(one6G)

Taking communications
to the next level

6G & ROBOTICS

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Motivation to explore robotics applications

One6G envisions a future where 6G technologies and solutions allow to unleash the potential of smart connectivity for a secure, resilient and sustainable development of our society. One of the ways to understand the potential factors influencing our society is by observing market trends and evolving societal requirements. Among the different digital services and devices that are gaining significant attention, robotics is one such domain. Below we briefly present some of the trends in robotics that are being observed based on published reports.

Increasing annual installations of industrial robots

As per International Federation of Robotics (IFR) report on industrial robots, the worldwide annual installation of industrial robots has crossed half a million mark, and the operating stock of industrial robots has crossed three million mark [1]. Based on consolidated worldwide statistics, the electrical/electronics industry is a major customer for industrial robots, while other industries such as automotive, metal and machinery, plastic and chemical products, and food show a significant two-digit growth. As per their forecast, the industrial robots' market is expected to grow, with the highest number of installations in Asia/Australia market, followed by Europe and the Americas.

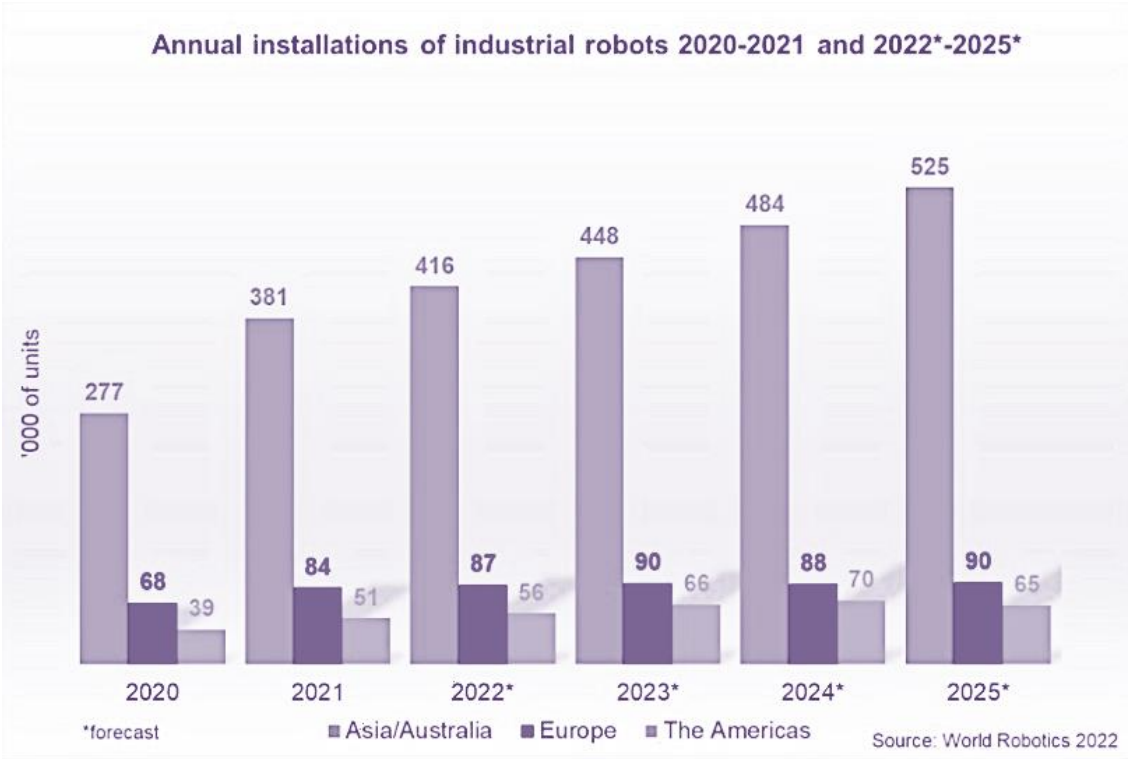

Figure 1: Forecast of annual installation of industrial robots

Increasing collaborative robots in industrial environments

Among the different industrial robots, the market share of collaborative robots compared to traditional robots are seen to steadily grow, as shown in Figure 2 [1].

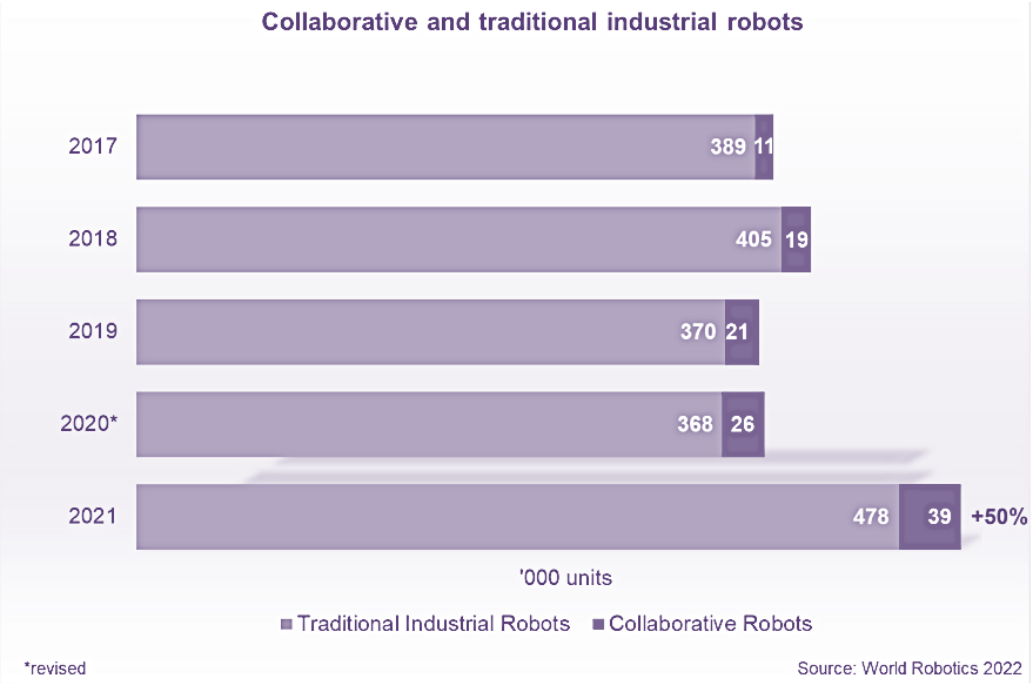

Figure 2: Market share of collaborative and traditional industrial robots

This could mean that different robotic applications such as material handling, welding, assembling and sorting may increasingly rely on human and robot collaboration to complete the tasks [1], [2].

Increasing service robots for professional and consumer use

Robots for professional use are usually found in warehouses, hospitals, and airports or even on dairy farms to carry out specific tasks [3]. Robots for consumer use refer to those that are used for domestic purposes such as vacuuming, floor-cleaning, or gardening. Studies show that the demand for service robots is increasing in several regions around the world: Asia, Europe and North America. Figure 3 shows the statistics from IFR comparing the sales of service robots in different application areas in year 2020 and 2021.

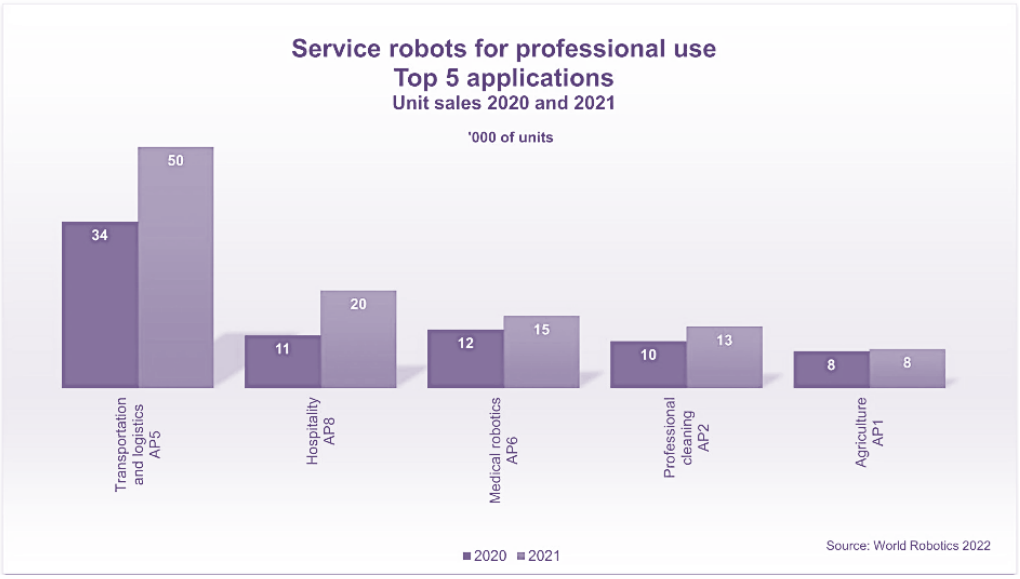

Figure 3: Sales of service robots for professional use

Growing demand for staff in key societal areas such as healthcare

According to a report prepared for European Commission [4], severe staff storage of professionals is seen in healthcare and long-term care sectors in Germany. It is projected that in the area of long-term care additional staff requirement can be as high as 263,000 – 500,000 professionals by 2030. Since medical robots is becoming one of the top application areas for professional use robots, personnel shortages in critical societal areas could be complemented by use of robots across many regions of the world to support medical and healthcare services on premises and remotely.

Why we discuss 6G for robotics?

The 5G communication system has started paving the way for supporting wireless communication in robotics applications such as remote robot operation using 5G URLLC capability mainly for campus applications with very limited service areas. Most of the requirements in 3GPP regarding robots target industrial robots with a very clear and limited flexibility [6][7].

However, to successfully support the foreseen demand of robotics applications in different scenarios and applications as discussed previously, communication systems must be capable of supporting higher density of communication links (including inter-robot and intra-robot communication) with stringent performance requirements, ensure service availability at almost all times, everywhere, provide highly accurate environment awareness e.g. positioning, support highly dynamic QoS adaptation mechanism to ensure safety when in close proximity with humans, and enhance sensing capability to aid robot operation efficiency, among others. Apart from enhancing communication system performance, developing robotics systems with much higher-degree of programmability by exploiting capabilities such as cloud and AI (e.g., distributed ML) technologies is required to help develop *cost-effective and lean robots* that are able to operate in diverse scenarios. *Lean* robots in the sense of having mandatory functionalities in the robots and relying on the cloud for more advanced and compute dependent functionalities. By offloading *flexible* large parts of robot *intelligence* to cloud platform could allow evolution of robotics system towards full autonomy, thus allowing them to quickly integrate and adapt in new scenarios, new tasks and develop new collaborations.

Evolution of 5G towards 6G is leading to enhancements and new research directions to include new capabilities such as integrated sensing and communication, distributed machine learning, use of new frequency bands e.g. THz or even the context aware spectrum aggregation to support robotic applications. These areas could directly influence robotics applications and would benefit from good understanding of robotics domain.

6G capabilities will fundamentally change how robotics could be designed with new communication and radio-based sensing capabilities. Despite the diverse categories of robots, based on the definition of robot in [5], each robot comprises of capabilities to perceive the environment, operate with different, scalable degree of autonomy, and trigger actuators for enabling movement and controlling moving parts to carry out intended tasks.

Several robotics related use cases are being discussed within standardization organizations [6], [7], different industry alliances [8], and European projects [9]. These are related to, among others, collaborative robots, adaptive robot swarms, co-existence of robots with humans and other objects, interacting and cooperative mobile robots. Depending on the use case and the way they are executed, they can pose varying demands on different functions of a robots. For example, consider a cooperative robot scenario wherein the robots are cooperating to pick and carry an object from one place to another. To enable this use case additional functions such as the followings need to be considered:

- **Perception:** e.g., object localization, object identification, cooperative robots' localization and environment awareness
- **Carrying out tasks autonomously:** e.g., motion and task planning, 3D safety zone planning, and multi-modal interaction
- **Actuation mechanisms:** e.g., move robot itself and parts along one or more axes

From the briefly discussed scenario, it can be observed that diverse set of tasks can be associated with different functions of robots. The tasks associated with different functions depends on several factors: the dynamicity in the environment, the type of object being carried, the type of collaborative robots, and so on. In order to perform the intended task efficiently and safely while maintaining stability of the multi-robots' system, it is of utmost importance to carryout accurate sensing, precise localization, real-time communication and actuation in a highly synchronized manner.

Developing a huge variant of single-purpose robots with all the required and desired functionalities *built-in* could come at a high cost and limit the flexibility and adaptability of the robots. Opportunities to enable efficient, flexible, adaptable, and cost-effective robotics systems might be worth exploring whilst ensuring safety. In addition, it is worth considering a new framework for robots that enables a kind of mass-market capable universal robot design as an intelligent combination of robotics and the extended capabilities of 6G radio interfaces and native AI.

With ongoing global brainstorming efforts towards developing 6G systems, understanding the use cases and requirements of potential robotics applications can enable development of communication systems that can efficiently integrate and cater the evolving set of robotics use cases from their onset.

Based on the market trends and the broadly envisioned robotics use cases, enhancements in areas such as: supporting scalable URLLC+ type deployments, cm-level accuracy environment modelling (not only for the robot as a whole, but also its moving parts), integrated sensing and communication, context aware device and network sensing, development of native AI/ML systems for robotics applications, supporting massive connection density (depending on how a robot is developed, it could be considered as a single or multi-UE system), integration of ambient sensors, multi-modality synchronization, ultra-high communication system availability, and secure sensing and communications between collaborative robots as well as robots and humans could be crucial for future wireless networks to support robotics applications.

Robotics focus areas in one6G

Within one6G, as a starting point, the focus is on the following categories of robotic applications [5]:

- **Industrial robots:** Remotely controlled, semi-autonomous or fully autonomous, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications.
- **Medical robots:** Robots intended to be used as medical electrical equipment or medical electrical systems
- **Service robots:** Robots in personal use or professional use improving the quality and convenience of human life.

It should be noted that one6g categories follows the OSI definition of robot categories but takes also into account the extended definitions by IFR [WR 2022 Industrial Robots - Sources & Methods section 1.7.3] and other leading robotic organisation.

Outlook

Driven by the need for deeper understanding of robotics scenarios and requirements to develop suitable and efficient mobile radio communication technologies including the extended capabilities like sensing, one6G will undertake a systematic approach. With prominent partners from diverse industries, verticals, city authorities, academia and robotic experts involved in one6G, relevant and pressing use cases will be first identified. For the identified use cases, detailed analysis comprising of, among others, actors, service flow and requirements will be carried out. Based on these findings, an attempt will be made to recognize new functional blocks and 6G technologies for executing the different use cases. In addition, one6g is considering with the support of the experts how to build new framework for robots that enables a kind of mass-market capable universal robot design as a smart combination of robotics and the extended capabilities of 6G radio interfaces and native AI.

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