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Harmony

Assistive robots for healthcare

Enhancing Healthcare with Assistive Robotic Mobile Manipulation

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Contents

Summary

The objective of this document is to describe the two use cases shown in HARMONY. The first use case consists in just-in-time delivery of hospital goods and it will be demonstrated at University Hospital of Zurich. The second use case is about the automation of bioassay sample flow and will be demonstrated at Karolinska Hospital.

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 conducted by over-qualified staff. While existing systems can automate parts of these processes, e.g. specialized bioassay machines, these 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 compelling solution to this problem since it offers the capability to bridge these gaps while maintaining a high degree of flexibility to adjust to varying service demands and adapt to different user requirements and preferences.

Scenario Description

The following scenarios result from different meetings held between the project partners, which aimed to relate the technical challenges of the project to the needs of the end users.

Use case 1: Just-in-time Delivery

Delivery tasks in the healthcare domain present an especially well-motivated use case for robotic mobile manipulation technology.

Autonomous mobile manipulation robots that fulfil just-in-time delivery demands can substantially reduce the burden on facilities management personnel as well as ward nurses.

This will require robots that can search for, identify and keep track of the myriad equipment and resources in use in a hospital so as to collect and deliver them to the requester. This demands robust navigation in all environments of the hospital, e.g. tight corridors or spaces with many people, such as the wards. It also necessitates generalized approaches to grasping and interacting with different, potentially novel, tools and objects, as well as adaptation for safe interaction with human co-workers and patients. The specific scenario that we will investigate is automating on-demand deliveries of boxes with lab samples from the ward storage rooms to the requester (see Figure 1).

Figure 1: Lab sample environment in the university hospital Zürich.

At University hospital Zürich hundreds of lab samples are taken from patients everyday. Each of these lab samples needs to be transported to the designated labs in the hospital. The Process asks a lot of the employees, because they have to walk long distances (sometimes up to 20 Km). Furthermore, there are 3 different levels of lab samples: delivery to the lab in 15, 30 or 60 minutes. Due to the different levels, it is necessary that the orders are allocated efficiently in order to deliver them on time. The current process at the university hospital Zürich is described below:

1. Ward staff prepares the lab samples at the pick-up point for transport
2. Ward staff pushes the lab sample button which generates an order to pick up the lab samples
3. Control station receives and disposes the order to allocated staff
4. Staff verifies and accepts the order
5. Staff navigates to the pick-up point
6. Staff collects and sorts the lab samples in the designated bags on the trolley
    a. Lab samples are sealed in plastic bags with corresponding color
    b. Plastic bags are checked on leaks and sealing
    c. Staff pushes the lab button to end the pick-up order
7. Staff navigates to the next pick-up point.

    a. If a new order is received, staff will navigate to the next pick-up point and repeats step six.
8. If no orders are pending, staff will navigate to the several drop-off points (pre-analytical labs) corresponding type of lab sample.
    a. Navigates to the distribution center in case of Lab samples that are, for example, for external labs.
9. Staff delivers all the sorted lab samples at the corresponding drop-off point.
    a. Directly handover or deposit on the counter
10. Process ended

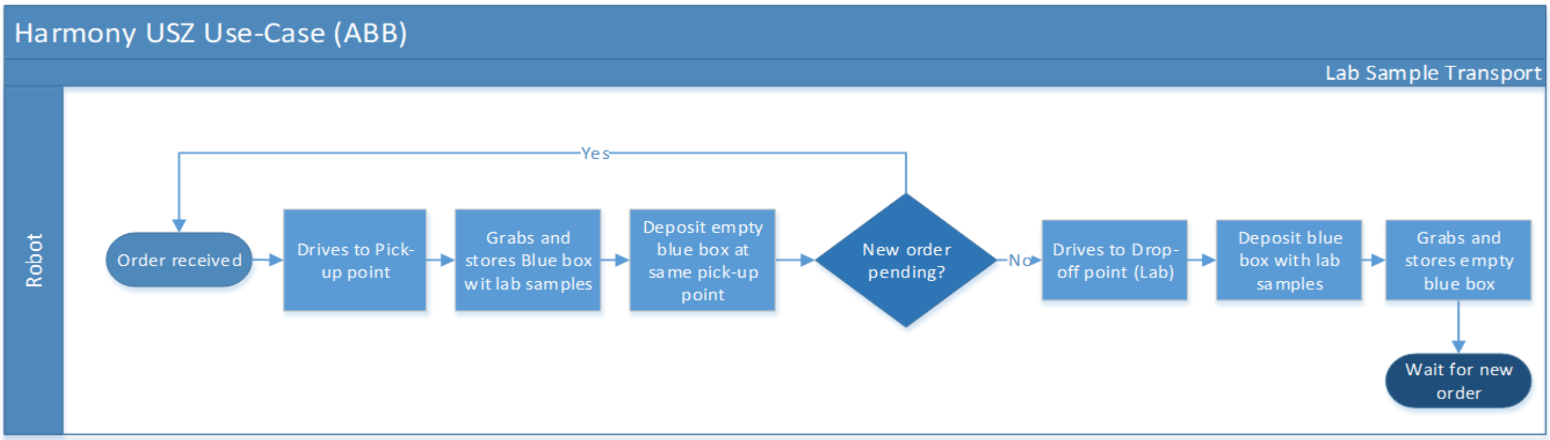

Figure 2: Process steps Use-Case 1

Figure 2 shows the Robots Use-Case at USZ. Because the Robot is not able to sort the lab samples as described in the current situation - the Use-Case is adapted to the Robots capabilities. The process steps adapted to the Robot are described below.

In particular, use case 1 is constituted by the following steps:

1. Human operators order the robot the lab samples to deliver, specifying a location and pick- up time.

2. The robot collects a few orders and picks the different boxes containing lab samples at the wards, using the onboard arms and storing the boxes onboard.

3. The robot delivers all the different goods in given locations.

The robot should be able (i) to drop the goods on the floor or table, (ii) to deliver them to a human, or (iii) to perform direct handover.

- The robot can locate, pick up, transport and deposit the blue box
- The robot can collect, store and carry several blue boxes
- The robot can deposit several blue boxes

1. The Robot receives a pick-up order.
2. Drives to the pick-up point
3. Picks up blue box with sorted lab samples
4. Unloads Empty blue box at pick-up point
5. New order received?
    a. Yes - Start at step 2
    b. No - Drives to the drop-off point
6. Drop off the box at the lab
7. Grabs empty box and store onboard
8. Waits for new order

To maximize the value of the new technologies for the end user, the following additional requirements are needed:

- The robot(s) moves within the hospital where also humans are present and has to be free to move around
- It should be general-purpose with capabilities of manipulation, navigation, and picking goods
- The robot should be able to work 24/7
- The delivery process should also include a safe handing over of objects to humans
- The robot should transport the goods safely and maintain their security while transporting.

The robot(s) can interact with elevators, doors, light signals, fire alarm systems, and similar systems. To fulfil the use case requirements, we will aim at having the technical capabilities described below in Table 1.

Table 1: System capabilities for use case 1

Month	Capabilities	Assumptions
12	• Build object models online for large open-set environments. • Plan and navigate between logistics hub, ward material room and patient rooms using pre-built maps • Execute grasps on identified materials • Stable whole-body motion while moving the base and grasping objects • Basic interactions with staff and patients	• Controlled environment with no dynamic obstacles • Object models obtained in relatively clutter-free environments • External localisation tools (e.g. QR tags) present in some places for high accuracy grasping • Staff and patient interactions tested in isolation of other capabilities

24	• Identify and locate requested items from stored models • Grasping and transporting logistics boxes with samples • Plan and navigate between hub, ward and labs • Coordinate with staff actions • Interactions with staff are integrated with primary task	• Controlled environments with no dynamic obstacles • No time constraints on fetching and delivery tasks • Robots interact only with trained personnel
36	• Gasping boxes with different weights • Collect and deliver requested items from hub to ward and ward to labs • Coordinate with staff actions and request urgency • Interactions with staff and patients are integrated with primary task • Operate safely in close proximity to people	• Fetching and delivery time must occur within a given time frame • Robots interact only with trained personnel
42	• Locate, collect and deliver boxes with samples to various labs • Operate safely in close proximity to people • Perform safe object delivery around humans • If needed, interact with elevators, doors, light signals, and fire alarms	• Requests arrive sporadically and must be handled within a given time frame • Staff are trained to work in the same physical space as the robot

Use case 2: Bioassay Sample Flow

Overview and expected benefits

At Karolinska University Hospital (KUH) several hundreds of boxes with samples, shown in Figure 3, are received each day. Each of these boxes needs to be unpacked to extract and sort the samples that they contain. These activities are tedious, labor-intensive and may cause work injuries because of its intrinsic repetitive nature. Many samples need to be additionally scanned, packed, and transported for analysis to other hospitals in Stockholm. The entire process is described below:

1. Drivers arrive at lab by car with transport boxes
2. A box is brought to staff by use of a short conveyor belt
    - Out of Karolinska's 6 laboratories in Stockholm, two receive the boxes by use of a conveyor
3. The plastic seal from the box is removed by cutting it
    - If the seal is pink or red, the box contains emergency samples
    - If the seal is white or blue, the box contains only routine samples
4. The barcode on the seal, if any, is scanned to mark box as received
5. The box is opened by unlocking the box and then lifting the lid
6. The box is visually examined to determine how many racks are within, if there are any paper referrals accompanying the samples and if anything has happened to the

samples (if they have been overturned, a lid has come off and the content has spilled out).[1]

7. Racks, shown in Figure 4, are removed from the transport box and placed on one out of three trolleys.
    - Trolley A is for emergency samples
    - Trolley B is for racks with paper referrals that needs to be registered, the paper referrals are placed together with the racks
    - Trolley C is for racks with samples which require no processing
    - Any trolley that is filled with racks will be replaced with an empty one, continuously reusing previous ones as they are emptied
8. The trolleys are brought to the pre-sorting station
    - Trolley A: Emergency samples are identified, taken out of the racks, and brought to the emergency station. The rest follow same workflow as Trolley B
    - Trolley B: Paper referrals are registered in the Laboratory Information System, accompanying samples are placed in racks. Once finished they are placed in queue for the laboratory automation
    - Trolley C: Bypass the pre-sorting stage and are placed in queue for laboratory automation.
    - Any samples that cannot be placed in the laboratory automation (such as jugs with urine) are taken and manually processed at this stage.
9. Empty racks are placed into the transport box, which is then closed and returned to the driver. Sometimes also documentation that come in a plastic folder may also need to be placed back in the box.
10. The racks with samples are brought to the laboratory automation for sorting. Each rack is placed into the machines. Colours indicate whether the racks contain samples that have not been centrifuged (red or white) or samples that have been centrifuged (green)
11. The laboratory automation takes the samples out of the racks and put them into station specific racks/containers
12. The new racks with sorted samples are taken out of the laboratory automation and are brought to the analytical stations for analysis
    - Some samples are transported to another floor
    - Some samples require further processing, such as being decanted and frozen.
    - Some samples are sent to another site for analysis

A layout of the relevant facilities at Karolinska is shown in Figure 2.

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[1] We can put 4 racks in a box. Each box also contains a coolbrick and an icepack. The weight of a standard rack with 50 tubes is 660g, the weight of a coolbrick is 940 g, and the weight of an icepack is 350 g. More details about the boxes are listed in Table 3.

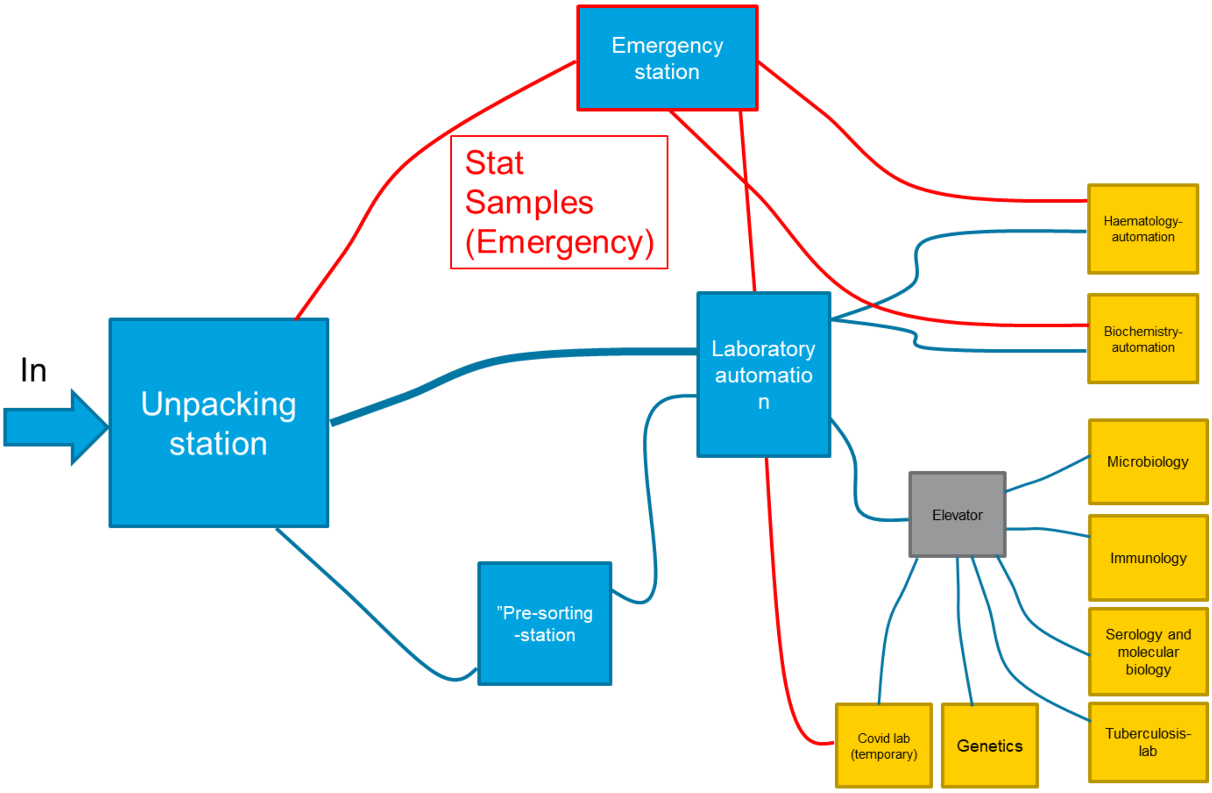

Figure 2: Layout of Karolinska facility

Out of all these steps, the *opening* and *emptying* of transport boxes will have the greatest value for the end user, as it is a physically demanding and very time-consuming position. As such continuous work is very important here.

Automating this process has the potential of reducing the time required to examine the samples and additionally allowing the qualified hospital staff to focus on tasks where their skills are required. Already in 2019, KUH carried out a pilot project regarding the introduction of the first collaborative robot (YuMi from ABB) in the Preanalytical department at KUH. The programs originated from this project are in operation since the beginning of 2020 and have received great appreciation and acceptance for the new technology by the healthcare staff.

The use of mobile manipulation technology, as addressed in HARMONY, is a crucial extension for handling these duties, since it will offer the required degree of flexibility to adjust to varying service demands arising from the dynamic income of boxes, unpacking and relocation of the samples to different stations for scanning and further processing.

We describe the steps to be performed by the robot:

1. A box with samples is received, the robot pay attention if the box is labelled for emergency samples (pink or red seal), or regular samples (white or blue seal)
2. The robot opens and unpacks the box

3. The robot picks up the racks in the box
4. The robot moves the racks to station pre-sorting station or, if a priority sample box is identified, to the emergency station
5. The robot proceeds to unpack all incoming racks or perform another task after an instruction from a human
6. Once a sample is brought to the relevant station and scanned, we consider it delivered. Having a mobile manipulator that performs the scanning operation is optional in this use case.
7. Humans can ask the robot to help or collaborate to handle some unexpected events

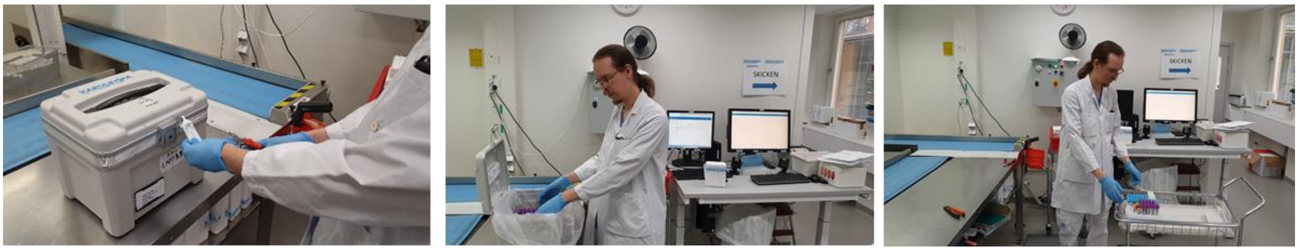

Figure 3: The box is received (left), opened (centre), and the racks are loaded on the carrier (right)

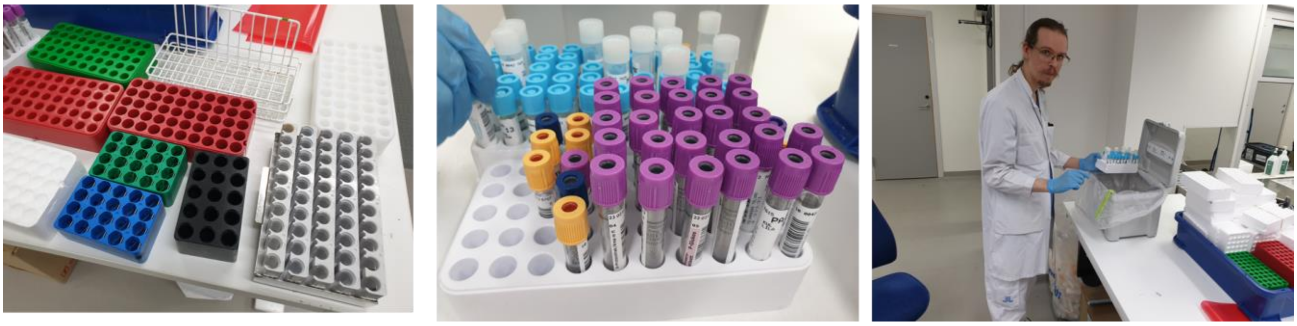

Figure 4: Racks and samples contained in the boxes

In order to perform the task described above, the robot should be provided with the capabilities listed in Table 2.

Table 2: System capabilities for use case 2

Month	Capabilities	Assumptions
12	• Build object models and execute grasps on equipment (e.g. boxes, vials, sample tubes)	• Controlled environment with no dynamic obstacles

	• Plan and navigate between workstations using pre-built maps • Stable whole-body motion while moving the base and grasping a tray of samples	• Object models obtained in relatively clutter-free environments • External localisation tools (e.g. QR tags) present in some places for high accuracy grasping
24	• Execute grasps that can open and close boxes, and open vials to extract samples • Scan and sort samples into trays • Pack racks into boxes • Plan and navigate between workstations to deliver racks or boxes • Basic human-robot collaboration	• Controlled environments with no dynamic obstacles • No time constraints on extraction, scanning, sorting, packing and delivery
36	• Extract samples arriving in boxes or vials • Scan, sort, pack and deliver all samples according to requested tests • Operate safely in close proximity to staff	• Samples must be handled within a given time frame • Robots interact only with trained personnel
42	• Extract samples arriving in boxes or vials • Learn to extract samples from new container types as well as learn to handle new types of test tubes. • Scan, sort, pack and deliver all samples according to requested tests • Safe and understandable human-robot collaboration • Coordinate with varying numbers of staff to facilitate changes in demand • Operate safely in close proximity to staff	• Samples arrive sporadically and must be handled within a given time frame • Staff are trained to work in the same physical space as the robot • Staff are trained in how to provide grasp demonstrations to the robot

	Small box, Inner dimensions	Small Box, outer dimensions	Big box, inner dimensions	Big box, outer dimensions
Width (mm)	225	250	240	280

Length (mm)	300	330	300	340
Height (mm)	140	240	210	290
Weight (g)		1570		1700

Table 3: Specifications for Karolinska boxes. We have two main type of boxes (small and large). We can put 4 racks in both type of boxes.

Conclusions

The described use cases provide a chance to evaluate the performance of the different aspects and objectives of the project.

The presence of objects with transparent surfaces, like the glass test tubes, requires that the object-based representation is capable of discovering and reconstructing those surfaces. In our hospital environments, the information from the object-based representation will in turn enable the robot to maintain a better localization accuracy despite the presence of dynamic obstacles and lighting changes in the environment. The presence of these obstacles and in particular of humans, will put to test the safety and robustness of the entire planning/controlling pipeline. The safety of the manipulation in the presence of potential collisions is evaluated by measuring the contact velocities and forces and their related risks according to medical procedures. While guaranteeing the safety of the humans and the capability of a safe human-robot interaction, the robot has to execute complex tasks like non-prehensile manipulation tasks with a high success rate. Carrying an object on a tray is clearly such an important example. Finally, the social acceptance of the robot will be tested by the quality of the interactions between people (medical staff and patients) and robots, both via objective and subjective metrics. Objective measures consider the robots' joint velocities, as already for the safety aspects, while examples of subjective measures are the perceived ease of interaction with the robot.

The use cases and the scenarios requirements identified in this document are not only fundamental for the initial field studies for robot design and data acquisition, as well as the testbed setup; but will also refine the specifications for the development of socially aware local motion planning, datasets of learning from demonstration, extraction of synergies, and evaluation of social implications and in particular validated set of multimodal social robot intent behaviors and whole-body behaviors.