Real-Time Monitoring and Remote Guidance of Mobile Robots Using Multimodal Digital Twins

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***Abstract*—Although digital twins have been playing a pivotal role in the management of the lifecycle of physical robotic systems of systems, they have hardly been employed to guide mobile robots in real-time. In fact, the guidance of such systems requires functionalities, including the perception of targeted locations and avoidance of collisions, that build upon spatial information beyond internal robot states usually acquired using proprioceptive sensors. In this case, exteroceptive sensors help meet this demand. Nevertheless, such sensors have received little attention thus far in the development of digital twins. On the other hand, the completion of various spatial objectives, such as reverse motions, might require the awareness of the historical internal state of the distant robot. For instance, the current energy budget is likely to constrain the reachability of the initial state after a while, even when spatially and kinematically feasible. We therefore embrace these challenges with a multi- modal approach to provide and employ digital twin of mobile robots. We collect data about the internal state and camera- captured neighborhood of the robot in real-time. The robot operator is thereby provided with a multi-dimensional state and perception view that characterizes the robot, elevates situational awareness, and facilitates decision support. We then develop a versatile graphical interface that helps monitor and steer mobile robots. Since the bidirectional approach is intuitive and user friendly, even novices can remotely guide a mobile robot with multi-modal situational awareness. We show the versatility and effectiveness of our approach in use case scenarios in practice.**

***Index Terms*—Robotics, Multimodal Data, Digital Twins, Industry 4.0, Industry 5.0, Society 5.0, Human-Mobile Robot-Interaction, Systems of Systems**

I. Introduction

The Robot Operating System (ROS) is one of the most popular pieces of software when it comes to creating a basis for robots and creating robot applications [1]. Nevertheless, it is a challenge for people with little or no knowledge of robot software to familiarise themselves with this software. Especially people who are dependent on the help of robots should have intuitive access to these robots. With this in mind, a web application was developed that is as platform-independent as possible. This web application enables users to monitor and control the robot located in the local network. Furthermore, relevant data such as the battery status and the temperatures of the motors are visualised. The application can also be used via any device with web browser support. The robot in question is the Husky Unmanned Ground Vehicle (UGV) from Clearpath, which is a medium-sized mobile robotics platform as shown in fig. 1. With a maximum payload

Fig. 1. Picture of the Husky UGV by Clearpath

of 75 kg, other robots or tools can be transported or mounted on the platform, for instance [2].

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Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \tag{1}$$

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- The word "data" is plural, not singular.
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- The abbreviation "i.e." means "that is", and the abbreviation "e.g." means "for example".

An excellent style manual for science writers is [7].

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TABLE I
TABLE TYPE STYLES

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
copy	More table copy[a]		

[a]Sample of a Table footnote.

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity "Magnetization", or "Magnetization, M", not just "M". If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write "Magnetization (A/m)" or "Magnetization {A[m(1)]}", not just "A/m". Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)", not "Temperature/K".

Fig. 2. Example of a figure caption.

ACKNOWLEDGMENT

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REFERENCES

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Unless there are six authors or more give all authors' names; do not use "et al.". Papers that have not been published, even if they have been submitted for publication, should be cited as "unpublished" [4]. Papers that have been accepted for publication should be cited as "in press" [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

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