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Edge robotics and emerging platforms with sensing and human interaction capabilities

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Abstract. Robotics is rapidly developing and changing. There is a clear trend toward enabling and improving human-robot interaction and the manual guidance of robots in industrial environments. The robotic community is expanding its portfolio of open-source software solutions to ease the implementation of new robotic platforms. This article provides a short overview of practicable architectures for modern robotic platforms and the role of edge robotics, with a quick discussion of the implications and current research trends for social and industrial robotics. The recent literature is reviewed. This work foresees interesting new developments for social and industrial robotics in the future.

Key words. Edge robotics – Internet of Things – Robotic sensing – Human-robot interaction

1. Introduction

The development of innovative robotic platforms and the seamless integration of computing boards, connectivity services, server computers, sensors, and actuators can still revolutionize how robots are conceived and perceived. Achieving effective integration and realizing the full potential of robotic systems presents significant challenges since robot parts, sensors, and end-effector tools often need to be designed to be put together and form a holistic system. Robotics has undergone a fundamental change over the last decade. The advent of new open-source software frameworks has made robotics more accessible to new users in research and consumer applications (Koubâa (2017)). A key pillar of these open-source frameworks is the notion of not reinventing the wheel by providing easy-to-use libraries for different capabilities like navigation, manipulation, control (and more). The rapid increase in the number of intelligent devices connected to the Internet is resulting in large-scale data, which has caused problems such as bandwidth load, slow response speed, poor security, and poor privacy in traditional cloud computing models. Traditional cloud computing is no longer sufficient to support the diverse needs of today's intelligent society for data processing, so edge computing technologies have emerged. It is a new computing paradigm for performing calculations at the edge of the network (Rose (2015), Cao (2020)). Similarly, the same concept is increasingly being applied to develop new robotic platforms at a smaller scale. Like edge computing, edge robotics emphasizes the advantages of processing the sensor data as close as possible to the data source.

The architectures of humanoid robots used in civil social environments and industrial robots used in manufacturing environments are similar in many aspects. Social robotics develops anthropomorphic platforms to facilitate the interaction of intelligent robots with their human counterparts. Although industrial robots do not necessarily need an anthropomorphic aspect to perform assembly, packaging, manufacturing or quality inspection tasks on industrial shop floors, the current trend is to develop robots capable of operating side-to-side with human operators, sharing a common safe working environment. As such, industrial robots are being equipped with intelligent sensors and the capability of perceiving the presence of humans and adapting their behavior (Stieber (2015)).

This article briefly overviews the current research direction for social and industrial robotics. Section 2 describes the parts that typically constitute a robotic platform. Section 3 discusses edge robotics in anthropomorphic platforms, providing simple examples. Section 4 makes a parallel between industrial robotics and the current trends. Finally, Section 5 concludes.

2. Constituent parts of a robotic platform

A robotic platform is made up of several parts that can be grouped into five categories:

- the hardware dedicated to computation;
- the sensors that make up the perceptive apparatus of the robot;
- the devices dedicated to supplying energy;
- the mechanical parts;
- the software components that determine the behavior of the robot.

An essential aspect concerns communication and data exchange between the different hardware components. The perceptive sensor part must transmit and receive data which must be managed and interpreted by the software modules that deal with perception, understanding, and action.

A typical software solution for connecting all platform parts uses middleware, such as the Robot Operating System (ROS) (Koubâa (2017)). ROS provides the standard services of an operating system, such as hardware abstraction, device driver control, inter-process communication, application (package) management, and other commonly used functions. A set of processes within ROS can be represented in a graph as nodes that can receive, send and multiplex messages from and to other nodes, sensors, and actuators. Thus, the middleware connects similar or very different components that are put together mechanically and electronically to form a platform.

Furthermore, it is necessary to choose a conceptual architecture to implement the software components that will create the robotic platform. Fig. 1 represents a rather general multilayer architecture that the authors of this work have already used in other works (Maniscalco (2020)). The communication among the layers, managed by a topic-based communication handler, has been devised as topic-based to model the event-driven asynchronous nature typical of human-robot interactions. The architecture accesses sensory data and controls the actuation of the robot drivers via a hardware virtualizer component, mainly implemented in Python based on the Robot Operating System (ROS), a set of open-source Python libraries and tools for building robotic applications. Part of this architecture, always concerning the software layer, are some client/server components to manage particular functions of some devices and small firmware applications that implement the adopted macro-behaviors, such as blinking the robot's eyes or other similar, so to speak, autonomous behaviors.

The Perception layer includes various components that opportunely process the robot's sensory data to create high-level information. Most modules operate a process of filtering and merging multi-sensory data to obtain the highest level of information.

The manager layer allows for managing and generating the interaction responses de-

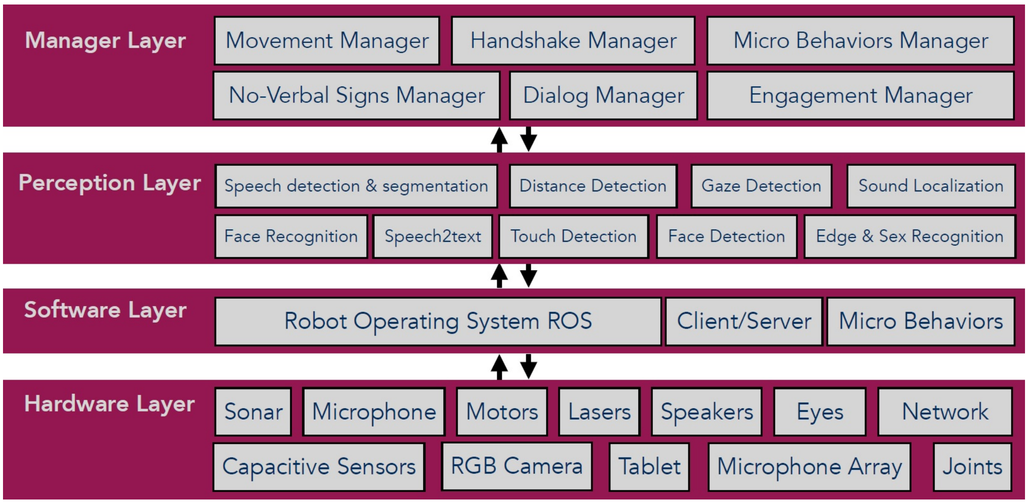

Fig. 1. Example of multi-layer architecture for robotic platforms.

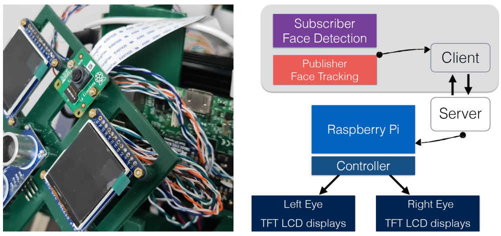

Fig. 2. Example of micro-behaviour and edge robotics: eyes movement.

rived from the previous layer, controlling the robotic devices involved in a particular interaction response. This layer implements the verbal and non-verbal behaviors of the robot. The manager layer receives the information necessary to implement the actions through topic-based communication. Topics related to verbal aspects implement the appropriate communication channels.

3. Edge robotics in anthropomorphic platforms

There is a growing tendency to process as much information as possible near the sensor, where it is collected (Cao (2020)). The reason is the growing availability of intelligent components, which is what usually goes under the so-called Internet of Things (IoT) (Rose (2015)). These components can perceive the environment in which they are located, process information, and transmit it on the network to other parts. It is a matter of enriching the information as much as possible where it is somehow perceived. This kind of technology facilitates the modularity and scalability of robotic platforms, thanks to the fact that a distributed and connected computational capacity can acquire information and enrich it at a semantic level. The enriched information can then be used to build complex systems and do things much more advanced than what a single part of a platform can do.

The ROS communication system is based on two fundamental concepts: that of “node” and that of “topic”. The node is a software application. A topic is a communication channel within a node. The topics can be “publishers” as communication channels that publish the information on the middleware in such a way as to make it available to other nodes. Other topics are “subscribers” since they benefit from the information published on the middleware. Let us imagine using a camera connected to an electronic controlling board. We can take a frame from this camera and post it to the middleware through a publisher. For example, a node that performs Face-detection can use this frame and contain a publisher to release new helpful information to the subscriber of another node that performs Face-recognition, to identify the person to which a given face belongs. It must be noted that the node doing Face-detection could also do Face-tracking. So it is clear that placing intelligence very close to the sensors allows us to carry out a series of operations that can gradually contribute to a more complex machine. Concerning the micro-behaviors mentioned above, for example, we could use a Raspberry Pi board (Zhao (2015)) to control two small LCD screens representing the anthropomorphic robot's eyes (see Fig. 2). The LCD screens can take advantage of the Face-detection node to allow the Raspberry Pi to control the two LCDs. Each of these LCD screens shows a stylized human eye, the movement of which is intended to give the sensation that the robot maintains eye contact with the human agent in front of it and whose face it is following (Maniscalco (2022)). Therefore, a simple board costing a few tens of euros, equipped with a camera, two LCD screens, and eye movement control software, exhibits a modular and independent functionality (micro-behavior) that can be used in robots of any scale. In the context of anthropomorphic robots, two categories must be distinguished. The first category is that of robots with anthropomorphic features. The second category is that of robots with anthropomorphic behavior. The two categories may apply to some types of robot platforms but may also be unrelated to other types of robots. A very trivial example is often represented in cartoons, where objects that are not anthropomorphic from the point of view of their body instead have human behaviors and are recognized as anthropomorphic. In the Disney cartoon “Cars”, the cars are not humans, but the viewer recognizes them as anthropomorphic because they have human behaviors. Robotic platforms based on intelligent and connected parts (edge robotics) are becoming more popular in the research community. Engaging modular robotic platforms capable of interacting with human counterparts are achievable at limited costs, allowing large experimental campaigns in the social and rehabilitation robotics field (Maniscalco (2021)). The small cost is only one of the reasons. Researchers appreciate the availability of open-source software that can be reused to obtain specific micro-behaviors. Multiple low-cost controlling boards manage to reach significant computational and memory capabilities. Additionally, no external computer is needed to control the robot platform through ROS when the communication middleware is embedded within every single controlling board of small modular parts. That aspect is crucial to minimize a robot's latency and reaction time to stimuli since no time is wasted to transfer data over Ethernet or WiFi communication protocols towards an external machine. Other important aspects include the possibility of simplifying the reconfiguration of existing robots or the conceptualization of new robots, functionalities, and algorithms, thanks to the modular nature of single intelligent parts. In this direction, 3D printing is greatly helping the fast prototyping of new robot hardware to bring together any new set of sensors and actuators. Finally, the capability of robotic platforms based on the edge robotics paradigms to process the information where that is generated is not of minor importance since it allows to avoid many privacy and security issues.

4. Industrial robots with sensing and human-interaction capabilities

Besides humanoid robots and robots with anthropomorphic behaviors used in social environments, as human assistants, or for rehabilitation, industrial robots constitute a much larger subset of the currently employed worldwide. An industrial robot does not necessarily resemble the morphology of the human body. Beyond being used for automated assembly, packaging, and manufacturing operations, industrial robots are nowadays employed for quality inspection tasks. Humans have an immediate perception of shapes and surroundings through their senses and their cognitive capabilities. This innate ability enables the manual inspection of components in manufacturing environments. Trained inspectors combine their senses and handling skills with bespoke non-destructive testing instrumentation.

However, manual inspections can be slow for large and/or complex geometries and prone to human factors. Automated non-destructive testing systems have recently emerged to increase data acquisition speed, part coverage, and inspection reliability. These tools work well when the robotic inspection takes place in a well-structured environment and an accurate part model is available. However, precisely registering the position of a part in the robot reference system makes the inspection setup very time-consuming. Furthermore, the geometry of a part may differ from its digital model, spoiling the inspection accuracy. New robot control approaches have recently allowed mimicking the human perception capability and are giving full autonomy to robotic sensing applications. Mineo (2022) used a single robotized sensor and advanced software to introduce fully autonomous single-pass geometric and volumetric inspection of complex parts. Meanwhile, the new generation of industrial robots is equipped with accurate force-torque sensors and high-precision mechanics to meet stringent safety standards for operating outside fences. Besides relying on the sensors, the safety of these robots relies on lightweight construction materials, rounded edges, inherent speed, and force limitations, or software that ensures safe behavior. These robots are often called collaborative robots or “cobots” for short. Cobots are intended for direct human-robot interaction within a shared space or where humans and robots are in close proximity. Cobot applications contrast with traditional industrial robot applications in which robots are isolated from human contact (Stieber (2015)). These developments open significant opportunities for human-robot interaction in manufacturing/industrial environments. The current direction of the research aims to merge humans’ ability to quickly perceive the environment with the capability of robots to perform repetitive tasks accurately. For example, a human operator close to a cobot can quickly grab the cobot end-effector and manually bring it to any point above a part that needs to be robotically inspected or processed. Then, the cobot can start its autonomous task guaranteeing all safety standards at all times and leaving the surrounding human operators free to interact or interrupt. Modern robotic sensing applications can collect vast volumes of data in industrial environments. That is paving the way to a new research thread. Indeed, new data visualization and data analysis tools, suitable to assess the data obtained through high-speed inspection systems, are urgently required to decrease the time needed for human data analysis (Mineo (2018)). Recently, Mineo and Montinaro (2022)) introduced an innovative inspection platform consisting of a pulsed thermography setup, a six-axis robotic manipulator, and a novel algorithm for image alignment, correction, blending, and presentation. Augmented reality offers new opportunities for improving the visualization of robotic inspection data by superposing the data to the real part geometry. That may be done after the robotic inspection or while ongoing, which may pave the way to seamless human-robot interaction.

5. Conclusions

This article provided an overview of viable architectures for modern robotic platforms and the role of edge robotics. This kind of technology facilitates the modularity and scalability of robotic platforms, thanks to the fact that a distributed and connected computational capacity can acquire information and enrich it at a semantic level. The enriched information can then be used to build complex systems and do things much more advanced than what a single part of a platform can do. Moreover, the capability of robotic platforms based on the edge robotics paradigms to process the information where that is generated is not of minor importance since it allows to avoid many privacy and security issues. In industry, the current direction of the research aims to merge humans’ ability to quickly perceive the environment with the capability of robots to perform repetitive tasks accurately. Collaborative robots are being introduced to enable direct human-robot interaction within a shared space or where humans and robots are in close proximity. Finally, augmented reality offers new opportunities for improving the visualization of robotic inspection data by superposing the data to the real part geometry, paving the way to more seamless human-robot interaction.

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