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An open-source multi-DOF articulated robotic educational platform for autonomous object manipulation

Sarah Manzoor, Raza Ul Islam, Aayman Khalid, Abdul Samad, Jamshed Iqbal *

Department of Electrical Engineering, COMSATS Institute of Information Technology, Islamabad, Pakistan

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ABSTRACT

This research presents an autonomous robotic framework for academic, vocational and training purpose. The platform is centred on a 6 Degree Of Freedom (DOF) serial robotic arm. The kinematic and dynamic models of the robot have been derived to facilitate controller design. An on-board camera to scan the arm workspace permits autonomous applications development. The sensory system consists of position feedback from each joint of the robot and a force sensor mounted at the arm gripper. External devices can be interfaced with the platform through digital and analog I/O ports of the robot controller. To enhance the learning outcome for beginners, higher level commands have been provided. Advanced users can tailor the platform by exploiting the open-source custom-developed hardware and software architectures. The efficacy of the proposed platform has been demonstrated by implementing two experiments; autonomous sorting of objects and controller design. The proposed platform finds its potential to teach technical courses (like Robotics, Control, Electronics, Image-processing and Computer vision) and to implement and validate advanced algorithms for object manipulation and grasping, trajectory generation, path planning, etc. It can also be employed in an industrial environment to test various strategies prior to their execution on actual manipulators.

1. Introduction

Robots, initially meant for entertainment and fun, have dramatically changed the human life in recent years. The current technological revolution in robotics and automation has transformed the concept by accomplishing industrial tasks in a safer, optimized and much more efficient manner. Robotic manipulators are composed of rigid links interconnected by joints and are designed to function like a human arm but with enhanced strength and payload capacity.

Increasing applications and developments in the field of robotics demand trained graduates who are proficient in related technologies. Here arises the need to develop state-of-the-art platforms to serve the purpose. Scientific literature reports many platforms developed specifically for teaching mobile robotics [1–9] and robotic hands [10] to help engineering students to stimulate their concepts and to enhance their innovative skills. Moreover, there are generic platforms that can be used to develop multi-configuration robots including wheeled or tank-like track based or simple humanoids. The most popular among these is LEGO™ Mindstorms [11], which has been extensively used for teaching various robotics courses [12,13]. However, such systems may not be able to fulfil training requirements needed in case of articulated multi-Degree Of Freedom (DOF) robotic arms.

Training systems for robotic arms have also been reported in the literature. However, most of these offer software based simulation. Rajesh et al. presented a virtual robotic system to give insight into controls and working of a robotic arm [14]. The system is based on Mitsubishi RV-M1, a 5-DOF robotic arm. The developed model of the arm represents its kinematic behaviour in a simulated environment. The platform does not take into consideration other key features like robot dynamics and analysis of its workspace. Lack of sensory and vision capabilities further restricts the scope of the training system. Another virtual platform, ROBLIB, based on Delphi language, demonstrates the fundamental concepts of robot kinematics, dynamics and control [15]. However, experiments on ROBLIB are restricted to manipulators having 2 DOF. Other pertinent examples of virtual platforms include [16–24]. The virtual robotic systems provide illustrative and cost-effective solution. However, such systems being totally 'soft' in nature, may not offer necessary exposure corresponding to the real robot performance. Practical limitations on actuators and force/torque transmission mechanisms may affect specifications and stability of the virtual model controller. Moreover, virtual models do not usually address the non-linearities such as backlash, friction, non-collocation, etc associated with the physical systems. Typically, the accuracy and credibility of results obtained in a

* Corresponding author. Tel.: +92 3245229326.
E-mail addresses: jamshed.iqbal@comsats.edu.pk, iqbal.jam@gmail.com (J. Iqbal).

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simulated environment are not comparable with physical experiments owing to the fact that the virtual models may not imply a true practical approach.

Contrary to these simulation tools, fewer hardware based training platforms have been reported. Some of these are deficient in terms of flexibility, scalability or modularity while others lack financial affordability or have fewer DOFs. A commercially available platform, OWI-535 has been presented by OWI Inc. with 3+1 DOF [25]. The manipulator, having a payload capacity of 100 gm, offers base, elbow and wrist rotation and opening/closing of its gripper. The arm is controlled by a five switch wired controller. AL5A by Lynxmotion is a 4+1 DOF manipulator having wrist rotation as optional [26]. Fabricated with Aluminium, the platform has a payload capacity of about 370 g. The control software implements advanced Inverse Kinematics (IK) algorithm to position the end-effector in 3D space accurately. Another educational robotic platform developed by Rhino Robotics Ltd. [27], with 5+1 DOF, is based on XR-4 serial robotic arm. This platform is controlled with Mark IV controller and can be programmed using a set of kernel commands. SCORBOT-ER 4u is another similar system by Intelitek [28]. Based on a 32-bit RISC microcontroller (NEC V853), the platform can be used for stand-alone operations or can be integrated for automated applications.

Availability of limited commands or functions in the above mentioned platforms put a constraint on the type of control algorithms and strategies that can be tested using these platforms. So, this limits the implementation of control strategy to the Proportional Integral Derivative (PID) algorithm while an undergraduate/graduate student may be interested in implementing more advanced control algorithms like Sliding Mode Control (SMC), Linear Quadratic Regulator (LQR) and Disturbance Observer Based Control (DOBC). Furthermore, there is no provision of any interface to re-program the controller by downloading the code into its flash. Lack of vision and unavailability of force or tactile sensors in these platforms further limits the radius of activities that can be performed. So, there is a need to develop an open-source robotic platform with enhanced features to teach students in an academic environment and to train young graduates and internees in industry. Such a platform could be used more effectively for training if the dynamic behaviour of the robot is known, since the design of a sophisticated robot controller demands having a realistic dynamic model.

This paper is structured as follows. Section 2 introduces the proposed robotic platform. The developed kinematic and dynamic models of the robot are discussed in Section 3. Section 4 explains the design details of the electronic hardware while Sections 5 and 6 describe the vision and tactile sensing in the proposed platform respectively. Section 7 presents results of the applications developed to demonstrate the platform capabilities. Finally Section 8 comments on conclusion and elaborates the potential of the proposed platform.

2. Platform description

The proposed platform is centred on a 6 DOF serial manipulator since such robotic arms are widely used in industry. The platform manipulator (ED7220C [29] by ED Corporation, Korea) can be controlled either from a host PC or directly from a teaching pendant. The platform is equipped with real-time imaging capabilities while force sensor fixed at the robot's end-effector facilitates to differentiate objects having different stiffness. Fig. 1 shows block diagram of the proposed platform while the robot with its workspace is illustrated in Fig. 2.

The proposed framework combines robot modelling and control and image-processing to perform desired operations. In a typical application, once a user's command is encountered, the whole workspace is scanned and corresponding images are captured. These images are processed to identify target object

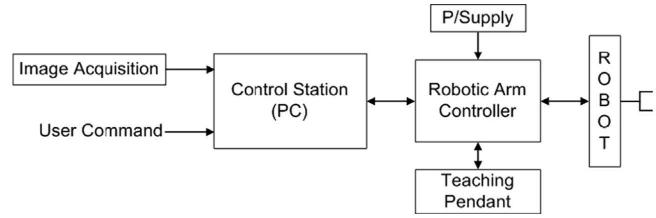

Fig. 1. Block diagram of proposed platform.

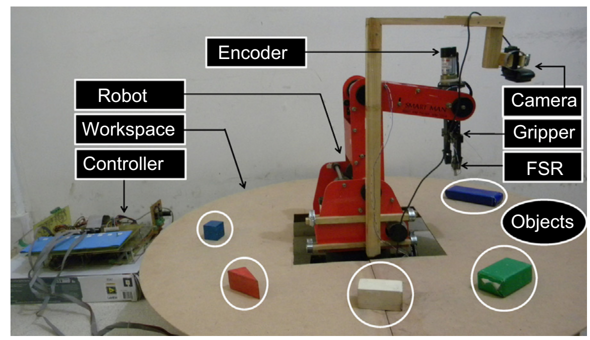

Fig. 2. Overall system showing robot manipulating objects in workspace.

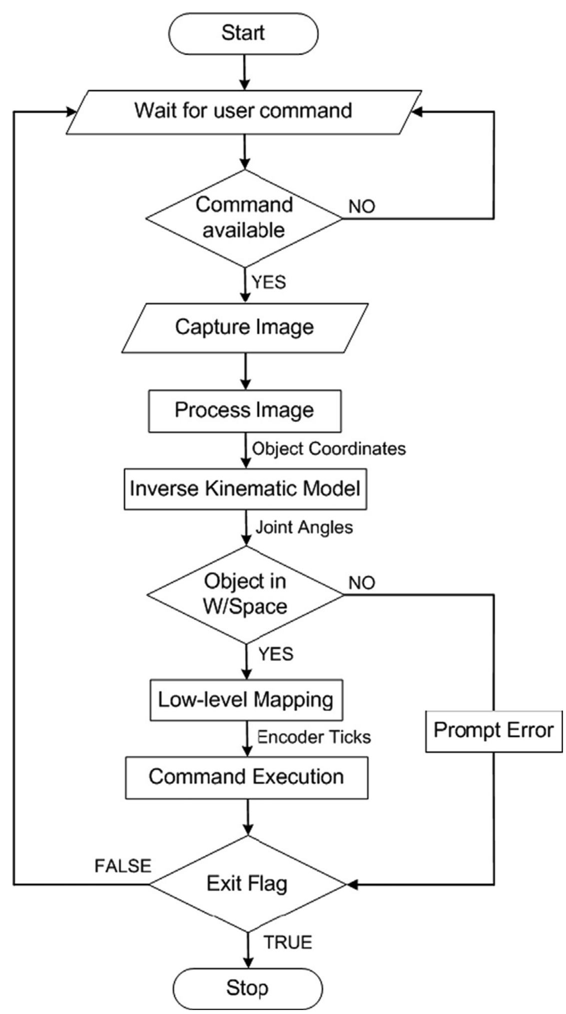

Fig. 3. Functional chart of a typical application using the platform.