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**State-of-the-Art Document**

**Robonimbus Project**

***May 2024***

**Introduction**

Cloud-based robot management systems represent a significant advancement in the field of robotics and automation. By leveraging cloud computing, these systems provide enhanced computational power, real-time data processing, and advanced AI capabilities, enabling more efficient and intelligent robot operations. This document outlines the current state of the art in this technology, highlighting key features, applications, and future directions.

These systems offer several key features that are transforming the robotics landscape. Scalability is achieved through platforms like Kubernetes, which allow for handling large datasets and complex algorithms without the need for extensive on-premises infrastructure. Real-time data processing capabilities, as seen in platforms like C2RO, support critical applications such as collision avoidance and object recognition, essential for autonomous navigation and operational efficiency.

**Key Features**

* **Scalability (Kubernetes):** Cloud-based systems offer scalable computational resources, allowing for the handling of large datasets and complex algorithms without the need for extensive on-premises infrastructure. Thanks to the Kubernetes structure, services are automatically scaled and the resulting load is met even if the user load increases.
* **Real-Time Data Processing:** Platforms such as C2RO enable real-time applications like collision avoidance and object recognition, which are crucial for autonomous navigation and operational efficiency.
* **Supervised Autonomy:** Systems like those from Fetch Robotics allow for supervised autonomy, where robots can receive task-level commands from human operators via the cloud, enhancing safety and flexibility in various environments.
* **Predictive Maintenance:** Predictive maintenance features monitor robot performance and predict potential failures, reducing downtime and maintenance costs.
* **Task Optimization (Multi-Robot Coordination):** Task assignment optimisation is ensured through robot capabilities, task space limitation, robot’s availability, battery status, location of the robots and their distance from the task points.
* **Graph-Based Mapping:** Compared to other mapping methods, the 2-dimensional graph-based mapping can map larger areas with fewer errors. Another advantage of this method is that it is less affected by environmental changes
* **Social Navigation:** It can detect humans with high accuracy by using the sensors together, which is not sufficient in human detection when used alone. In this way, more convenient path planning and navigation is provided without disturbing people
* **Smart Object Detection:** Smart object detection is a technique to find out what things are. When you take a video in real time, you analyze the video and find out what the object is and display the information. It plans to carry out object recognition by attaching a camera to the robot environment. Reliability adjustment is needed for object recognition. YOLO (You Only Look Once) library and CUDA (Compute Unified Device Architecture) is used for object detection.
* **Multi-tenancy**: Multiple users can define their own robots and assign tasks to robots simultaneously on the Cloud Management Platform.
* **Imitation Learning (IL):** IL is a way to control robots. Behavior cloning (BC), a method of IL, is a basic approach for learning manipulation; however, it is not easily adaptable for environment changes. The reinforcement learning (RL) is a major research topic for robot control. Like as many deep learning based control, the data gathering is a big problem in RL. In particular, the IL algorithms requires additional pre-process to identify the human motion and transferring the dada to robot domain. Image transferring methods are suggested for the pre-process, but it can not guarantee the convergence of the algorithm. We follow the above suggested algorithms and get a direct method to get human data from well-known like as OpenPose.
* **AR/VR Based Human Augmentation System:** If the cobot arm can't find a good grasp using its current model, it asks a person for help. The person supervises the robot in a virtual reality (VR) control room, and they can take control of the robot to provide grasping demonstrations. The robot learns from these demonstrations, and then continues learning on its own. This allows the robot to learn faster and keeps the person's workload reasonable.
* **Voice Recognition:** Voice recognition functionality supported by MR SDK has been integrated into the project, as an added-value. Currently, 5 voice recognition commands are registered.
  + “Sim”: Go to the simulation room and pick and place simulation linked to the robot.
  + “Control”: Go to the control room and control the robot through remote hand tracking.
  + “Back”: Move to operation selection state
  + “Start”: Start operation
  + “Stop”: Stop operation and reset
* **Inverse Reinforcement Techniques (IRL) and Trajectory Learning:** The inverse reinforcement learning is the field of finding robot motion generation strategy. In which the control policy is learned by observing agent's behavior, in our case the human motion. The basic assumption is that there is/are reward function and the human behavior is a decision process to produce that behavior to maximize the reward function. We used a 6-dof cooperative robot arm with robotic hand. The approaching motion of manipulator and the grasp policy are learned from the human data for various environment. The results of IRL in robot is compared to the human behavior.
* **Smart Motion: Context Based SLAM:** The smart motion AI capability is developed to support motion control as well as the navigation of cloud robots. The map of an environment has been created with semantic meanings, which contains separate object models with semantic and geometric information. The map maintains 3D point clouds by projecting semantic messages to 3D models and also separate object entities independently. Since it can provide a better understanding of environment, a robot is able to do more advanced missions with a semantic map, for instance, finding a specific object or a person. Generic concepts (such as ‘patients’ room’) have been defined and incorporated into the SLAM algorithm is also used by the navigation algorithm to predict and adapt to its surroundings.
* **Robot Management Software:** Robot management software provided SAAS is responsible of coordinating the mobile robot (AMR) with the Cobot Arm during the collection and delivery processes as well as directing the mobile robot to a specific location or directing the Cobot Arm to pick and place the samples brought by AMR. AMR can be directed to a patient’s room for remote examination/visit or delivery of equipment can identify the patient, collect data from the patient to send to the management software. The management software directs the robots according to the user commands and provide two-way communication between robots or the robot and the doctor during remote examination.

**Conclusion**

Cloud-based robot management systems represent a transformative advancement in robotics, offering significant benefits in terms of scalability, real-time processing, and advanced AI capabilities. These systems are instrumental in addressing current challenges and driving future innovations. By focusing on the continuous improvement of these technologies, they will further enhance efficiency, productivity, and safety across various industries. The integration of advanced features and the ability to adapt to dynamic environments underscore the potential of cloud-based robotics to revolutionize the field, paving the way for smarter and more autonomous robotic solutions in the future.

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