. The availability of camera information together with the 2D LiDAR sensors will be further exploited to extend the research in object-based localisation.

Lastly, most of our work in Harmony has been already published as open-source implementation on our GitHub repository, and we will continue our efforts to provide code for our developed approaches. We plan to further exploit the developments in Harmony to drive our future research on indoor localisation and mapping.

### 3.1.6. USZ

We intend to use the integrated Harmony outcomes to enhance our services. The newly acquired integrated robot solutions will assist us in analysing and creating new business opportunities in our hospital, contributing to the advancement of healthcare and promoting robot solutions in the healthcare environment. Therefore, we offer a real hospital environment for the project to test the robot's functionality to achieve the defined objectives. Furthermore, we will use the results of the different validation studies conducted by UT to define the robot's communication behaviours — how the robot should behave in a healthcare environment. In other words, which communication behaviours are perceived as understandable and successful for the hospital environment, including navigation behaviours and interaction behaviours with the staff, patients, and visitors.

### 3.1.7. ABB

The participation in HARMONY gives ABB a unique opportunity to have first-hand interaction and collaboration with academia and operative units (solution end-users) within Hospital labs. This has allowed ABB to gain in-depth knowledge of hospital lab automation opportunities and requirements, which also extend far beyond the selected specific HARMONY use-cases. Also, the first-hand insight of "technologies that enable lab automation and experience their TRL-level is considered very valuable for ABB. This knowledge will be utilised in ABB's future endeavour to penetrate this emerging market. Through HARMONY ABB has expanded its network within academia and thereby strengthened our position to participate in developing new collaboration projects in future. It is indeed ABB's ambition to initiate discussions to formulate a proposal for coming project calls.

For around two years ABB has had a comprehensive mobile robots product portfolio as a result of an acquisition of ASTI. In addition, Life Sciences & Healthcare is part of ABB's robotics strategy. Indeed, ABB is building a business within this segment and has solutions. Regarding mobile manipulation, ABB occasionally delivers mobile manipulators as part of overall lab automation solution projects. These have currently the character of "engineering-to-order" meaning that a mobile platform is combined with a robotic arm as a two-system robot. The application is then implemented requiring a high level of structure in the environment and robot tasks. A generic solution for mobile manipulation, where a holistic view for both the robot mechatronics system as well as key application technologies should be applied, is currently part of the product portfolio planning discussion. No decision has been made yet.

### 3.1.8. IDM

Every day in healthcare environments there are numerous tasks that require non-specialized human intervention. Figure 3.1 depicts some of these tasks.

Figure 3.1. Examples of daily repetitive tasks in healthcare environments

The rationale behind developing a solution to address this type of task has already been presented. IDM intends to develop a business plan around a robotic solution that can be integrated into daily routines, acting as a co-worker with existing staff. Figure 3.2 summarises our offer taking into account the identified problem.

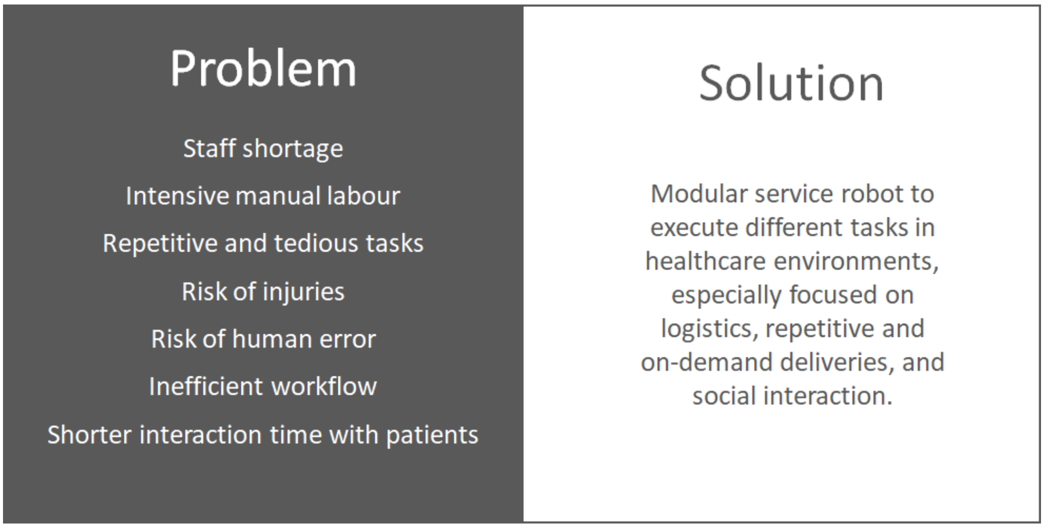


Figure 3.2. Identified problem and proposed solution

**<u>Exploitable product:</u> IDM Harmony Robot**

**The IDM Harmony robot** is modular and customizable to different services. It is based on a mobile platform (omnidirectional or differential), it has the possibility of adding multiple storage spaces, and a single robotic arm. Designed specifically for healthcare environments it can perform different tasks:

- Repetitive and on-demand deliveries of different objects (medication, laboratory samples, boxes, bags, bed sheets, towels, hospital supplies, medical devices, etc).
- Manipulation of small objects with the robotic arm.
- Social interaction.

| | | |
|---|---|---|
| **Robot type** | Locomotion - Omnidirectional or differential |  |
| **Function** | Deliveries, manipulation of small objects, and social interaction | |
| **Dimensions** | 1400 x 600 x 600 mm | |
| **Weight** | ~ 60 kg (differential) or<br>~ 85 kg (omnidirectional) | |
| **Payload** | ~ 80 kg | |
| **Range of velocity** | 0.7 m/s - 1.2 m/s | |
| **Autonomy** | ~ 4 hours (can be increased) | |

Table 3.1. General features of IDM Harmony robot basic configuration

**Product offerings**

The robot was designed in a modular way (see Figure 3.3), customisable with multiple storage spaces, a robotic arm and other adaptations to execute different tasks in healthcare environments.

The soft edges and materials, and the light colours were chosen to translate a friendly and non-threatening image. Light colours are also commonly predominant in a hospital setting, as they are usually associated with a clean and sterile environment, and that was combined with some utility and formal elements for a professional technological appearance.

Regarding HRI the IDM Harmony robot has a touchscreen, positioned on the “head” to be used to display information and input for user’s commands, and to display the robot's emotional states and create connection and relatability with people. It also has LEDs on the “head” and on the platform base, to communicate status and intentions, promoting predictability and legibility, and two speakers to output non-verbal sounds, complementing the communication capability.

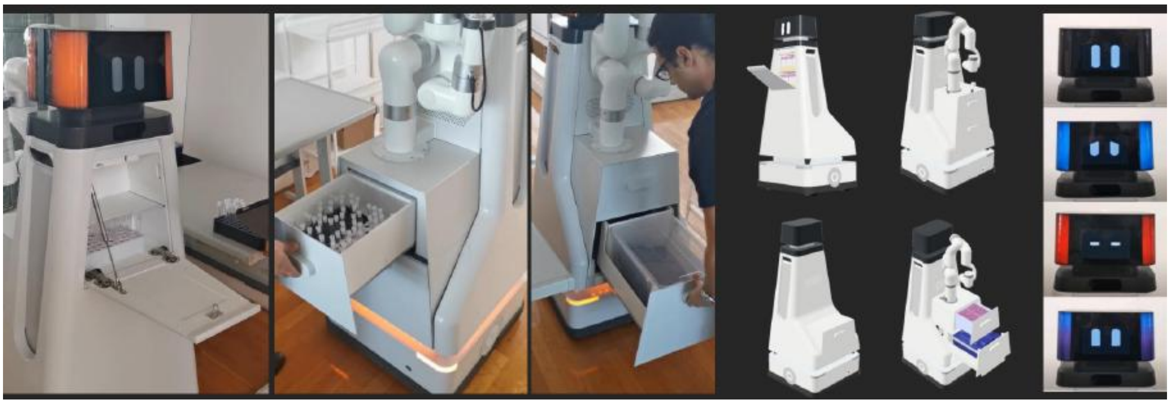

Figure 3.3. Product offerings: modular service robot customisable with multiple storage spaces, a robotic arm and other adaptations to execute different tasks in healthcare environments.

## Technology Overview

Figure 3.4 overviews the main technological features of our solution.

| Mobility | Add-on modules | Sensing and Perception | Human-Robot Interaction |
|---|---|---|---|
| The robot navigates autonomously in hospital environments, safely manoeuvring through crowded hallways, avoiding obstacles, and operating in patient-sensitive areas. | Storage modules adaptable to different load needs, using sensors to maintain specific conditions, insulation, size, or even a robotic arm for unattended pickups. Automatic locks ensure the security of the deliverables. | Advanced sensors, including cameras, depth sensors, and tactile sensors, enable the robots to perceive the environment, detect obstacles, and ensure safe interactions with patients and staff. | User-friendly interfaces and natural language processing capabilities, and the design facilitate the communication with staff and the image perceived by other cohabitants. |

Figure 3.4. Overview of the main technological characteristics of the product.

## Benefits


Automating tasks that would normally require human labour, reducing staff workload and improving the overall speed and efficiency of healthcare operations.

The automation of repetitive tasks allows the redistribution of human resources and time.

The robot can help to increase job satisfaction, and reduce repetition-related injuries and burnout among healthcare staff, freeing up their time, allowing them to focus on patient care and more complex duties.

By automating unspecialised repetitive tasks, healthcare providers can focus more on patient care, leading to better outcomes for patients.

### Business Model Canvas

We present a preliminary approach to IDM's exploitation by mapping out the business on a high level: only the most important, vital aspects of the business model. For this, we follow the map depicted in Figure 3.5.

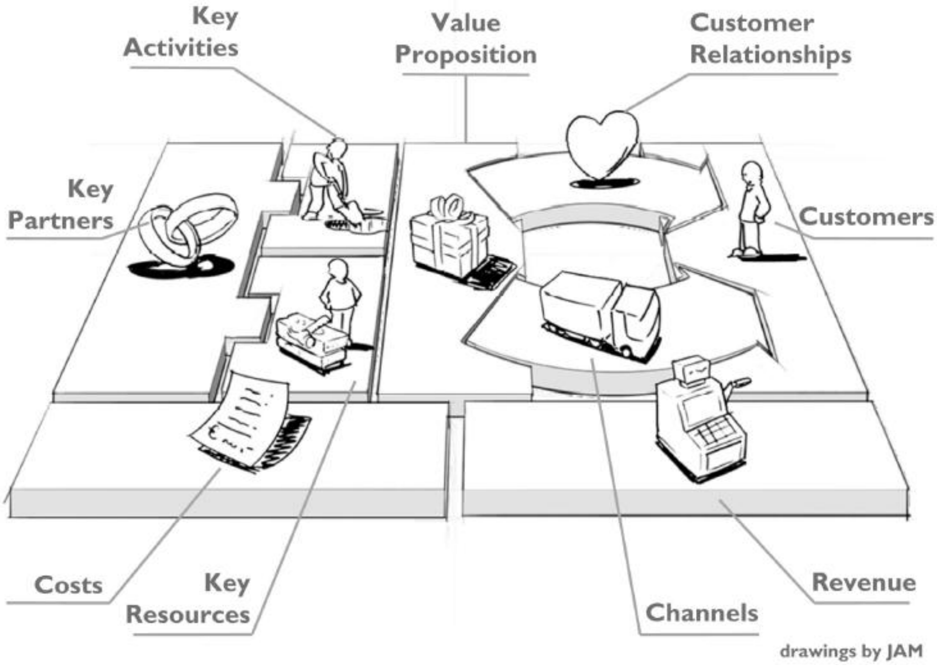


Figure 3.5. Business Model Canvas: nine business model building blocks, Osterwalder, Pigneur & al. 2010

**Value Propositions**

The value propositions of Harmony were introduced in Sections 1 and 2.

**Key Partnerships**

We identify the following key partnerships:

- End users. Harmony is particularly interesting for hospitals and other healthcare environments, where there is a high demand for picking and delivering tasks, currently conducted by over-qualified staff. The end user scenarios hosted by the partners USZ and KUH are representative of the majority of the potential scenarios, and IDM expects to run, in the scope of Harmony, pilot experiments to increase the general perception of the benefits of introducing robotic co-workers to these types of working processes.
- Hardware suppliers. IDM has been producing robot platforms for a long time. The company already has a big chain of local and international suppliers for all the required hardware components.

- Software suppliers. IDM has a team of programmers for most of the required software requirements. The company intends to integrate additional software programmers for this niche of applications.
- Integrators. Robot system integrators should also be part of the key partners. This will allow us to reach more end users.
- Business developers. To support the business strategy, finding new business niches and financial background to consolidate and increase the business.

**Key Activities**

We identify the following activities to develop the prototype and resulting product:

- R&D. The research and developments made in the scope of the Harmony project and future developments to fine-tune the prototype.
- Marketing/sales. The marketing strategy, not covered in this deliverable, is critical to the proper exploitation of the product.
- Certification; standards; safety. The aspects related to certification, standards and safety of the harmony robot are critical for its use in a healthcare environment.
- Design. The design can be an important distinctive factor from potential competitors.

**Key Resources**

We identify the following resources related to the development and improvement of the IDM Harmony robot:

- Funding. The public funding through the Harmony project has been crucial for the development of the prototype. IDM is considering private funding for further development and fine-tuning of the prototype as a product.
- Individual expertise (theoretical knowledge). The previous expertise of IDM has been essential for the prototype development.
- Prototype. IDM managed to have a final prototype within the Harmony development process which can be used in pilot experiments to highlight the potential of the solution.
- Process knowledge. The involvement of the two end-user partners, KUH and USZ, in the definition of the use case scenarios has been critical to guide the development of the solution.

**Cost Structure**

We identify here the costs related to the future commercialization of the product/service. We will not present financial projections in the scope of this deliverable.

- R&D. The costs related to the research and development made in the scope of the Harmony project and future developments to fine-tune the prototype.
- Integration and customization. The costs related to the integration and customization of the solution to specific tasks and environments.
- Certification. Costs related to the certification of the final solution.
- Marketing & sales. Costs related to the marketing and promotion of the solution.
- Salaries. Costs related to all the business structure.
- Support costs. Other costs related to the business support.

**Customer Relationships**

Within Harmony, we identify the following business relations with potential clients:

- Know-how provider/enabler. IDM will be providing know-how to improve the client's business based on the Harmony solution.
- Co-design of solution. In certain cases, the client will provide important information to customise the Harmony robot to operate in specific scenarios.
- Constant improvement/support and maintenance. IDM will maintain continuous contact with their clients because of improvements and maintenance of the Harmony solution. This will also be an important source of revenue.

**Channels**

Preferable ways to reach the customers are summarised below.

- Whisper marketing (word-of-mouth). This is most probably the most effective way of reaching customers, "if it worked for my neighbour, it will work for me".
- Working prototype/demos. Live demonstrations are also a very effective way of getting the attention of potential customers.
- Trade fairs and face-to-face meetings. Face-to-face meetings in the scope of trade fairs are another way of reaching customers.
- Specific events of niche markets. Events attended by professionals of the sector (e.g., management and administrative staff, warehouse operations, etc)

**Revenue Streams**

We identify the following revenue streams which have been already introduced in section 2.4.

- Hardware. Selling the stand-alone robot platform.

- Integrated solutions. Selling or renting integrated solutions, composed of one or more robots, and software packages for the system.
- Services. Providing services based on the Harmony solution. This will probably come from B2B opportunities, where the target clients will be companies developing service robotics applications.
- Maintenance. Providing support and maintenance to Harmony installations.

**Customer Segments**

The two main customer segments are the following:

- Hospitals and other healthcare units. This has been introduced in section 2.

Academia/research. IDM Harmony robot platform is an interesting platform for research purposes.

### Market traction

**Background**. Before the Harmony project, in 2019, IDM had already produced and installed a collaborative robot to carry out the repetitive transport of medications in a healthcare unit in Lisbon. This robot, depicted in Figure 3.6 (left image), has been working on a 24/7 basis ever since. Also in the same year, the company produced and sold a couple of robots with manipulation capacity, for research purposes (Figure 3.6, right image). The company took advantage of this previous experience and its participation in the Harmony project to rethink these types of solutions and design a versatile robot in the face of the most common needs in usage scenarios.

Figure 3.6. Transport of medications in a healthcare unit in Lisbon (left pictures). Research robots with manipulation capabilities (right pictures).

**Pilot Studies**. Within the scope of the HARMONY project, pilot studies were carried out with the project partners KUH Stockholm and USZ Zurich. Also in the hospitals ZGT Almelo and more recently the CUF Tejo Hospital in Lisbon. Besides allowing the solution to be tested in a real environment, these pilots also serve as a showcase for the solution. The IDM Harmony Robot was also the subject of a citizen survey within the Robotics4EU project (Figure 3.7, right picture).

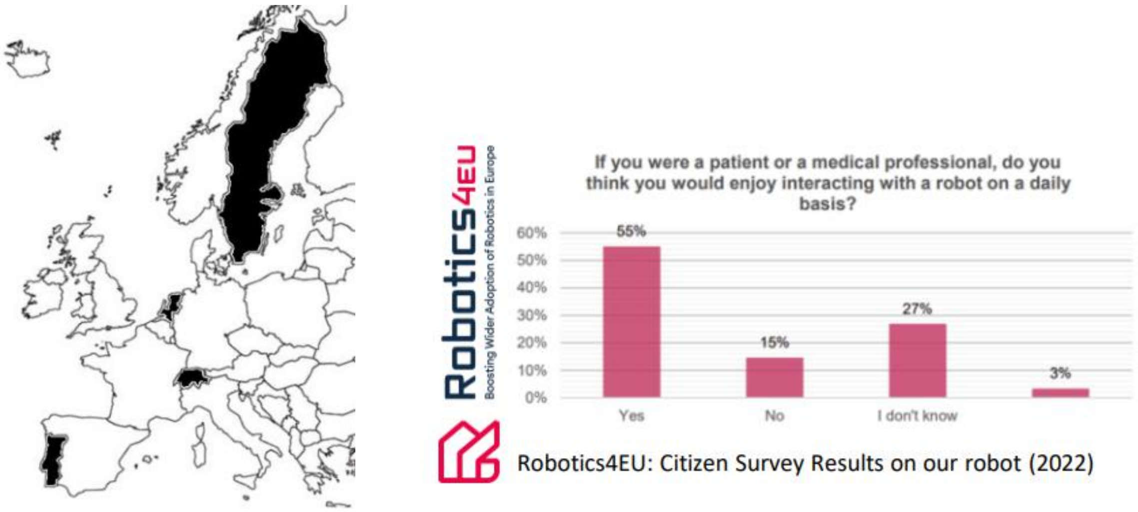


Figure 3.7. Pilot studies in different locations (left picture). Citizen survey results on IDM Harmony Robot (right picture).

**EU Innovation Radar.** IDM has submitted the IDM Harmony Robot innovation to the EU Innovation Radar platform with the following title: ”Customizable robot for different healthcare supporting services”. This innovation has received the following classification:

- Market Maturity: Business Ready
- Market Creation Potential: Very high

### Competitive Landscape

Although the market context for the proposed product can still be considered a “Blue Ocean”, there are already some players operating in it. Two of these players are Aethon and Diligent Robotics depicted in Figure 3.8.

Figure 3.8. Aethon's TUG robot (left picture) and Moxi from Diligent Robotics (right picture)

### Next Steps

We foresee some steps before placing the solution on the market:

- Optimising the product based on user feedback and EU Project Harmony results
- Start pilot study in 2024
- Development and conclusion of business plan
- Raising capital
- Integration in the health and care market

HORIZON RESULTS BOOSTER an initiative of European Commission

To develop a business plan, we are looking for support from experts. We are in contact with a Portuguese company with expertise in raising capital and business acceleration programs. Following our application to the Horizon Results Booster Program, a European Commission initiative, we will be receiving expert free-of-charge support services to boost the exploitation potential of our Harmony Robot solution, namely, in the preparation of the business plan and go-to-market strategy.

# 4. Discussion and Conclusion

The HARMONY project has been a transformative endeavour in advancing autonomous mobile manipulation technology for human-centred environments, particularly within the healthcare sector. The collaborative efforts of the consortium, comprising six academic institutions, a leading European robot manufacturer, a small-to-medium enterprise (SME), and two end-user organisations, have yielded significant technological advancements and practical solutions.

## 4.1. Achievements and Innovations

The dual-arm YuMi robot by ABB and IDM's Harmony robot have been central to the project, serving as platforms for developing and testing advanced manipulation and navigation capabilities. These robots have demonstrated the ability to perform precise and complex tasks within dynamic hospital environments, showcasing the potential for wide-scale adoption in healthcare.

The project has achieved substantial improvements in object pose estimation and motion planning. These advancements enable the robots to accurately identify and manipulate objects, a critical requirement for tasks such as on-demand delivery and bioassay sample handling in hospitals.

A significant focus of the HARMONY project has been on developing intuitive and safe human-robot interaction. The robots are equipped with multimodal interfaces that facilitate seamless communication and cooperation between humans and robots, enhancing user acceptance and operational efficiency.

The project has successfully integrated various components into a cohesive system capable of adapting to different operational demands and user preferences. This flexibility is crucial for addressing the diverse needs of hospital environments and other human-centred settings.

The collaboration among academic and industrial partners has fostered a rich exchange of knowledge and expertise. This synergy has not only accelerated the development of innovative solutions but also ensured that the research outcomes are grounded in practical, real-world applications.

## 4.2. Impact and Exploitation

The impact of the HARMONY project extends beyond its immediate technological achievements. The project has set the stage for long-term exploitation and commercialization of its outcomes.

The research findings from the HARMONY project have been disseminated through numerous publications, contributing to the broader scientific community's understanding of mobile manipulation and human-robot interaction. These contributions will continue to inspire and inform future research in the field.

Industrial partners are poised to integrate the developed technologies into their product lines, offering enhanced robotic solutions to the market. This integration is expected to drive innovation in the robotics industry, particularly in applications requiring high precision and flexibility.

For end-user organisations, primarily hospitals, the project's outcomes promise significant improvements in operational efficiency and patient care. The deployment of autonomous mobile robots will alleviate staff from repetitive tasks, allowing them to focus on more critical aspects of healthcare delivery.

Some components of the HARMONY project will be made available as open-source, enabling broader access to the developed technologies. This approach will facilitate further innovation and adoption across different domains.

## 4.3. Future Directions

As the HARMONY project concludes, the consortium remains committed to advancing the field of autonomous mobile manipulation in unstructured environments like labs and hospitals. Future research and development efforts will focus on continuing to refine and optimise the robotic platforms and their components to enhance performance and reliability in real-world settings. Exploring new applications and use cases for the developed technologies, extending their benefits to other sectors beyond healthcare. Accelerating the commercialization process to bring the innovative solutions developed during the project to market, ensuring their wide-scale adoption and impact. Maintaining and expanding the collaborative network established during the project to foster ongoing innovation and address emerging challenges in the field.

# References

Osterwalder, A. and Pigneur, Y. (2010) Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers. Wiley, New Jersey.