I-TROPHYTS Project: Human Activity Recognition for Next Generation Motor Rehabilitation Systems

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***Abstract*—In this paper, we present the goals and reference architecture of the I-TROPHYTS and SORTT projects, funded by MUR under the PRIN 2022 and PRIN PNRR 2022 programs. Both projects aim to innovate rehabilitation systems by introducing real-time monitoring solutions for patients and semi-autonomous decision-making capabilities. We describe the research contributions of the UNIBO teams in designing and implementing cutting-edge solutions for IoT data collection and motor routine identification through AI techniques.**

I. Motivations

The recent Covid-19 pandemic has highlighted the urgent need for innovative healthcare systems capable of remotely monitoring patients. To address this need, the Internet of Things (IoT) offers devices and platforms that collect vital and motor data through wearable devices or sensors embedded in common non-intrusive mobile devices like smart bracelets, rings, or watches. The integration of IoT with data analytics techniques provided by Artificial Intelligence (AI) gives rise to the novel Artificial Intelligence of Things (AIoT) paradigm, which unlocks previously unrealized customer value in various domains, healthcare being a primary example. In this paper, we explore the application of AIoT in smart rehabilitation systems for diverse patient populations, including type-2 diabetics (both obese and non-obese), pregnant women (both normal and diabetic), and individuals with Parkinson's disease, all of whom can benefit from customized physical activity programs. Traditionally, physical rehabilitation requires the constant presence of healthcare professionals, such as physiotherapists or rehabilitators, to supervise and guide patients through their routines. However, the Covid-19 pandemic has challenged the physical accessibility of medical facilities and raised questions about alternative methods to alleviate pressure on hospitals while ensuring continuous patient monitoring and safety.

II. The I-TROPHYTS and SORTT Projects

In this paper, we present the structure and ongoing activities of the I-TROPHYTS[1] and SORTT[2] projects, funded by the Italian MUR agency under the PRIN 2022 and PRIN PNRR 2022 programs. Both projects introduce a pioneering approach to real-time and semi-autonomous supervision of motor rehabilitation activities, aiming to increase the efficiency of healthcare services while ensuring patient safety. To achieve this, we utilize modern IoT technologies combined with state-of-the-art distributed learning techniques. Figure 1a shows the reference architecture of the I-TROPHYTS project [1]. We consider three agents:

- **Patients**. IoT devices are worn by patients to monitor: motor routines using IMU sensors; and vital signs such as heart rate and blood pressure using smart rings.
- **Humanoid robot**. The robot provides the physical exercises for the patients to execute.
- **Human physiotherapist**. The physiotherapist monitors physiotherapy sessions using data from the IoT devices and is notified in case of hazardous situations.

Based on the IoT data gathered, the robot may decide to: continue the therapy plan by executing the next exercise in the sequence, assign cool-down periods, perform alternative exercises, or alert the human supervisor. Figure 1b illustrates the reference architecture of the SORTT project. While this project shares similar goals with the I-TROPHYTS project, it addresses a different scenario. Specifically, we consider an indoor, private environment where each patient performs the physiotherapy session solo and from home. In this context, the robot has been replaced by a more traditional personal device, such as a smartphone. Additionally, the project's objective is to model and implement a Digital Twin (DT) of the physiotherapy session. The DT aims to adjust the sequences of motor routines based on the patient's current motor and vital performance, assign cool-down periods, or perform alternative exercises. In cases of predicted or actual situations requiring attention, the medical operator is alerted by the system. Figure 1c shows the logical organization of the framework, which is shared by both the projects. Specifically, the architecture comprises the following layers:

- *Sensing* Layer: This layer includes an IoT monitoring system for patients participating in physiotherapy sessions, capturing both biometric and motor data. The collected data are processed using AI techniques to detect the current human activity and assess the quality of the motor routine, as further detailed in Section III.
- *Knowledge* Layer: This layer focuses on representing contextual information from the rehabilitation session to construct the knowledge base of the robotic system. It involves the use of semantic technologies and ontologies

[1] https://site.unibo.it/itrophyts/en
[2] https://www.loa.istc.cnr.it/sortt/

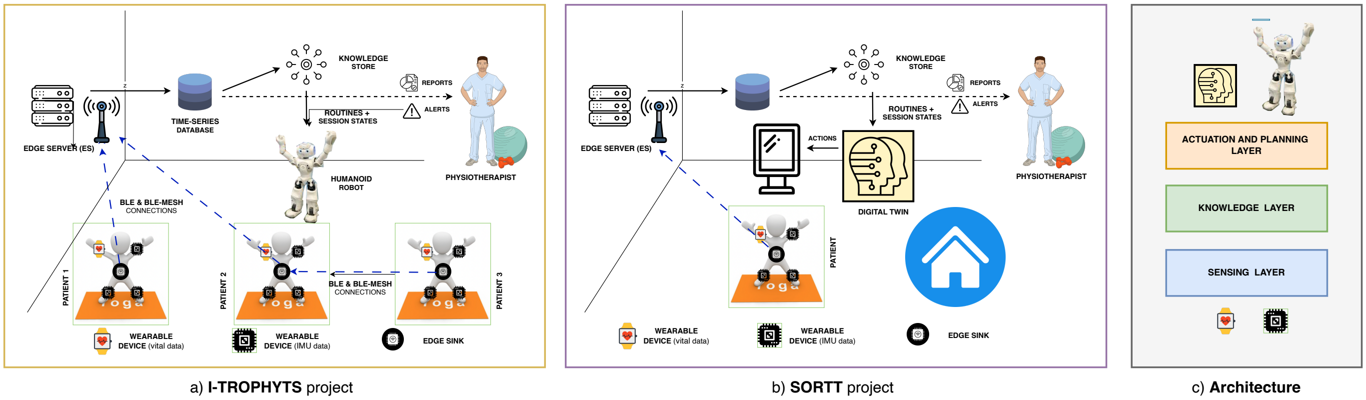

Fig. 1. The I-TROPHYTS and SORTT scenarios are represented in Figures a) and b), respectively. The framework architecture is shown in Figure c).

to model the physiotherapy session and its data.

- *Planning and Actuation* Layer: Situated atop the *Knowledge* Layer, this layer serves as the decision control system. It leverages inputs from the knowledge base to determine the next course of action based on the current state, goals, and preconditions. For the I-TROPHYTS project, this layer is responsible for orchestrating the robot's actions. For the SORTT project, it includes the strategy to create the Digital Twin (DT) and model the states and evolution of the physiotherapy session.

In the following, we focus the attention on the operations of the *Sensing* Layer.

III. IoT DATA ACQUISITION AND PROCESSING

The UNIBO team is currently working on the design and implementation of the *Sensing* Layer, responsible for patient monitoring and IoT data acquisition. The *Sensing* layer implements the acquisition and processing pipeline, which includes the following components:

- **IoT Data Gathering**: During the physiotherapy session, all patients wear a smart ring to monitor vital signs and a wearable microcontroller with embedded IMU sensors to track motor routines. On the edge, features are extracted from the raw signals.
- **Data Transmission**: All IoT devices are equipped with BLE connections to offload sensing data towards an edge server. In I-TROPHYTS, we further investigate the performance of BLE Mesh technology [2] to create multi-hop, multi-sink wireless mesh networks among IoT wearable devices. In contrast, the SORTT project does not impose specific networking requirements as each deployment involves only one patient.
- **Activity Identification**: The features extracted from IMU data are input to this module, which is responsible for detecting the current motor routine within the physiotherapy session. We treat this problem as a supervised learning task and employ machine learning and deep learning techniques to address it.
- **Routine Quality Assessment**: Besides identifying the motor exercise, an additional task is to assess whether the user is performing it correctly. This information is fundamental given the semi-autonomous scenario of physiotherapy. In the I-TROPHYTS project, the robotic actuator decides the next actions based on the current patient's performance. Similarly, in the SORTT project, the information is fed into the Digital Twin (DT). We exploit a kinematic model to track the trajectory of the sensors and compare current positions and angles with predefined thresholds set through a clinical assessment.

In the I-TROPHYTS project, we analyzed the use of Edge AI techniques for activity recognition, with inference migrated to the edge to reduce the amount of data transferred outside the microcontroller [3]. We are further investigating the utilization of Federated Learning (FL) to protect the privacy of patients during training tasks, while simultaneously benefiting from knowledge sharing for more accurate motion recognition.

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