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Pathfinder–Development of Automated Guided Vehicle for Hospital Logistics

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ABSTRACT This paper describes the development of Pathfinder—an autonomous guided vehicle intended for the transportation of material in hospital environments. Pathfinder is equipped with the latest industrial hardware components and employs the most recent software stacks for simultaneous localization, navigation, and mapping. As the most significant contribution to the current robotics development, powerlink interface enabling direct data transfers between robot operating system and powerlink compatible hardware was developed. This combination is in our best knowledge reported here for the first time and the results with comprehensive tutorial were made publicly available as a GitHub repository. The capabilities of Pathfinder were explored during preliminary on-site tests in local hospital. From experimental results in a hospital it was confirmed that the robot can move along its global path, and reach the goal without colliding with static and moving objects.

INDEX TERMS Ethernet networks, logistics, path planning, powerlink, robot operating system, service robots, simultaneous localization and mapping.

I. INTRODUCTION

Healthcare systems around the world are currently being challenged by growing numbers of elderly people, chronically ill patients and increasing costs of treatment. These factors place significant demands in terms of treatment needs as well as patient expectations, which heighten the need for healthcare systems to work more efficiently on all levels. Therefore hospitals need to consider means by which to increase efficiency and productivity in order to be able to treat more patients without increasing costs. The optimization and automation of logistics processes is one of the ways in which the efficiency of resource use in the hospital environment can be improved.

Several different approaches including mobile robotic platforms, pneumatic tube systems, and even sophisticated conveyors have already been utilized in order to boost the automation of hospital logistics. From these options, the concept of Automated Guided Vehicles (AGVs) seems to be the most suitable solution for the majority of modern hospital facilities. The latest progress in the field of autonomous navigation in combination with user friendly interfaces and modern materials enables the transfer of AGV technology originally developed for industrial plants into the healthcare sector. The results that have already been achieved within this field reinforced by specific demands from local hospitals and the lack of ROS support for Ethernet Powerlink protocol were the main reasons for focusing further on this work.

A year of intensive development resulted in the introduction of Pathfinder – a prototype of automated guided vehicle for hospital logistics which is a unique combination of industrial-based components and the latest state-of-the-art technology for autonomous navigation. Pathfinder was partially inspired by similar existing commercial AGVs but the project intended to develop a vehicle which would be optimized for the requirements of working in a local hospital.

The main focus was therefore placed on robust mechanical design, sufficient space for material transport, collision avoidance features and a simple user interface. This paper provides a detailed overview of all of the above mentioned features of the Pathfinder technology.

II. RELATED WORK

The idea of introducing mobile robots to the hospital floor is more than 30 years old and various platforms have found use

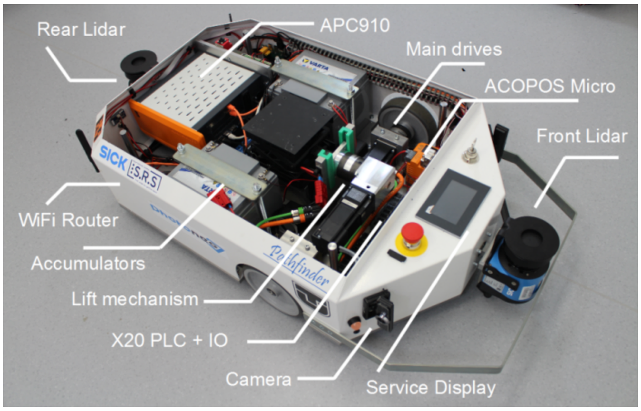

FIGURE 1. **Mechanical overview. Pathfinder is a differential platform with two driven wheels and one supporting wheel. The lifting mechanism in the centre allows the loading of self-supporting shelfs if required. The compact but still robust design was one of the main requirements of local hospital.**

in hospital environments during this period. Current development in this field can be divided into two branches. The first branch is comprised of standard AGV platforms intended primarily for material handling purposes. Several commercially available products already exist such as MiR100 [1] by Mobile Industrial Robot, JBT [2] or Swisslog AGVs [3], but the development still continues with the aim of increasing the robustness of navigation functionality, improving user interfaces and lowering manufacturing costs.

The second branch is related to the development of so called robotic assistants. Current systems can be categorized as a bridge between AGVs and fully humanoid robots. Robotic assistants are usually built on omnidirectional platforms and equipped with one or two robotic arms which allow the performance of simple manipulation tasks. Since assistants are developed to work closely to humans, user interfaces are much more native, often providing some level of emotional response with signs of artificial intelligence. Robotic assistants are utilized for a wide range of different purposes, including greeting patients, providing navigational guidelines for visitors, collecting patient's data on medical rounds, food delivery and the transfer of medical supplies or documents between various departments. However due to the typically light mechanical construction of the devices, they are not able to carry the type of high volume loads which standard AGV platforms are capable of.

The first mobile hospital robot was introduced as part of the HelpMate project in 1992 [4]. It was designed to deliver pharmacy supplies and patient records within the facility. The navigation system of HelpMate robot leveraged the specific structure of a hospital hallway environment and relied on contemporary innovations in provable sensor-based motion planning algorithms which specifically addressed the issue of navigation in unknown and unstructured environments. Another interesting implementation in the hospital domain was realized within the research of the hybrid localization method called Multi Hypothesis Localization (MHL) [5]. MHL used multi-hypothesis Kalman filter based pose tracking combined with a probabilistic formulation of hypothesis correctness to generate and track Gaussian pose hypotheses online. Extensive testing of this localization method was conducted in hospital buildings.

From the category of robot assistants, several advanced robots have entered the market in recent years, the most famous of which is perhaps the Care-O-Bot [6] by Fraunhofer. Starting as a hospital assistant, Care-o-Bot has undergone an intensive development process and the current fourth generation is even able to actively support humans in domestic environments. Another robotic assistant, HOSPI [7], is an autonomous hospital delivery robot manufactured by Panasonic. HOSPI can move autonomously around environments while remaining aware of its surroundings, enabling the delivery of medical specimens and patient documentation without colliding into passersby or various objects along its route. HOSPI is currently being tested in four hospitals in Japan.

Another Japanese research team, Takahasi et al., is also known for developing the Muratec Keio Robot [8] an autonomous omni-directional mobile robot system for hospital applications. Takahasi's group solved the problem of limited cargo space by attaching a wagon truck to the robot. In their latest publication they focus on the development of obstacle collision avoidance capability for an omnidirectional platform with attached wagon truck by using a hierarchical action control technique based on virtual potential fields. As is shown in the experimental section of the paper, the Muratec Keio Robot was able to use this technique to deal with emergency situations and reach the trajectory goal without colliding with either static or moving obstacles.

Therapio robot [9] developed by the Tasaki research group is also expected to contribute to the alleviation of the personal demands placed on medical workers. The robot is characterized by its functions to transport armamentarium, record rounds data and to communicate with humans by showing facial expressions. Therapio leverages an omni-directional mobile platform and uses a human tracking control system to allow it to follow a specified person on medical rounds while avoiding other obstacles.

Particular features of the hospital robots towards common industrial AGVs should be summarized as follows. The hospital robots should:

- have the option to be switched from automatic mode to manual mode at any time,
- immediately stop the motion in the case of human or other obstacle crossing their trajectory,
- warn its nearby surrounding about their presence (by music, sound, light, etc.),
- be designed the way so they look pleasantly for humans.

Although it is more than 30 years since first robots entered hospital domains, intensive development in this area continues especially with the aim of increasing the precision and robustness of SLAM algorithms [10]–[12], sensor data fusion [13] and laser scanning technology [14] and lowering manufacturing costs.

However, the overall progress which has been made in this field within the last five years and the results of dozens of pilot projects confirms that the current technology is not far from implementation on a large scale.

III. MECHANICAL DESIGN AND HARDWARE COMPONENTS

A. MECHANICAL DESIGN

The mechanical dimensions of the Pathfinder were primarily determined by the dimension of the hospital elevators but it was also necessary to ensure that the design provided sufficient space for all of the hardware components, drives, the lifting platform and two battery packs. The footprint of the current Pathfinder version is 600 mm, the height of the base is 270 mm and the platform length is 1250 mm. Pathfinder weights 75 kg and nominal load is limited to 60 kg of cargo. The mechanical design of Pathfinder integrates the proven concept of a differential platform with two driven wheels and one supporting wheel. The drive itself consists of two B&R servomotors 8LVA23 series with planetary gearbox ratio 1 : 15.

The maximum speed of the actual configuration is 0.65 m/s, which is limited to 0.15 m/s in hospital. Braking distance for the maximum speed and full load is 10 cm. The platform is able to carry loads in firmly attached cabinets or even self-supporting shelves. If a self-supporting shelf is required, lifting top platform option must be fitted in order to lift the shelf from the ground; a B&R 80MPF stepper motor with incremental encoder is utilized for this purpose. Mechanical overview of Pathfinder is in Fig. 1.

B. HARDWARE COMPONENTS

Pathfinder employs the most up-to-date industrial B&R hardware components. The basic overview scheme is shown in Fig. 2. The core of the entire system is APC910, an automation PC equipped by with i3 3120ME processor. APC currently runs Ubuntu 14.04 LTS and provides computational power required by the navigational stack and related business logic. It is also closely coupled with the PLC X20CP series what is the main I/O device of Pathfinder. In addition to controlling all low-level I/O components such as panel buttons, emergency stops and LED back light, it is also equipped with X20SM1436 stepper motor module enabling control of the lift mechanism drive. The Ethernet Powerlink protocol serves as the backbone of Pathfinder's communication equipment. Powerlink connects APC910 with an ACOPOS micro drive unit and X20CP1486 PLC and due to its advanced real-time features provides a robust communication pipeline between the key Pathfinder components.

The mobile platform is powered by two 12 V lead traction accumulators with a capacity of 55 Ah connected in series. According to real environment tests, this combination provides Pathfinder with a range of approximately 10 km, a value which covers the logistic requirements of an average 8 hour shift. A supercharger running in combination with power balancer is able to completely recharge the vehicle's batteries within 2 hours. Since the main power source of the vehicle is limited to 24 V, the ACOPOSmicro drive system with integrating similarly low level 8LV series synchronous motors was chosen as the Pathfinder power drive. Accurate positioning feedback was later revealed to be crucial aspect of the design during the development of Pathfinder's localization capabilities. Due to the 16-line multiturn encoders it is possible to calculate the vehicle odometry directly in PLC and this information can be used as an important data source affecting the general pose estimation process.

Two SICK LMS100 lidars provide the bulk of the data required for localization and navigation purposes. Connected over TCP/IP, laser scans of the surrounding environment are streamed to the APC navigation stacks 25 times per second. Other installed components are related to user interfaces and communication with the external environment.

A 4.3'' T30 touch panel mounted directly on the Pathfinder platform is the main service and maintenance interface and is used for control mode selection and basic diagnostics. Two wide angle cameras mounted on the front side of the platform are used for video streaming but also for synchronization tag recognition.

Pathfinder is also equipped with 4G/LTE Secure Remote Maintenance module which allows notification of authorized personnel in various situations. Depending on specific use requirements, this may be used for elevator calls, shipment delivery notifications or for diagnostics purposes. The TCP/IP network of Pathfinder and wireless connection with the facility network is realized through an embedded dual band Gigabit Wifi router capable of communicating on both 2.4 GHz and 5 GHz wireless bands. When the transporting cabinet is firmly mounted on the Pathfinder's top platform, users may find it more convenient to use an additional touch panel attached directly on the cabinet doors. For this purpose a Raspberry Pi module with a 7'' touch screen is utilized. By interfacing with the Raspberry Pi module, authorized personnel can select goal destinations from a predefined list and issue start and stop commands to the vehicle.

IV. LOCALIZATION AND MAPPING

Earlier generations of AGVs utilized magnetic tape or similar infrastructure components which were distributed along paths in order to simplify navigation. Although still widely used, the significant drawback of this approach such as the need for environment interventions, initial costs and regular maintenance, are obvious. Recent development in the field of autonomous localization and mapping has eliminated the need for environment interventions for most indoor navigation tasks.

The Pathfinder navigation functionality is built upon state-of-the-art SLAM technology [15], which constructs and continuously updates a map of the surrounding environment while simultaneously keeping track of the Pathfinder location in the map. The main data sources for the navigation stack are

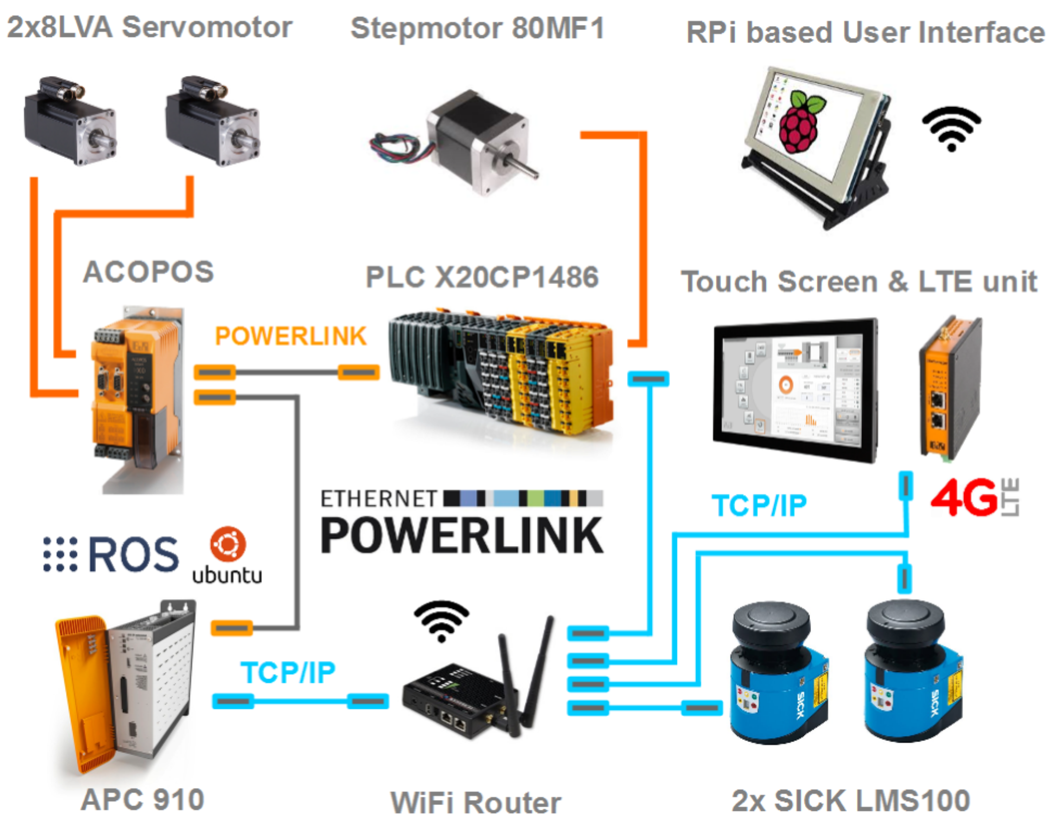

FIGURE 2. Basic overview of Pathfinder hardware components with Powerlink as the backbone of system communication.

the front and rear lidars. The current version of Pathfinder utilizes two SICK LMS100 Lidars which provide line scans of the robot surroundings with a resolution of 0.25°, a maximum range of 18 m and a 270° FOV running at 25 Hz. In order to guarantee safe and collision free operation, it is essential to have a full 360° scan of the robot surroundings. The sum of the two LMS100 fields of view is 540°, however is it not possible to combine these two laser scans directly due to the misalignment of the lidar placement. Therefore an additional laser scan transformation algorithm, which mathematically aligns scans acquired by rear lidar into the coordinate system of the front lidar, had to be developed in order to obtain a full 360° scan of the robot surroundings. In addition, raw laser scans must be filtered before entering the processing pipeline. The *LaserScanAngularBounds* plugin from *laser_filters* package [16] removes points located outside of predefined angular bounds by changing the minimum and maximum angles.

Fig. 3 gives an example of the final laser scan alignment during the Pathfinder runtime. A full 360° scan is essential not only for collision avoidance but also for localization purposes. Pathfinder localization is based on two data sources; the first pose estimate comes from the Canonical Scan Matcher [17] which is a very fast variation of the ICP algorithm [18], using point-to-line metric and optimized

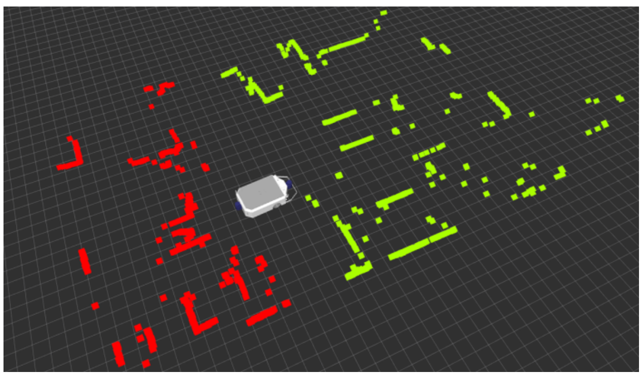

FIGURE 3. An alignment of laser scans from two Pathfinder SICK LMS100 Lidars. Scan acquired by rear lidar (red) is mathematically transformed into the coordinate system of the front lidar (green). The result is full 360° laser scan of robot surroundings required for proper localization and collision avoidance.

for range-finder scan matching. The second estimate is a standard odometry which is calculated by the B&R PLC directly from drive feedback data. These two poses are fused together using an advanced stochastic filter. The final result is usually very close to the ground truth data. However due to integration errors and offsets acquired during runtime, the pure sensor odometry does not provide a sufficient level

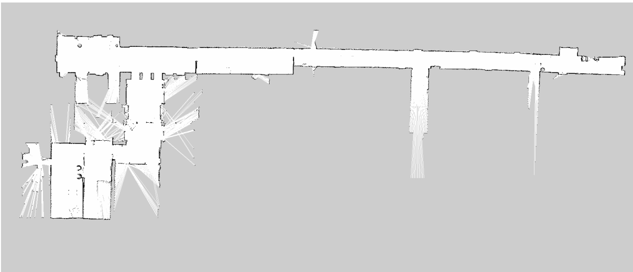

FIGURE 4. Map of the first floor of Kosice-Saca Hospital created by Pathfinder using two SICK LMS100 lidars, wheel odometry calculated by X20CP1486 PLC, Laser Scan Matcher, Angular Bounds filter and *gmapping* package.

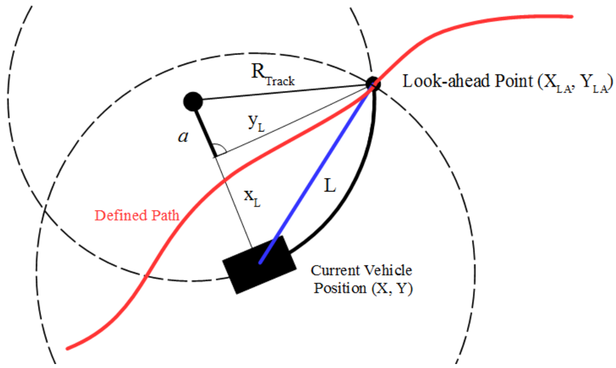

FIGURE 5. Illustration of Pure Pursuit algorithm principle. Knowing the current robot location and the look-ahead point on the path, the radius of arc joining the current and look-ahead distance point can be calculated.

of accuracy for use on longer paths. In order to overcome this hurdle, an advanced probabilistic localization system is used. An *Adaptive Monte-Carlo Localization* (AMCL) algorithm [19], which utilizes a particle filter to track the robot's pose against a known map, was the most appropriate solution in this case. AMCL takes a laser-based map, current laser scans, and subsequently transforms messages and outputs the pose estimates. When properly tuned and combined with sensor-based odometry, this technique gives the robust pose estimate even on longer trajectories. The map itself is created by another software package known as *gmapping* [20]. *Gmapping* is a highly efficient Rao-Blackwellized particle filter used to learn grid maps from laser range data, and this technology has provided the best results on laser scans acquired by the Pathfinder sensorics during several runtime experiments. In contrast to a similar mapping stack *hector_mapping* [21], [22], *gmapping* does not estimate its own position within environment and therefore requires localization to be performed externally.

This combination of external localization and mapping functionality is clearly visible during the initial on-site integration phase when a map of the target environment needs to be created. In order to acquire a 2D map, the Pathfinder running localization stack and *gmapping* package is manually guided over the facility several times in order to properly distinguish between static and dynamic obstacles and estimate the pose of walls and other firmly fixed objects. Fig. 4 shows an example map of the ground floor of Košice-Šaca Hospital created by Pathfinder. By combination of all this approaches the precision of the Pathfinder's navigation is ±5 cm.

V. PATH PLANNING

Comprehensive localization and mapping is essential for all state-of-the-art AGVs, but this does not solve the fundamental problem of how the robot will move to the goal destination within the known environment. Therefore, the integration of a further level of functionality known as Path Planning is necessary.

Once the actual position of the robot and its target position are determined on the map, it is then necessary to create a trajectory between these two points. Several different approaches are possible and the choice depends on the particular use case, the size of the robot and related environmental conditions in the operating facility. In the case of a dynamic environment with a lot of movement, which is typical for public areas, the most convenient solution is to implement an adaptive trajectory planner, which is able to avoid obstacles dynamically, while travelling to the target destination.

However for industrial environments, where larger volume robots are more typical and dynamic collision avoidance is not always possible or desirable, the use of strictly predefined trajectories is considered to be appropriate. This solution is very similar to the deprecated magnetic tape approach, but modern technology allows the definition of purely virtual tapes on existing maps. Regardless of the technique chosen, trajectory definition is only the first element of the Path Planning functionality. A runtime controller ensuring smooth and accurate trajectory following is also required. Again, several approaches exist, the most popular of which is the *Pure Pursuit Path Tracking Algorithm* [23], [24]. The pure pursuit approach was originally designed as a method of geometrically determining the curvature that will drive the vehicle to a chosen path point, termed the goal point. The implementation of the pure pursuit principle is illustrated in Fig. 5.

The current location of the vehicle (X, Y) in the global coordinate system is known. With a constant look-ahead distance L, the goal is to find the look-ahead point (X_{LA}, Y_{LA}) on the path. The algorithm calculates the radius R_{Track} of the arc that joins the current location of the vehicle (X, Y) with the look-ahead distance point. Based on two rectangular triangles, shown in Fig. 5, following equations hold:

$$x_L^2 + y_L^2 = L^2, \tag{1}$$
$$a_L^2 + y_L^2 = R_{track}^2, \tag{2}$$
$$x_L + a = R_{track}. \tag{3}$$

We express a from Eq. 3 and put it in Eq. 2:

$$(R_{track} - x_L)^2 + y_L^2 = R_{track}^2, \tag{4}$$
$$R_{track}^2 - 2R_{track}x_L + \underbrace{x_L^2 + y_L^2}_{L^2} = R_{track}^2, \tag{5}$$

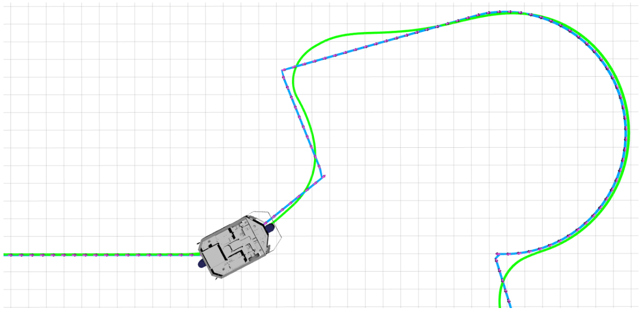

FIGURE 6. Visualization of the pure pursuit algorithm impact on real Pathfinder movement. Robot was able to perform smooth and continuous movement along a predefined path, even manoeuvring around corners and edges.

and finally we can express:

$$R_{track} = \frac{L^2}{2x_L}. \tag{6}$$

R_{track} value determines the actual arc radius the vehicle is to follow. The curvature of that radius is obviously its reciprocal value $(1/R_{track})$.

The algorithm is iterated every cycle meaning that the actual vehicle position is updated, a new look-ahead point is determined and the new arc radius is calculated again. The impact of pure pursuit algorithm implementation on the real movement of Pathfinder is shown in Fig. 6. With the look-ahead distance set at 0.75 m, the robot was able to perform smooth and continuous movement along predefined paths.

VI. BRINGING ROS AND POWERLINK TOGETHER

Over the last few years Robot Operating System (ROS) has emerged as the de-facto standard in the service robotics domain. The shared contributions of many people to this open source project have resulted in the development of strong middleware which includes a wide range of advanced tools and state-of-the-art libraries for use in robotic development [25], [26]. Pathfinder's development leveraged ROS capabilities from the very beginning and therefore one of the main questions which had to be resolved was choosing the method of communication between the ROS framework and B&R hardware.

ROS provides drivers for communication over various industrial fieldbuses, including EtherCAT, CAN, PROFINET, Modbus and several others. However, when the Pathfinder project first entered development, an official ROS-Powerlink interface did not exist. Not even a basic example of the integrating ROS and Powerlink existed at the time. From a technological point of view, ROS-Powerlink integration was feasible; openPowerlink [27], an open source stack for implementing Powerlink, is compatible with UNIX based systems and, like ROS middleware, is written in C++ language. The final development of a ROS C++ node which incorporates openPowerlink API was one of the main milestones of this project, since it allowed us to transfer data between ROS topics and Powerlink data channels running on B&R hardware. From the higher level protocols which were available we finally decided to use CIA401, a CANopen device profile for generic IO modules. The main purpose of the ROS-Powerlink interface is to map CIA401 data entries on ROS topics to ensure that the Powerlink and ROS data entries are synchronized on each cycle. In the case of Pathfinder, the cycle time is set to 8 ms, however in tests we managed to achieve reliable data transfers with cycle times as high as 400 μs. In the case of Pathfinder, the ROS-Powerlink interface handles the most crucial element of the communication process – data transfers of drive commands and odometry feedback between the navigation stack running on APC910 and ACOPOS controlling the drive wheels. From a network configuration point of view, the X20CP PLC is the managing node, while ACOPOS and APC operate as the controlled nodes. Table 1 shows an overview of the Pathfinder Powerlink IO Configuration.

TABLE 1. Basic pathfinder powerlink IO configuration.

Channel Name	Data Type	Description
Module OK	BOOL	Module Status (1 = OK)
AnalogInput_I2000_S01	DINT	cmd_vel - linear.x *1000
AnalogInput_I2000_S02	DINT	cmd_vel - angular.z * 1000
AnalogOutput_I3000_S01	DINT	Odometry - X * 1000
AnalogOutput_I3000_S02	DINT	Odometry - Y * 1000
AnalogOutput_I3000_S03	DINT	Odometry Theta * 1000
DigitalInput_I6000_S01	USINT	Reset Odometry Origin
DigitalInput_I6000_S02	USINT	Lift Control Command
DigitalOutput_I6200_S01	USINT	APC910 shutdown flag
DigitalOutput_I6200_S03	USINT	Control Mode Switch

The basic ROS–Powelink interface was made available to the robotics community as a Github repository [28]. It was not our direct intention to directly develop a generic ROS Powerlink driver, but rather offer a real use-case example and comprehensive integration guidelines, similar to the Kalycito Raspberry Pi2 Getting started guide [29]. We hope that our real ROS-Powerlink integration example will encourage more robotic developers to experiment with the advanced features of Powerlink protocol [30].

VII. USER INTERFACE

A 4,3" service touch panel mounted on the base platform allows users to switch between the three different control modes. Fig. 7 shows the main panel screen as designed in the B&R Automation Studio. Currently, Pathfinder offers three different control modes:

- Manual mode,
- Tablet ode,
- Auto mode.

Manual mode is of particular importance during the implementation phase. When switched to Manual mode, Pathfinder listens to the steering commands issued by the remote controller; in this case a wireless Xbox 360 controller from Microsoft was utilized. This combination allows precise motion control of the entire platform, and this is of crucial importance, when creating a map of the target environment.

FIGURE 7. **Main Pathfinder Service menu. 4,3 inch service touch panel mounted on the base platform allows users to switch between different control modes. For standard transport task definitions, Android application or Raspberry Pi display mounted on the cargo shelf can also be used.**

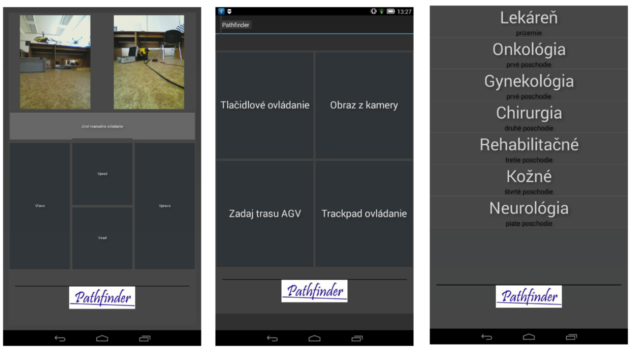

FIGURE 8. **Pathfinder Android application integrating existing ROS Java and ROS Android interfaces. The left screen shows a basic menu, the middle screen is a teleoperation mode while the right screen is a target goal selection menu specifically intended for implementation in hospital.**

The second control mode is *Tablet mode*. By integrating existing ROS Java and ROS Android interfaces, we developed a custom Pathfinder Android application (Fig. 8), which allows direct Pathfinder control over WiFi. The current version supports basic diagnostics, target goal selection and teleoperation – issuing steering commands while simultaneously observing video streams from both wide-angle cameras

The third control mode is *Auto mode* in which Pathfinder follows a trajectory as defined by virtual tape on an existing map. This is the standard production mode in which the robot completes transportation tasks as requested by operating personnel.

VIII. EXPERIMENTAL RESULTS IN HOSPITAL FACILITY

The capabilities of Pathfinder were explored during preliminary on-site tests in July-August 2017 in Košice-Šaca Hospital in the Slovak Republic (Fig. 9). Pathfinder was used to transport medical supplies between a logistics warehouse at the ground floor of the main building and various clinics located around the hospital facility. For this purpose, a special shelf cabinet, equipped with an electromagnetically controlled lock, an operator-controlled "GO" command button and an additional Raspberry Pi user interface panel was designed and assembled. Although Pathfinder is equipped with a lifting mechanism for manipulation with self-standing cabinets, in this particular use-case the cabinet was firmly fixed to the mobile base.

FIGURE 9. **Pathfinder during initial testing in Kosice-Šaca Hospital.**

From a developmental point of view, the main purpose of the test operation was the increase the overall robustness and reliability of the system. In full operation, Pathfinder must be able to deal adequately with different traffic situations and handle various environment related complications while remaining absolutely safe with respect to the surrounding environment. The data acquired during the initial test operation will help us in the development and comprehensive fine-tuning of the navigational features and collision avoidance functionality.

One of the most challenging tasks during the initial implementation of the Pathfinder platform in Košice-Šaca Hospital was ensuring proper navigation across all 11 floors of the main hospital building. The process of calling the elevator was simplified by the fact that one of the hospital elevators is continuously controlled by a human operator. Therefore when Pathfinder approaches the elevator door, it notifies the elevator operator by SMS with information about its current location and floor on which its goal is located. By pressing the green "GO" button at the top of the cabinet, elevator operator allows Pathfinder to enter the cabin at the current floor and to leave the elevator at the goal floor. However, dealing with the elevator issue is not the only problem involved in navigating across several floors. Comprehensive map management is also essential. In this case, a dynamic map switching approach was applied in order to guarantee consistency between the currently loaded map and the real floor environment. For this purpose, synchronization tags were placed on each floor next to the elevator doors. When leaving the elevator, Pathfinder utilizes its wide-angle camera to capture and recognize the synchronization tag. Each tag provides the information about the current floor and helps Pathfinder to load a map of current floor.

In addition to the developmental issues involved in introducing robots into a completely new environment, psychological aspect is also of great importance. Regardless of the robust functionality and advanced capabilities of the robot, it is still difficult to predict if such a device will be broadly accepted and utilized by hospital personnel in everyday life. Therefore a further goal of the pilot test operation is to explain and promote Pathfinder functionality to hospital staff, to demonstrate the basic usage and benefits of the system and to encourage hospital personnel to use the potential of the system.

IX. CONCLUSION

This paper has described the development of Pathfinder, an autonomous guided vehicle intended for the transportation of material in hospital environments. Using the latest B&R hardware components and the most recent software stacks for autonomous localization, navigation and mapping we have developed a logistics solution which is suitable for use in the more demanding tasks even in hospital environments. Pathfinder is also the first project which combines the strengths of Robot Operating System and Ethernet Powerlink protocol. As the backbone of Pathfinder communication, Powerlink guarantees quick response and reliable data transfer between the automation PC and ACOPOS micro drive which are essential for odometry measurement and related localization purposes.

From the economic point of view, we estimated the time of investment return for Pathfinder approx. to 2 years. Note that calculation of the investment returns depends on country-specific input values (salaries of hospital personal in Slovak Republic, etc.). Therefore the decision about Pathfinder replacing real human personal in future is beyond the scope of this paper.

The capabilities of Pathfinder were explored during preliminary on-site tests in July-August 2017 in Košice-Šaca Hospital, where Pathfinder was used for the transport of medical supplies between a logistics warehouse on the ground floor and various clinics located around the hospital facility. Initial test results are encouraging and led to the commencement of a 6-month long pilot operation which is scheduled to begin in September 2017.

Our research makes a significant contribution to current robotics development with the Pathfinder communication interface between ROS running on Ubuntu distribution and Ethernet Powerlink bus; this interface has been made available for public use. With the use of the attached sources and the detailed Wiki tutorial we hope that this first real use case example will encourage other robotic developers to experiment with the ROS and Ethernet Powerlink protocol in their future applications.

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