ROS-Neuro: A common middleware for neurorobotics

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***Abstract*—Recent years have seen a growing interest for the neurorobotics field, a new interdisciplinary research topic that aims at studying neuro-inspired approaches in robotics and at developing innovative human–machine interfaces. However, in most cases, evidence of interactions between robotics and neuroscience is currently scarce and the latest advances in both fields are often mutually neglected. One of the reasons for this limitation could be due to the lack of a common research framework that may facilitate the integration of these two technologies.**

In this scenario, we propose ROS-Neuro, an open-source middleware based on ROS, that aims at overcoming the aforementioned limitations and at providing a common development ecosystem for neuro-driven robotic applications.

***Index Terms*—ROS-Neuro, neurorobotics, brain-machine interface**

I. INTRODUCTION

Recent technological advances in the intertwined fields of robotics and neuroscience have opened the opportunity for a new generation of neuroprostheses that are able to extract, process and decode human intentions from neurophysiological signals and to translate them into the control of external devices. Translational applications and everyday usage have always been the paramount promise of such novel interfaces with the aim of restoring the independence of people suffering from severe motor disabilities. Indeed, last years have seen a flourish of neurorobotic prototypes ranging from electromyography (EMG) driven upper and lower limb prostheses to brain-machine interface (BMI) driven powered wheelchair and telepresence robots [1].

However, despite these impressive achievements, the current level of interaction between robotics and neuroscience fields is still scarce. On the one hand, the former does not usually consider the non stationarity nature of neurophysiological signals and the consequent uncertainty of the derived control signal. On the other, the latter mainly focuses on investigating and proposing new methods and solutions to correctly decode user's intentions from neural sources by neglecting the robotic part and by considering the robot as a passive actuator of the delivered intention. As a consequence, the development of neurorobotics is still at its infancy and the potential impact of the technology is strongly limited.

Although several reasons might be adduced for such a widespread tendency, in this work we focused on two main practical limitations of the current approaches to neurorobotics. First, the lack of a common ecosystem between neuroscience and robotic research. Second, the fact that each research group is inclined to adopt their own robotic solution—often home-made—to control the neuro-driven device. This has led to a heterogeneity of neurorobotic applications and, as a consequence, a widespread lack of standards.

To face the aforementioned limitations, we have recently proposed ROS-Neuro, an open-source framework for neurorobotics [2]–[4]. The aim of ROS-Neuro is to provide a common implementation and research framework to boost the mutual integration and interaction of the neuroscience and robotic fields. ROS-Neuro may be considered as an extension of the Robotic Operating System (ROS) that—in the last decade—has become the worldwide standard *de facto* in robotics. The main characteristic of ROS is to be an open-source project developed by a constantly growing community. The collaborative software development approach underlying ROS allowed a rapid spread of robust, multilanguage and intensively-tested packages between different groups with minimal development effort. Furthermore, it provides a modular multi-processing architecture and a reliable communication infrastructure that are fundamental also for neural driven systems

II. ROS-NEURO ARCHITECTURE

From an engineering perspective, ROS and neuro-driven applications (e.g., EMG based prostheses or BMI systems) share several similarities. Both of them are based on processes running in parallel and communicating each other with a minimal possible delay. In the ROS framework, such modules are in charge of different aspects of the robotic applications—ranging from the low-level management of the motor controllers and the acquisition of sensors' data (e.g., laser range finders, computer vision systems and odometry encoders) to the high-level behavioral algorithms for autonomous navigation and human-robot interaction.

Similarly, neuro-driven applications are based on a modular architecture in order to acquire, record and process the neural signals and to generate a control signal for the neurorobotic application. To date, the current release of ROS-Neuro provides the following modules:

- `rosneuro_acquisition`: the node is in charge of acquiring neural signals from a variety of recording

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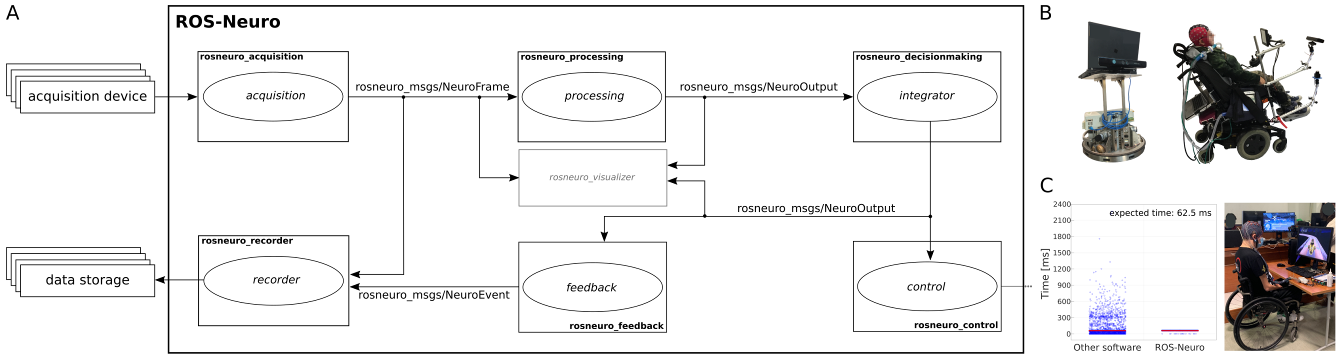

Fig. 1. A) Schematic representation of ROS-Neuro architecture with the available modules and messages. B) BMI driven robotic applications tested with ROS-Neuro. C) On the left, comparison of the data processing delays between ROS-Neuro and previous validated BMI software; on the right, the use of a BMI system implemented in ROS-Neuro during the Cybathlon 2020 event.

devices (e.g., EMG, electroencephalography (EEG)) and to output them in a specific topic as a custom message `NeuroFrame`.

- `rosneuro_recorder`: the node is in charge of automatically recording and storing the acquired data and possible discrete events in an external file.
- `rosneuro_processing`: the node processes the `NeuroFrame` and output the decoded intention as a `NeuroOutput` message.
- `rosneuro_feedback`: the node provides a visual feedback of the decoded intention to the user.
- `rosneuro_decisionmaking`: the node implements decision making algorithms that interpret the `NeuroOutput` accordingly to the requirements of the specific application.
- `rosneuro_control`: the node translates the `NeuroOutput` into a control signal for the specific application.

Figure 1A illustrates a schematic representation of the ROS-Neuro architecture. It is worth to highlight that the current release of ROS-Neuro is open-source and available online[1].

III. ROS-NEURO CASE SCENARIO

ROS-Neuro has the potentiality to be exploited in several neurorobotic applications accordingly to the neurophysiological signals acquired (e.g., EMG driven exoskeletons, EEG based control of mobile robots). In particular, ROS-Neuro has been carefully tested and evaluated in the case of an EEG based BMI where the user is asked to perform two motor imagery (MI) tasks (e.g., imagination of the movement of right or left hand) to control an external device (Figure 1B). From a technical perspective, ROS-Neuro guarantees a minimum delay and the absence of glitches between the acquisition of the EEG signal and the decoded output (Figure 1C). At the application level, ROS-Neuro has been extensively evaluated during the participation of the WHI Team (Department of Information Engineering, University of Padova) at the Cybathlon 2020, the first international neurorobotic championship[2] (Figure 1C). The robustness and reliability of ROS-Neuro has been one of the keys for the victory of the WHI team (gold medal) in the Brain-Computer Interface Race discipline.

IV. CONCLUSION

In this work we present the latest release of ROS-Neuro, the first integrated platform designed to promote the integration of robotics and neuro-driven solutions in the same development ecosystem. It is worth to mention that the successful of ROS-Neuro strictly depends on the fruitful interaction and discussion between different research groups. We firmly believe that such a collaborative development approach may boost the research on the interaction between BMI and robotic devices and may open new frontiers for an innovative way of analysing and re-thinking the next generation of neurorobotic applications.

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REFERENCES

[1] L. Tonin and J. d. R. Millán, “Noninvasive Brain–Machine Interfaces for Robotic Devices,” *Annual Review of Control, Robotics, and Autonomous Systems*, vol. 4, no. 1, 2021.

[2] G. Beraldo, M. Antonello, A. Cimolato, E. Menegatti, and L. Tonin, “Brain-computer interface meets ROS: A robotic approach to mentally drive telepresence robots,” in *2018 IEEE International Conference on Robotics and Automation (ICRA)*, may 2018, pp. 1–6.

[3] L. Tonin, G. Beraldo, S. Tortora, L. Tagliapietra, J. Millán, and E. Menegatti, “ROS-Neuro: A common middleware for BMI and robotics. The acquisition and recorder packages,” in *2019 IEEE International Conference on Systems, Man, and Cybernetics*, 2019.

[4] G. Beraldo, S. Tortora, E. Menegatti, and L. Tonin, “ROS-Neuro: implementation of a closed-loop BMI based on motor imagery,” in *2020 IEEE International Conference on Systems, Man, and Cybernetics*, 2020, p. In press.

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[1] https://github.com/rosneuro

[2] https://www.cybathlon.com