Human-robot collaboration for automatic garbage removal

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Abstract— **An easy task, such as emptying the trash bin, is essential and necessary for the health, safety and well-being of the occupants in commercial buildings.**

There have been developed smart bins that can measure and report the exact amount of garbage and alert for pickup. However a drawback is that they still require people to dispose the garbage. This type of work can be seen as non value-added work and a general waste of time. Thus in this paper, we investigate how a mobile robot and other Industry 4.0 technologies can be applied to automate and optimize the transportation of garbage in larger buildings.

Our system combines a smart bin with a mobile robot. The smart bin measures the garbage's weight and volume while a mobile robot transports the bin around for automatic disposal. The system has been developed, in close cooperation with sanitation workers, with the goal to reduce non value-added work. The proposed solution, even though experimental, turns out to be a more cost-effective solution as well.

I. INTRODUCTION

It has been shown that in a growing economy the amount of waste increases [1]. The amount of waste produced by consumers on average in the EU-27 is growing and it has been found that Norwegians, for example, dispose 776 kg of waste each year [2].

European Union's Green Deal and United Nations point out that the Circular Economy (CE) is vital for the climate goals both nationally and globally in order to strengthen competitiveness, create economic growth and regenerate jobs [3]. This has initiated a Circular Economy action plan to achieve better handled waste management. To accomplish this, digital technology and digitization play a central role in the battle for a healthier environment and in accelerating the transition into CE [4]. From an EU horizon 2020 project [5] which is developing a framework for CE strategies suggests investigating the functionality of smart bins and platforms that can monitor and optimize collection routes. This enables efficient waste collection and eases the use of raw materials with the CE principles. It is also suggested that smart bins should contain intelligent sensors that measure weight to remotely manage the collection system.

Smart bins uses sensors to measure the amount of waste and have internet of things (IoT) connectivity for real-time updates on the status and readings from the sensors [6], [7], [8]. In [9], a smart bin is connected to the cloud has the ability to send both email alerts and text messages when the waste bin is full. Machine learning was also applied to the system to predict future waste levels of the garbage bin. Smart bins can also be used for collecting relevant data about the user's waste management habits. An overview of this information maps the frequency and amount of waste at a specific location, the result of which can be used to plan collection routes to perform better, meaning that specified routes can be changed as the path is being executed. This can reduce the time and fuel needed to collect garbage [10].

These systems are able to use Industry 4.0 concepts such as IoT and cloud storage to collect information on the amount of garbage, and be connected to the network for efficient route optimization for waste collection.

The disadvantage of current smart bin systems is that they are dependent on people to discard and move the garbage. Transporting garbage is considered as non-value-added work and is a waste of resources. Garbage is often carried out by the sanitation workers or operators in industrial environments. These tasks are usually performed on hard concrete floors and may include unfortunate heavy lifts and increase the distance of motion for workers, which may over time cause health issues. Moreover, integrating new and innovative automation technologies with lean principles can complement and improve existing systems [11].

Motion or transportation are denoted as unnecessary movements and their associated tasks can potentially be reduced. Performing unnecessary movements and transportation can lead to lost time, utilization, unused skills and ideas of the employees. Research has shown that wasted motion and transportation are major wastes in production environments, and one of the seven wastes [12].

In the aspect of reducing time thieves, refuse collecting robots that collaborate with garbage trucks have been developed, with the purpose to automatically drive and pick up the waste bins along the sidewalk and transport them back to the garbage truck to empty the container [13]. This system uses an autonomous mobile robot (AMR) as a base that is sophisticated and intelligent. Mobile robots are often used in the field of manufacturing for transportation of goods or material handling where onboard sensors are employed to learn and visualize a map of an unknown environment of its position. This enables the AMR to navigate without any guidance by using pre-uploaded maps or constructed drawings of the on-site location via its software. Furthermore, the information gathered throughout AMR's cameras, built-in sensors and the laser-based navigational system allow it to move freely in its environment. The data obtained is used to calculate and execute the shortest path for its predetermined destination; it will also avoid any obstacles on its mission.

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The AMR is a flexible and efficient technology for a dynamic manufacturing environment [14].

This paper look at how the process of moving garbage from offices and industrial sites can be automated. A system was developed where an autonomous mobile robot in collaboration with humans improved the efficiency of garbage removal. The paper is structured as follows. The first section goes through the conceptual idea of the system and why it is needed. Section two and three look at how the modules are built up and how they works. Then follows a case study of the system, a demonstration, and finally a conclusion to this study.

II. A NEW CONCEPT

In large office buildings, industrial factories or storage warehouses, there can often be long distances between the working area and the garbage disposal area. In most cases, sanitation workers are used to move the garbage from the offices and working area to the disposal area. Transporting and disposing of garbage can be considered as non-value-added work and, in many cases, heavy work.

In collaboration with Robotic Innovation AS [15] and UiT the Arctic University of Norway, we wanted to develop a proof of concept system that can automatically transport and dispose of garbage. Robotic Innovation is a young robotics company that uses Autonomous Mobile Robots (AMRs) as a fundamental component in their business. They design and integrate automation solutions to handle transport and logistics with mobile robots.

The use of mobile robots can completely automate the process of carrying garbage from a working area to the disposal area. Mobile robots are becoming increasingly more independent and automated. They can navigate large areas without human intervention, control doors and elevators, and do not require any changes to the current environment.

After discussions with Robotic Innovation, it became clear that making a mobile robot go inside offices picking up and emptying garbage bins automatically without human intervention is not feasible. Driving inside the office requires that all doors can be controlled by the mobile robot. Offices are also usually small, and it can be difficult for a mobile robot to navigate inside and pick up and empty the garbage bin.

On the other hand, it is simple for humans to go inside the offices and remove garbage from bins. Therefore, Robotic Innovation suggested developing human-robot collaboration between sanitation workers and mobile robots. The new idea would be to create a system with mobile robots that can assist the sanitation or office workers and automatically drive the garbage to the disposal area.

III. SYSTEM STRUCTURE

This section describes how the proposed system has been designed and built-up. Our system is based on a MiR100 robot, as the fundamental mobile part of the system. The MiR100 can carry up to 100kg and is a highly flexible robot that can navigate environments autonomously without human intervention [16]. The top module must be as light as possible because of the limited payload. Therefore, the system was designed to be minimalistic, with a combination of extruded aluminum profiles to save weight and utilize the integrated T-slots to increase the mounting opportunities for components on the structure. The top module is equipped with the absolute minimum of components necessary to hold the parts while still being able to perform all of its assignment.

The system consists of a smart bin that is attached to a fixed pulley system. The pulley system is used to fulfill the emptying sequence, where the bin gets pulled upwards by an inclined framework to flip the smart bin. To make the waste bin move frictionlessly up along the inclined structure, six wheels are attached to the framework, as well as additional two larger wheels on top of the structure to enable rotation of the smart bin. To achieve the flipping sequence, one DC motor is used in combination with a gearbox, and a winch that is mounted on the end shaft; this is illustrated in figure 1. The gearbox (ratio 1:15) is used to decrease the output speed and increase the torque of the pulley system.

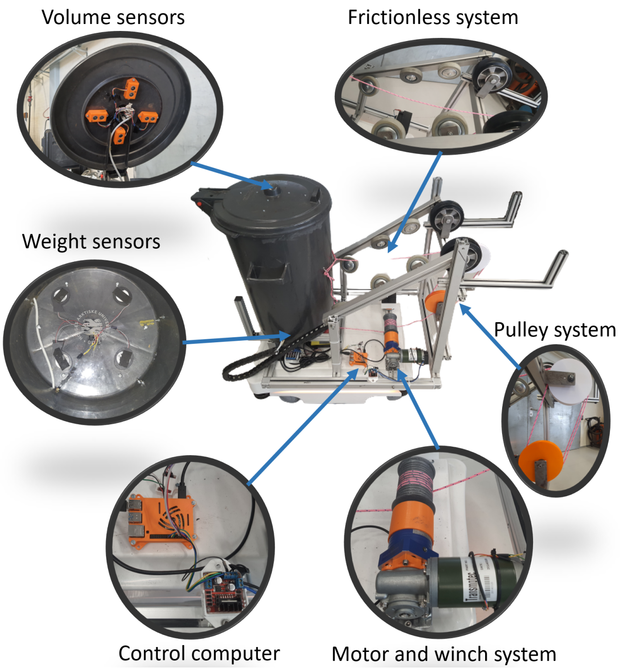

Fig. 1: Structure of the garbage module where the different parts of the system has been highlighted

Our system was made to be modular. Components can be added to the structure for new extended functionalities. The top module is designed to be easy removable, with only a few screws, and can be stored or transferred to another mobile robot within the MiR series. This makes the system more flexible and allows for multi purpose utilization of the mobile robots itself. The total weight of the top module is 45.5 kg and the system can carry a maximum load up to 54.5 kg without exceeding the MiR100 maximum payload of 100 kg. In special high pay-load situations another MiR robot can be selected and equipped with the top module as described above.

IV. Connectivity and Functionality

This section shows how the system is connected together and how it functions. The system can be divided into four parts: the main control computer, the winch system, the mobile robot and the smart bin as shown in figure 2.

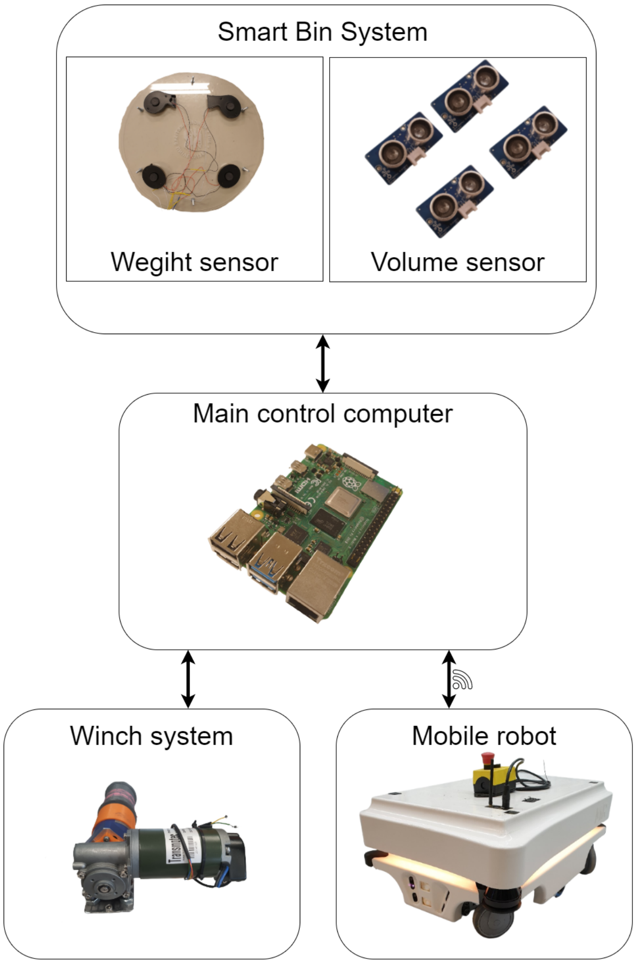

Fig. 2: System structure

A. Control system

As can be seen in figure 2, a Raspberry Pi is used as the main control unit for this system. The ultrasound sensors are connected to an Arduino, and again connected to the Raspberry Pi. The weight cells used to measure the garbage are directly connected to the Raspberry Pi, as well as the motor controller for the pulley system.

When it comes to the mobile robot, it has a REST API, which can be used to get information from the mobile robot and send information to it. The Raspberry Pi is used to communicate with the mobile robot and send missions/tasks.

B. Smart bin

As mentioned in the previous chapter, a smart bin is placed on the top of the mobile robot. It is equipped with sensors that enable it to measure both volume and mass. The weight unit consists of four load cells that are attached to the bottom of the bin. The volume unit consists of four ultrasonic sensors that are attached to the top lid, which is illustrated in figure 1. The load cells are used to measure the mass of any object, while the ultrasonic sensors are used to measure the volume of content inside the smart bin. Both the volume and weight sensors are used to check when the mobile robot has to drive to the disposable area for emptying. In this scenario, when a predetermined level and/or mass is reached, the mobile robot heads over to the disposal area.

As mentioned, the system has been made to work in collaboration with sanitation workers. The system works as follows:

1) When the sanitation worker is cleaning an office space, they call for the mobile robot to pick up garbage.
2) The mobile robot drives to the sanitation cleaner.
3) When the mobile robot arrives, the sanitation worker transfers the garbage into the bin.
4) The mobile robot measures the weight and volume of the garbage, and stores the data.
5) When the weight or volume exceeds its predetermined settings, the mobile robot automatically drives to the garbage disposal area. If not, the mobile robot continues its routine to pick up garbage.
6) When the mobile arrives at the disposal area, it positions itself to the drop off place and will then run the flipping/throw-over sequence.
7) When the garbage bin is emptied, the mobile robot continues to pick up garbage again.

An illustration on how the system works can be found in figure 3.

V. Case Study

A. Mobile robot system

A demonstration was carried out to showcase the functionality of the system. The demonstration aims to show how the system works and serves as a case study on the system's effectiveness.

In the demonstration:

- A human orders pick-up of garbage from the mobile robot.
- The mobile robot drives to the pick-up position and the human places the garbage into the garbage bin on the mobile robot.
- The smart bin automatically measures the weight and volume of the garbage and stores the information.
- The system reads that the bin is full and therefore drives to the garbage disposal area to empty the bin. The mobile robot drives a total distance of 130 m to the disposal area, as shown in figure 4.
- When the robot arrives, it runs the garbage bin flip sequence, emptying the garbage bin.

A video was recorded of this system, which can be found at `https://youtu.be/C6hxciV3p5c`. The parts where the mobile robot is driving have been speed up by 5x.

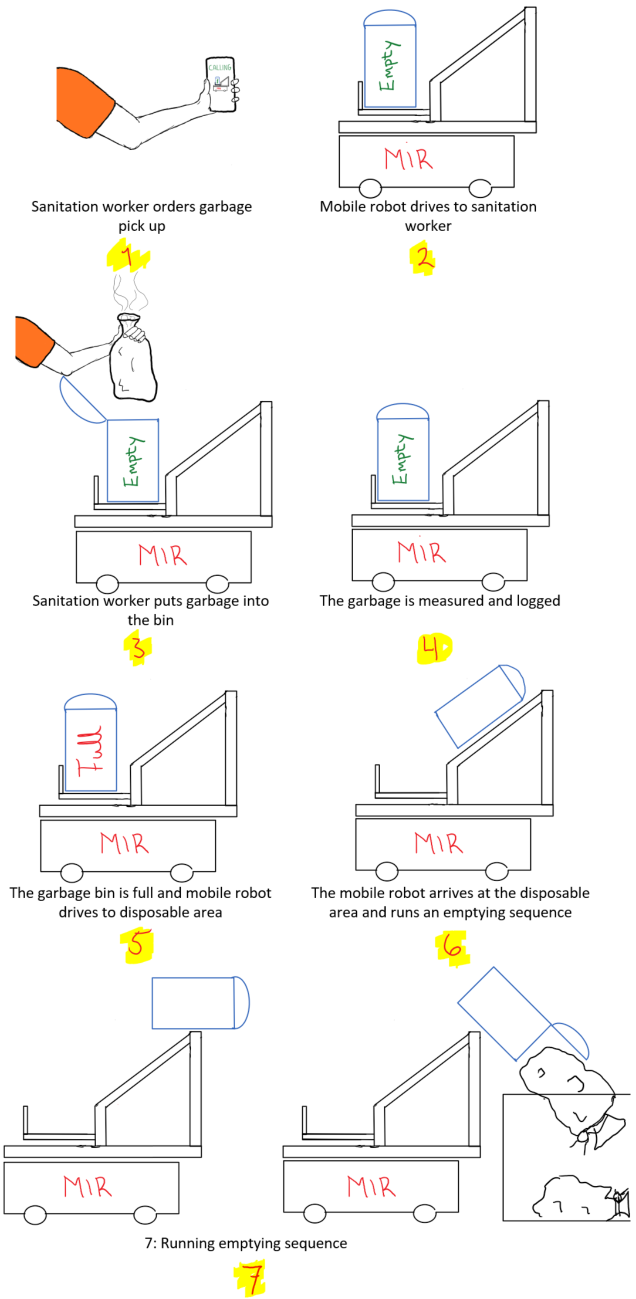

Fig. 3: System operation.

It should be noted that the mobile robot does not control the elevator in the demonstration. The elevator is opened up manually by a human.

Since this is a proof of concept there are some smaller concerns such as; when executing the emptying sequence and then retrieving the bin, slack builds up, which can cause the waste bin to fall on the inclined framework. Additionally, when the garbage falls out of the bin it hits the lid where the distance sensors are placed. This, again, can cause damage to the bin and sensors over time.

From the demonstration, it takes 431 seconds for the mobile robot to drive to the human, measure the garbage, and drive and dispose of the garbage. The individual times

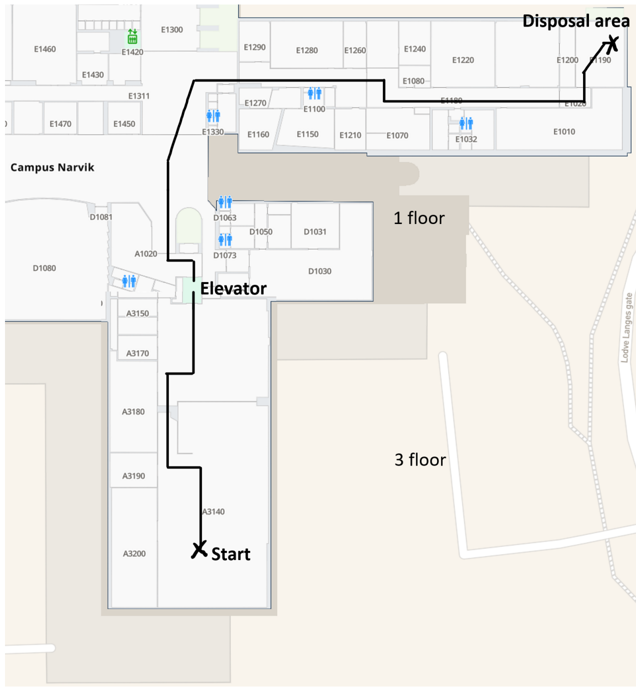

Fig. 4: A map of campus Narvik, showcasing where the mobile robot has to drive in the demonstration to dispose of the garbage. The map is taken from [17]

of the sequences can be found in table I.

Sequences	**Time (sec)**
From being signalized to arriving at pick up point	31
Transferring litterbag into bin	13
Heading to elevator (3rd floor)	84
From elevator (1st floor)	208
Emptying sequence	95
Total transport time	431

TABLE I: Table of the time used in the demonstration

B. Sanitation workers

To measure the system's effectiveness, the assistance from sanitation workers were utilized as part of the case study. The goal was to see how this semi- automated solution can save time, money and decrease the amount of heavy lifting and walking associated with the disposal routines.

A rough estimation of the Return on Investment (ROI) can be calculated where the sanitation workers need to walk the same route as demonstrated in the video four to five times a day. The time it takes for a person to walk the same route as the mobile robot from the demonstration is 265 seconds. The cost of the mobile robot is around 350 000 NOK, while the top module's parts cost 21 000 NOK and the development cost is estimated to 220 232 NOK. In this example the maintenance cost will be estimated to be 10 000 NOK per year.

Description	Cost/factor
Mobile-industrial-Robot (MiR100)	350 000 NOK
Technical equipment (top module)	21 000 NOK
Research & Development	220 232 NOK
Salary employee	249 NOK/hour
Maintenance	10 0000 NOK/year
Product life span	5 years
Transporting litterbags	4,5 times/day
Time used to transport litterbag	265 seconds
Working days a year	230 days

TABLE II: Table with costs related to the system and relevant data to calculate the ROI

$$\begin{aligned}
4.5\ times\ a\ day\ \times (265/60)\ min &= 19.88\ min\ a\ day\\
9.5\ employes\ \times 19.875\ min\ a\ day &= 188.81\ min\ a\ day\\
or\ 3.15\ hours\ a\ day\ for\ all\ personnel\\
230\ working\ days \times 3.15\ hours &= 724.5\ hours\ a\ year\\
724.5 \times 249 \frac{NOK}{hour} &= 180401\ NOK\ yearly \quad (1)\\
10000\ maintenance \times\ 5\ year &=\ 50000\ NOK\ total\\
ROI = \frac{(350000+220232+21003\ +\ 50000)NOK}{180041 \frac{NOK}{year}}\\
&= \mathbf{3.55\ \ years}
\end{aligned}$$

If there are 230 working days per year and an average salary is 249 NOK/hour, the ROI will then be 3.55 years.

From the manufacturer the mobile robot has a life span of 5 years [16]. With a ROI of 3.55 years gives a possible cost saving of $180401 NOK * (5-3.55) Year$ = 261 581 NOK saved compared to using a sanitation worker.

It is important to mention that the analysis is being considered under today's circumstances, regarding the global pandemic, and will most likely differ from a normal situation. The difference is that there are fewer students and employees on the campus under the COVID-19 pandemic.

Finally, the calculation is more like an optimistic estimation, mainly for four reasons:

1) The travel time of the cleaning staff is only considered from 3rd floor to 1st floor, but in reality, they may come from anywhere in the building to the disposal area, and a more accurate estimation would be to take into account average travel time.
2) The calculation is not that rigorous, since the cleaning staff may not return to the same point.
3) Finally, if commercializing the adaptive top module system, the R&D cost will not be as high. The manufacturing cost would be reduced if producing e.g. fifty systems like this one, since the main part of R&D would already be done.

The calculation needs more specific data and research to defend the return on investment.

VI. Conclusion

This paper proposed a garbage disposal concept with an adaptive module that suits the MiR100 series. The prototype has the functionality to be of assistance to humans and reduce time thieves such as transportation. Our system was developed for office buildings but the concept can be utilized in many other locations and situations. The system fulfills the CE model in compliance with waste management. The top module is unique, as we could not identify any similar adaptive solutions for AMRs.

Our concept can be applied at our campus locations without any further improvements. However it would be limited to certain areas and to achieve full efficiency it is recommended to implement an IoT system that enables the AMR to open electric doors and access elevators. It is also worth mentioning that the prototype does not have any of these limitations if implemented in a "smart" building.

Our system automates the transportation part of the garbage removal. In addition, it removes unnecessary motion, since the mobile robot plans and finds the shortest route to the disposal area. The rough ROI calculation of 3.55 years has shown that such a system can be cost-effective. It should be mentioned that the ROI has been calculated for one module. If more modules are developed, the ROI could be reduced.

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