Performance Boost with Hybrid Cloud Robotics

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Abstract— **Since its emergence in 2010, cloud robotics has been a major trend in today's robotics, however, there are some real-time robotics applications for mobile robots that are not able to use this paradigm due to their sensitive latency requirements. In this paper, *hybrid cloud robotics* is proposed as a processing model utilizing both edge and cloud computing in robotics. This model is implemented for two computation-intensive algorithms, object recognition and SLAM, for a robot with a light single-board computer on-board.**

Introduction. Cloud robotics enables network-connected robots offloading the intensive and complex computation tasks to take advantage of parallel computation and data sharing available in a centralized location [1]. Despite its attractiveness, cloud robotics requires a constant connection to the cloud infrastructure, which in practice, is difficult to fully maintain [2]. Moreover, issues like traffic or reliability of the network can lead to a higher latency that further degrades the performance. The concept of edge (i.e., fog) computing [3], has been recently proposed in domains such as Internet-of-Things (IoT) to fill the network incompetency gap in real-time applications [3], [4]. From the performance point of view, robotics applications can be broadly classified into three types of; hard-real time applications (e.g., collision avoidance) that only tolerates a latency of fewer than ten milliseconds; soft real-time applications (e.g., object recognition - OR) that tolerate a latency in the order of hundreds milliseconds; delay tolerant applications (e.g., mapping) where a latency in the order of minutes would be acceptable. This paper introduces *hybrid cloud robotics* model, where the processing is dynamically distributed among resources on-board, on the edge, and on the cloud.

Hybrid Cloud Robotics. Although clouds will continue to grow and will include more use cases, the concepts of edge computing is adding an additional dimension to cloud computing. While cloud robotics can truly empower the application of artificial intelligence (AI) in robotics, it is still limited to soft real-time or latency tolerate applications. In *hybrid cloud robotics* model, the power of cloud robotics can be extended to all types of robotics applications. Such a processing model includes three layers as follows: (i) The first layer is running a light computation and is done on the device. This includes a quick control reaction of the robot in an environment via a closed control loop. The basic functionality of a robot is mainly included in this layer; (ii) The second layer is pushed to the edge of the network, where edge nodes can be considered as hosting infrastructure [2]. (iii) The last layer is for intensive processing or accumulative data that are sent to the cloud. More examples of such a hybrid computation on device, edge, and cloud respectively include: a LiDAR sensor, car processing unit, and cloud; a vacuum cleaner or toy, personal computer or home network router, cloud; a surveillance camera, significant robot, cloud [5].

Applications of Hybrid Cloud Robotics. We implemented two use cases based on the proposed model. A robotic platform is equipped with a single-board computer (SBC), Raspberry Pi 3, and an RGBD sensor. If this use case is performed only on the SBC, the performance of the process is $\sim$ 0.07 fps, the user sees new images with detected objects every $\sim$13 seconds. While using our proposed model, the entire process improves to $\sim$ 30fps, which from the user point of view it means a real-time visualization of the detection process[1]. As a second use case, a SLAM algorithm was implemented using the previous robotics platform setup. The generated map was stored on the C2RO cloud-based dashboard [2] and can later be shared with other robots on that environment as a shared available map. This way, the burden of exploration and map building is omitted for the new robots and the need for additional sensors are minimized. Our results show if the map is built locally on the SBC the SLAM algorithm update rate is $\sim$ 5Hz, while by using our *hybrid cloud robotics* model, the map update rate was enhanced to 30 Hz[3]. **Conclusion.** Although cloud robotics has been significantly pushed the barriers of robotics applications, it is not still a proper model for latency sensitive applications in robotics. To this aim, we proposed *hybrid cloud robotics* model where the computation is dynamically distributed among three layers including the computation on the robot, edge, and cloud. The application of this model for an object recognition and a SLAM algorithm was reported.

References

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[1]C2RO OR demo video: `https://youtu.be/tg1h6bvLfvU`
[2]For academic usage: `http://lnked.in/c2ro-cloud-rob`
[3]C2RO SLAM demo video: `https://youtu.be/RdLwU0uKD08`