Cloud-based learning for robot control

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***Abstract*—This paper introduces the Virtual Manufacturing Platform (VMP), a cloud-complete educational platform targeting manufacturing industries providing tutorials and sandboxing. The scope of this paper focuses on the robot control architecture of the platform which allows for seamless control of both virtual and physical robots and end-effectors accompanied by supportive educational materials. The platform seeks to de-risk automation investments for small to medium enterprises by offering confirmatory environments and knowledge transfer opportunities.**

***Index Terms*—robotics, automation, control**

I. Introduction

As with remote-based robot control, cloud-complete robot control is a form of teleoperation. Teleoperation control of robots, and manipulation thereof, is becoming an increasingly desired skillset particularly in hazardous and challenging environments. Control applications, both via direct and remote interfacing, is often a by-product of existing ecosystem design choices [1]–[3] and industrial fatigue [1], [3]–[6] which often requires expert knowledge to leverage fully; additionally the requirement of expert domain knowledge introduces complex weak points within manual and semi-automated production lines. One key advantage of cloud-complete architectures is the ability to unlock robotic servoing from the tightly coupled control software – navigating the issue. This is not strictly possible for each practical implementation given manufacturer design choices and lock-in, but the advantage of hot-swappable simulations is a desirable feature set to obtain. We propose a cloud-complete learning environment scoped for the transfer of robot control knowledge to end-users, this environment is called a "Virtual Manufacturing Platform" (VMP). Cloud-complete in this instance refers to an environment completely hosted in browser as opposed to more traditional hybrid software which combines specialised system-level software functionalities with streaming aspects. Arguably a cloud-complete architecture is a stricter variant on remote-based architectures. The VMP is a diverse portfolio of manufacturing tools and methodologies accompanied by educational materials, practice scenarios and access-to-expert training; the scope of this paper is the robot control delivery module of VMP which focuses on stationary robot cell manipulation scenarios. The VMP robot scenarios are all designed around Robot Operating System (ROS 1/2) compatible robots [7], [8]. It is important to note that the VMP does not solely rely on a simulation-only approach for knowledge transfer and learning; simulation-only prevents users from validating methodologies which are subject to real-world limitations such as those found in manufacturing environments. Thus, we have paired several simulation scenarios with physically constructed robotic cells available for remote access by advanced VMP users. The physical robotic cells are highly designed with rich sensorisation to enable discretisation of real-world variables. The VMP is designed to be scalable in terms of users and usage.

Going forward in this paper we will refer to the stationary robot control scenario, both simulated and physical, as virtual manufacturing testbeds (VMTs). Fig. 1 showcases the interaction philosophy of a single end-user and a single VMT. The user generates commands through interaction with the human-machine interface (HMI) presented via an internet browser; the commands are transferred to a client interaction module hosted in the cloud which validates and parses commands before handover to direct VMT logic controls. The VMT logic controls affect the hosted simulation and trigger a state check and rendering process; the rendered output is encoded and returned to the user via a video streaming service where it is decoded and displayed. For better understanding, the VMP can be codified as a "streaming" platform while VMTs can be thought of as the "streamed" content.

To summarise, this paper outlines the architecture and nature of the VMP within the scope of robotic control knowledge transfer to end-users. The goal of the VMP is to provide access to leading industrial practices, technologies, and information for the purposes of education and training. The works in this paper are work-in-progress.

II. Related Works

This section provides a brief overview of works related to the VMP and the VMTs. Previously we laid out the definition of the VMP as a cloud-complete hosting architecture and a VMT, in the context of this paper, as a remote access testbed for stationary simulated (or physical) robot control. Remote access for robotic control has been a realised feature of many testbeds since the advent of the internet and modern communication protocols [9]–[11]. Educational remote robot control testbeds such as in [3], [12]–[21] are popular mechanisms for learning [13], [16], [22] especially as observed during recent global events. All of the cited are examples

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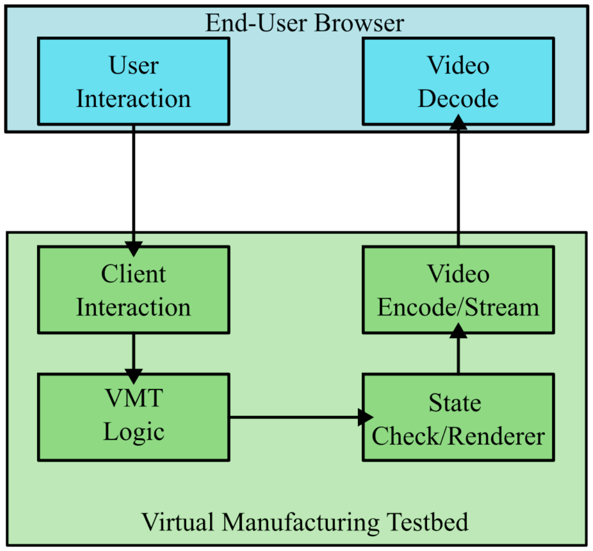

Fig. 1. Single-user single VMT journey

of remote accessible robot controls specifically designed for educational purposes and serve as inspiration during the design and development of VMTs. The architecture of the VMP is inspired by [23], [24] in terms of computation, VMTs are like virtual machines running graphics intense software on a cloud service. The video streaming architecture highlighted in [25], [26] serve as direct inspiration for the VMP video encoding and decoding relationship as shown in Fig. 1.

III. Architecture of the VMP

The VMP is a cloud-complete platform designed to host a learning environment including, but not limited to, interactive simulations (VMTs), statistical tools and training materials. The primary goal of VMP is to increase the availability of access to industry practices relating to automation, data usage, and efficiency for the purposes of education; it is, in part, informed through the "Industry 4.0" [27] initiative. The VMP is designed to scale resources based on specific user demands, provide save states and backups as required, and to transfer knowledge through interactive tutorials/written guides/video walkthroughs/live seminars. The VMP proposed here uses Amazon Web Services (AWS) to provide the back-end platform and utilises the elasticity of AWS in terms of computation power, storage, streaming pipelines, and virtual machine controls to achieve the above. The VMP uses a single sign-on (SSO) authentication scheme to allow for seamless access to all platform hosted content, community forums, and support; once signed into the platform users are able to filter available VMTs by scenario, type, and general text search. Once a VMT is selected the users are provided with a temporary access remote desktop protocol session allowing them to use the VMT and its included technologies until their session privileges expires (backups are automatically generated at set intervals of time and during run-time usage).

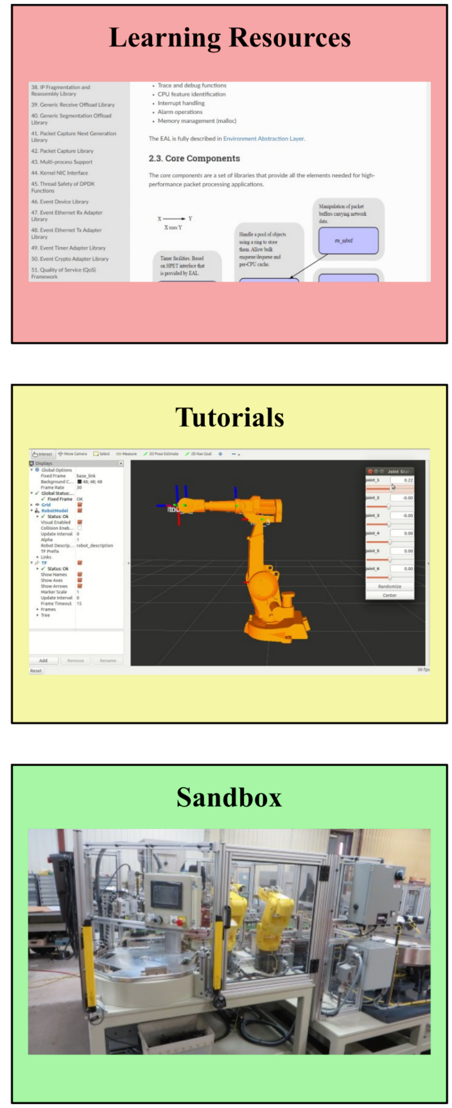

Fig. 2. the three key parts of a VMT: 1) learning resources - videos and written documentation designed to transfer knowledge solely through consumption, 2) tutorials – scoped scenarios designed to transfer knowledge through high-level interaction, and 3) sandbox – un-scoped scenarios containing pre-configured software allowing for explorative learning practices.

Several features of the VMP, including the access to leading data storage and analysis tools, integrate seamlessly with each VMT culminating in an knowledge transfer ecosystem designed for easy-of-use and versatility. At its simpliest the VMP hosts and auto-manages VMTs which are comprised of three key knowledge transfer parts:

1) Learning resources – material developed (videos, quizzes, getting started guides etc.) which do not require (but can be used with) a paired scenario simulation in order to transfer knowledge to the end-user.
2) Tutorials – material developed (virtual machines etc.) which are directly paired with a scenario simulation and are designed to transfer knowledge to the end-user

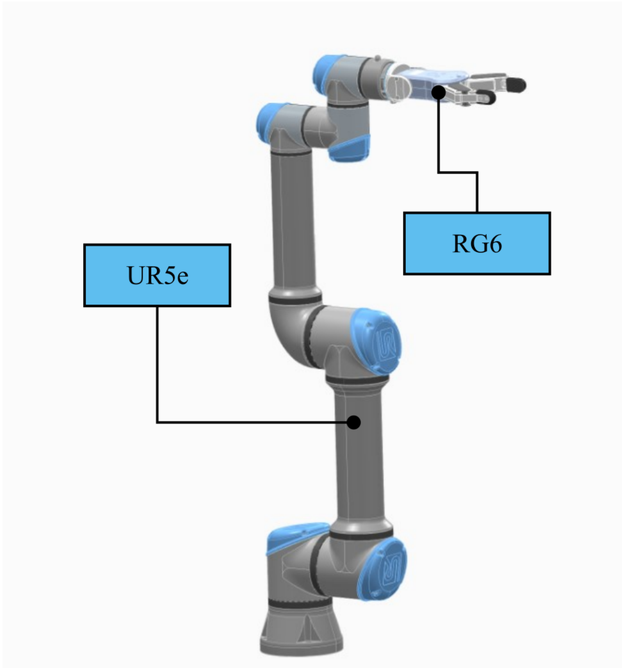

Fig. 3. An example of an available VMT simulated model showing a Universal Robots UR5e with an OnRobot RG6 end-effector attached.

through high-level interactions with simulation.

3) Sandbox – an, in simulation, unscoped version of a scenario simulation allowing end-users to explore and experiment with the technology; supporting materials (suggested tutorials and tasks etc.) are provided but are purely optional. Sandbox parts are designed to be accessed last within a VMT as a means of allowing users to build upon the knowledge transferred through the other parts.

The key knowledge transfer components are also illustrated in Fig. 2. The illustration highlights some of the content within a single VMT scoped to introduce users to robotic control for a pick-and-place scenario. This specific VMT is a digital twin of an existing physical testbed available for remote control through the VMP as part of the sandbox for the VMT. Fig. 3 illustrates one of the simulated models available inside the pick-and-place VMTs using a modelled Universal Robots UR5e and a modelled OnRobot RG6 end-effector.

Fig. 4 illustrates the functional architecture of the VMT within the scope of this paper, it is not a complete overview of the architecture of the VMP. Users can access VMTs through their browsers once they have passed the VMP single sign-on; the VMP landing page showcases the VMTs their controlling organisation has selected for them to learn. Each VMT is accompanied with unique parts as discussed above and shown in Fig. 2; namely learning resources, tutorials, and sandboxes. Some VMTs are digital twins of existing physical testbeds which are remote controllable through the VMT at an advanced level. An example is provided in Fig. 5 which shows the physical twin of the Universal Robots UR5e and a physical

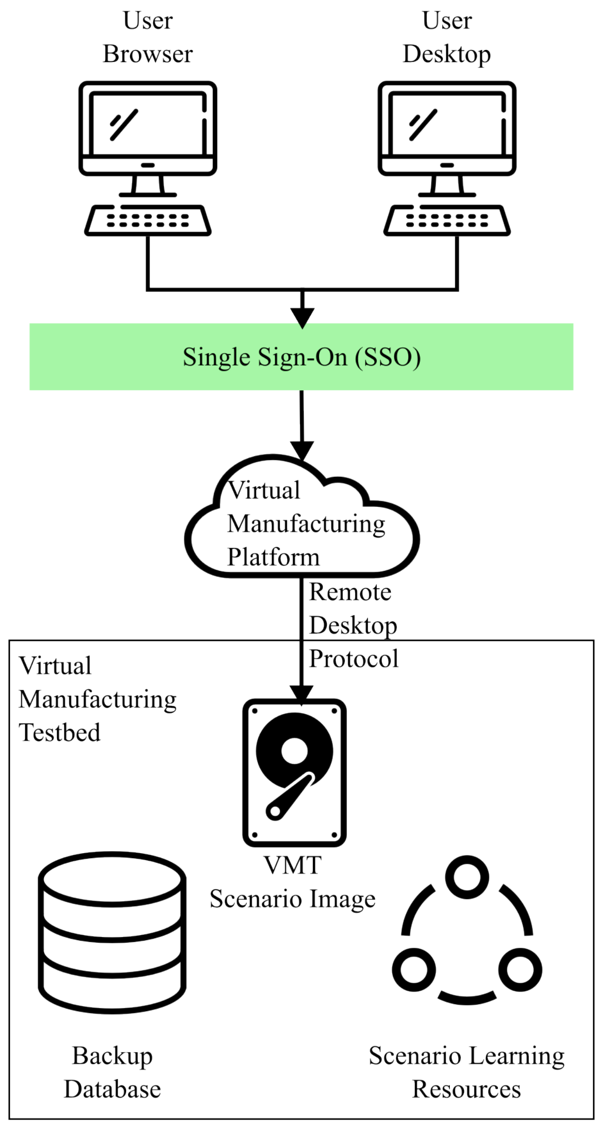

Fig. 4. VMP architecture illustrating VMT access. Users will be able to access VMTs after going through the VMP single sign-on; at its simplest (for the scope of this paper) the VMP consist of VMTs containing learning resources, tutorials, and sandboxes as shown in Fig. 2. VMTs are backed up regularly to ensure recovery in case of issues experienced by users.

OnRobot RG6 end-effector shown in Fig. 3 conducting a pick-and-place VMT activity.

IV. Conclusions

This paper presents the work-in-progress development of the virtual manufacturing platform (VMP) which is a cloud-complete platform designed for industrial learning and knowledge transfer. The VMP provides virtual manufacturing testbeds (VMTs) to users to facilitate practical knowledge transfer. The scope of this paper focuses on the features of VMP and unique VMTs design to facilitate to educate users in the control of robots both in simulation and physically through remote facilities.

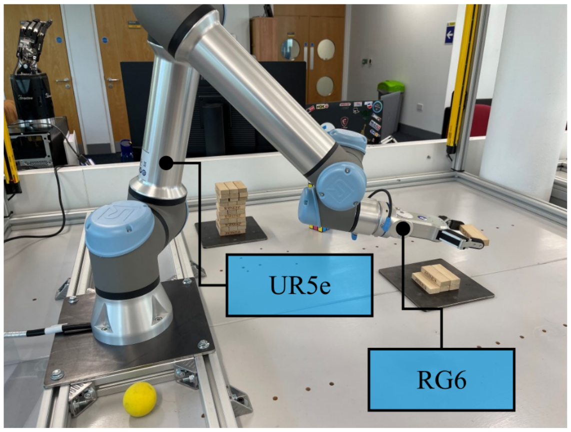

Fig. 5. An example of an available remote testbed controllable through a pick-and-place VMT. The testbed consists of a Universal Robots UR5e with an OnRobot RG6 end-effector attached. This is the physical twin of the model shown in Fig. 3.

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