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From classical to cloud robotics: Challenges and potential

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Abstract Nowadays, a rapid transition from the classical robotic systems to more modern concepts like Cloud or IoT robotics is being experienced. The current paper briefly overviews the benefits robots can have, as parts of the increasingly interconnected world.

Keywords Autonomous robots · Cloud robotics · Internet of Things · Model Driven Engineering

1 Classical autonomous robots

Among many definitions of a robot, one could be "an agent equipped with sensors and effectors, that can be programmed in order to exhibit intelligence". Breaking down this definition, an **agent** is an autonomous entity trying to achieve a goal. It perceives and/or acts in an environment, **sensors** are the software/hardware devices allowing the robot to perceive environmental properties and **effectors** are the software/hardware devices via which the robot alters environmental properties. **Autonomy** is the ability to act without external interference and **intelligence** can include autonomy, thoughts, emotions etc. Based on their domain, robots can be classified in several categories, some of which are industrial, household, medical, service, military, entertainment, space and/or research.

Whichever the domain, every autonomous robot models and implements fundamental behaviors i.e. the association of sensory inputs to actions driven by a specific goal. Traditionally, four main robotic architecture types exist, via which the behaviors are combined. *Hierarchical* architectures follow a top-down approach, where complex behaviors are decomposed to lowest levels operations applied to the hardware. *Reactive* architectures, do not exhibit hierarchy, rather define direct interconnectivity between heterogeneous behaviors. Next, *BlackBoard* architectures employ a board where behaviors are posted and selected; Finally, *Hybrid* behaviors are an arbitrary amalgam of all the above.

Despite of the architecture followed, an autonomous robot must be equipped with a set of necessary behaviors in order to achieve its goal. For example, Unmanned Vehicles, must support Localization or SLAM (Simultaneous Localization and Mapping), essentially giving them an accurate perception of the world. Other useful behaviors are Target Selection[1] (where the robot must go and why), Path Planning (how will the robot go to the current target) and Navigation (what velocities must be given in order to follow the path).

As obvious, the robotic software creation process is a quite specialized and sometimes painful procedure. Furthermore, some of the abovementioned components are computationally heavy, thus a low-end robot cannot realistically present higher levels of intelligence. Thankfully, the robotic controllers progressively leave the hard chassis of the robot, leading to more modern and distributed architectures, allowing extra degrees of flexibility in memory or computational management.

2 Cloud robotics

Nowadays, and specially with the rise of consumer robots, manufacturers focus on reducing their cost, leading to limited computational abilities. Therefore, it is a necessity that a technology exists which can offload computationally intensive processes out of the physical robot, in order for low-cost robots to be able to exhibit high

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level intelligence [2]. Cloud Robotics supports the utilization of cloud resources from the robots. Specifically, there are three main ways a robot can benefit from the Cloud. **Big Data**: Each robot can have access to updated libraries of images, maps, and object/product data, which typically require large storage capabilities. **Cloud Computing**: On demand access to parallel/ grid/ cloud computing for statistical analysis, learning, speech recognition and motion planning among others. Specifically, the offloading of computationally-heavy services and operations to the cloud is one of the most important benefits of cloud infrastructures, as far as consumer robots are concerned. **Collective Learning**: As robots may have access to shared data, knowledge sharing can be supported, either directly (e.g. maps exchange) or indirectly (via trained models).

Conclusively, the web-connected robots can reap the benefits of cloud resources, in order to present higher level of intelligence by utilizing 3rd party computational or informational resources. Of course, the robotic connectivity can also lead to benefits from another emerging technology; the Internet of Things.

3 IoT Robotics

The Internet of Things (IoT) is the network of physical objects - devices, vehicles, buildings and other items embedded with electronics, software, sensors and network connectivity - that enables these objects to collect and exchange data [3]. One could argue that when robots are concerned, they can be seen as "Things" in the IoT concept, since they essentially are complex devices collecting sensory data from their environment and offering services. Therefore, each robot can be seen as an endpoint in an IoT system, which consumes data from other devices or produces information for other Things. For example, in an integrated household IoT system, several devices can coexist, such as a humanoid service robot and smart devices including a smart TV, a smart thermostat and an Alexa device. A plausible scenario would be for the robot to perceive that the human feels hot and contact the smart thermostat to calibrate the room temperature. Of course the human could ask the robot what's on TV, the robot could utilize the $TV Program$ cloud service that Alexa offers and switch on the TV to a specific channel.

4 Low code robotic frameworks

With the advancement of Domain Specific Languages and Software automation frameworks it is becoming feasible for non-experts to use Iot-enabled or Cloud-enabled robots and build applications exploiting the related benefits. These Low-code frameworks hide the underlying configuration or programming complexity of robots and change the focus on the behavior of robots related to the expected functionality. Such mechanisms are practically able to automatically produce significant parts or even the whole envisioned system.

A methodology supporting the creation of such tools is called MDE (Model Driven Engineering). In MDE, models, meta-models and transformations form complete tools, which hide all the solution space and related technology complexity from the user, hence the user can solve the problem using high level concepts. In such automated mechanisms the "Solution Domain Knowledge (SDN)", e.g. constraints and well-formness rules are provided by Domain experts, thus no or little SDN is required from the end user. Usually an automated mechanism comprises a textual or graphical UI, the problem space's meta-model, structural/behavioural constraints and some Model-to-Model/ Model-to-Text transformations generating the envisioned output artifact, such as models or code[4].

5 Conclusion

As evident, the classical robotics domain has been expanded into more exotic and modern concepts that enable the easier integration between robots and their (smart) environment, as well as means to operate complex systems with minimal technical knowledge. As a conclusion, in the near future, the seamless collaboration of robots, devices and wearables will define the modern way of living.

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