Robotly – An Intuitive Way for Manipulating Industrial Robots

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Abstract—**Modern demands for more flexibility in automation processes claim intuitive methods of operating technical devices. Industrial robots are often used for mass-production as the complex and time-consuming programming is not economic when considering small lot sizes. An intuitive way for manipulating and programming an industrial robot helps in reaching profitability as it does not require expert knowledge in completing a complex application within a short time period. This paper introduces an intuitive way for manipulating industrial robots by a handheld mobile device, such as a mobile phone or a tablet, and discusses its advantages with respect to state-of-the-art intuitive manipulating methods.**

Keywords-intuitive manipuating, industrial robot, mobile device

I. INTRODUCTION

A. Motivation

Industrial robots are – so far – mainly used in companies producing mass market products. Even though hardware costs of industrial robots have decreased over the last couple of decades, the integration and programming costs still make them unaffordable for small and medium enterprises (SMEs). Integrating industrial robots in production processes and programming application specific tasks claim the need of expert knowledge, i.e. expensive professional programmers or technicians. As SMEs usually have frequently changing applications as a result of responding to rapidly changing market needs, it is not economic to afford a technician every time an application is changed. Furthermore, SME environments are typically less structured and involve more uncertainties than large-scale or mass-production industries which makes the integration of currently available solutions of manipulating industrial robots overly complex. In order to make industrial robots more economic for SMEs, the manipulation as well as programming of those has to be more flexible and intuitive [1]. Pires has stated that it means taking special care in optimizing human machine interfaces (HMI), i.e. devices, interfaces and systems that enable humans to easily manipulate industrial robots on the shop floor [2]. The development of robots to be more suitable for SMEs has also been appreciated at EU level, as shown by the SMErobotics project [3].

Nowadays, mostly the offline-programming approach is used for programming industrial robots. Simulation environments – often directly provided by robot manufacturers – make it possible to generate robot motion based on 3D CAD data and transfer the robot program automatically to the real robot controller. However, online programming efforts cannot be totally excluded due to following reasons:

- No available CAD data
- Imprecise model of real robot control (in particular motion control with regards to singularities and robot configurations)
- Imprecise models of real peripheral equipment and components due to manufacturing tolerances
- Inability to model specific object characteristics within the simulation environment, such as gravitation, friction, etc.

Thus, online programming needs to be done in order to adapt the robot program – generated within a rather ideal simulation environment – to the characteristics of a real production environment. Therefore, manual teaching needs to be applied. However, manual jogging of industrial robots is not intuitive by all means – especially as teach pendants differ from manufacturer to manufacturer and require technical expertise.

In general, there exist three typical motion modes for manipulating industrial robots (Fig. 1):

- ***Axis specific motion:*** Motion with respect to the individual axes of the robot (degree of freedom equals the number of individual driven axes of the robot)
- ***Linear motion:*** Linear motion with respect to a specific coordinate frame (degree of freedom equals three in three dimensional space, i.e. three for translating along each coordinate axis x, y, z)
- ***Re-orient:*** Orientation with respect to a specific coordinate frame (degree of freedom equals three in three dimensional space, i.e. three rotations around each coordinate axis x, y, z)

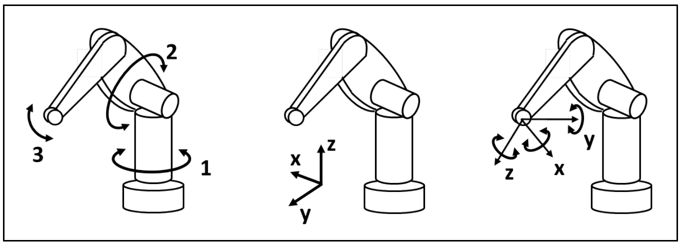

Figure 1. Typical motion modes of industrial robots – left: axis specific motion; mid: linear motion with respect to a specific coordinate frame (in this case the world coordinate system); right: re-orient around the axes of a specific coordinate frame (in this case the tool frame)

Common teach pendants have either buttons or a joystick for manipulating industrial robots in the above mentioned motion modes. One major drawback of teach pendants is the fact that the position of the user with respect to the robot is not taken into account while manipulating the robot This is the reason, why robot programmers always need to specify and know the orientation of the coordinate system in which they are manipulating the robot.

Consider following example (Fig. 2): The teach pendant used has a joystick with three degrees of freedom (DOFs). The user aims to move the robot in the positive x-direction of the base coordinate system. In one case (left), the user stands in front of the robot, in the other case (right), the user stands on the left hand side of the robot. In the first case, the user needs to push the joystick to him/her in order to move the robot in the specified direction. This is rather intuitive as the joystick indicates the direction of the robot's movement. However, in the second case, the joystick direction remains the same although the robot is moving to the right (from the user's point of view). A non-experienced programmer would intuitively jog the joystick to the right in the second example.

Reference [4] reflects the results of an investigation concerning the number of wrong user actions when jogging an industrial robot in different coordinate frames. In [5] and [6] a so called *matrix of confusion* is introduced which describes the robot movement depending on input actions conducted from different relative positions from the user to the robot. The research showed that a compatible mode in jogging, which adapts the coordinate system to the relative position of the user, simplifies the matrix of confusion.

B. Related Work

As teach pendants lack of intuitive handling, research has been conducted in finding new ways of manipulating industrial robots without the need of expert knowledge.

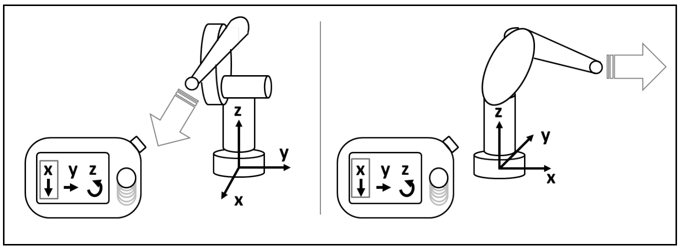

Figure 2. Non-intuitive jogging with joystick – left: user stands in front of the robot; right: user stands on the left hand side of the robot facing the manipulator

An investigation of identifying new appropriate ways for jogging robots can be found in [7]. In 1982 Tomás Lozano-Pérez [8] conducted a detailed review of robot programming systems. At that time, the range of robot programming methods was very limited, especially as robots were only common in industrial environments. With advances in robot technology, robots moved out of controlled industrial environments into uncontrolled service environments, such as homes, hospitals or public places which also made it necessary, to provide intuitive programming methods for unskilled people. While Lozano-Pérez divided programming systems into guiding systems, robot-level programming systems and task-level programming systems, new surveys – conducted for example by Biggs and MacDonald [9] – divided the field of robot programming into automatic programming, manual programming and software architectures. Learning systems, programming by demonstration and instructive systems were defined as state-of-the-art robot online programming methods [10]. Examples of how human-robot interaction can be developed to be more suitable for SMEs can be found in [11] and [12]. Intuitive methods for manipulating industrial robots range from newly developed input devices [13], [14], [15], over speech and gesture based manipulation [16] up to augmented reality based methods [17], [18].

Latest approaches show the usage of modern mobile devices, such as mobile phones or tablets, to jog as well as program industrial robots [19], [20], [21], [22].

Considering state-of-the-art techniques in intuitive manipulation of industrial robots it is obvious that the implementation of the proposed methods still requires a certain level of expert knowledge. Most methods need expensive and complicated equipment, such as vision systems, speech recognition software, or rather complex pointing devices. Encouraged by the drawbacks mentioned, the particular aim of the research project presented in this paper is to propose an intuitive method of manipulating an industrial robot with a mobile phone or a tablet PC without high implementation cost and effort.

II. SYSTEM ARCHITECTURE

In the following, the above mentioned intuitive method for manipulating industrial robots with a handheld device, such as a mobile phone or a tablet PC, without high installation efforts is introduced. The proposed system consists of three physical entities (see Fig. 3):

- a smart phone or a tablet PC,
- a stationary PC, and
- a robot system.

A. Smartphone or tablet device with built-in 3-axis gyroscope

A smartphone or a tablet PC with an integrated 3-axis gyroscope is used as an input device for sending jogging information to the robot controller. The mobile device (shown in Fig. 4) can be used for either moving the robot linearly in a specified plane or re-orient it around its tool center point. In order to manipulate the robot, the user specifies his/her relative position to the robot by a simple rotary disc visualizing the robot's base coordinate frame so as the disc looks in the same direction as the robot's base frame – from the user's point of view.

For linear movement, the core concept of manipulating the robot is based on a joystick with 2 DOF programmed on the tablet interface (instead of a 3 DOF joystick usually implemented on teach pendants). By holding the tablet in a specified orientation in space (by the user), the plane, in which the robot moves, is defined, i.e. the third DOF is intuitively defined by holding the tablet in a specific angle. Thus, the joystick can also intuitively be moved in either x- or y-direction while the robot moves parallel to the plane defined by the tablet as well as in the joystick direction defined by the user – in contrast to the example shown above. The necessary data for defining the orientation of the plane given by the tablet as well as the joystick direction is calculated by the built-in gyroscope.

For orientation, two consecutive orientations of the tablet are saved by pressing a button. The relative change in orientation is then calculated again by reading and comparing the data from the built-in gyroscope.

B. Stand-alone PC, router or some Wi-Fi or Bluetooth to RS232 module

The tablet application, i.e. the manipulating interface, establishes a TCP/IP socket connection to the server application running on the stand-alone PC. The tablet sends the calculated data from the gyroscope to the server and from there the data is passed to the robot controller via a RS232 or Ethernet connection.

C. Robot manipulator including controller

The connection from the stand-alone PC to the robot controller is done via a robot's native interface, such as Ethernet, a serial or parallel interface or a fieldbus. The data objects sent and received are independent from the communication interface. Based on the media independence and the object-oriented interface novel electronic devices, such as tablets, are enabled to act as manual control units for industrial robots.

On the robot controller an interpreter program is cyclically running. The program has a pre-defined, robot-manufacturer independent structure. The program interprets and translates the incoming commands. The interpreter program reads the actual position and orientation of the robot's TCP.

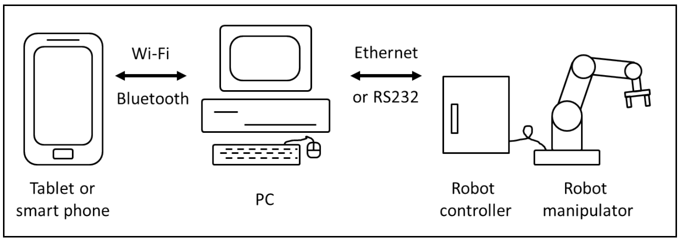

Figure 3. System architecture of an intuitive manipulating interface for industrial robots

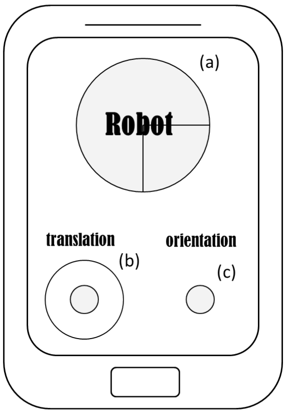

Figure 4. Manipulating interface on tablet – (a) rotary disc for specifying relative position of the user to the robot; the lines on the disc represent the robot's base coordinate system where the z axis is orthogonal to the plane of the tablet; (b) 2 DOF joystick for moving the robot parallel to plane defined by holding the tablet in a specific angle; (c) button for saving two consecutive orientations of the tablet in order to re-orient the robot

The data sent by the server is basically treated as an offset data, i.e. the position values for x, y and z or the angles around x, y and z are added to the actual TCP position and orientation for linear movement or re-orientation respectively.

III. HARDWARE SETUP – INTUITIVE MANIPULATION

The proposed intuitive manipulation method was implemented with following hardware components:

- ABB IRB160 and IRB120 Industrial Robots
- IRC5 (compact) Controller
- Apple Macbook Air
- Apple iPad 2

For translating the robot manipulator linearly (while keeping the orientation of the end effector), following steps need to be conducted:

- defining the relative position to the robot by rotating disc (a)
- holding the tablet in a specific orientation to define the plane in which the robot's TCP shall move
- jogging the 2 DOF joystick (b) for manipulating the robot

For re-orienting the robot's TCP, following steps need to be conducted:

- defining the relative position to the robot by rotating disc (a)
- pressing button (c)
- re-orienting the tablet to specify the amount of rotation
- releasing button (c)

Furthermore, the velocity of the robot manipulator and the increment for translating and rotating can be specified for both motion modes.

IV. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

In this paper an intuitive manipulating effort without high installation costs and effort was introduced. The main goal of the proposed manipulation method is to simplify robot programming on the shop floor – especially for SMEs. Results observed when testing the manipulation device are given in the following:

- Untrained people could immediately manipulate the robot to a required position in space with a pre-defined orientation and solve complex tasks.
- Time for manipulation is radically reduced in comparison to manipulation with conventional teach pendants.
- The implementation of the proposed system is easily adoptable for different robots from different manufacturers as only the interpreter program (running on the robot controller) needs to be translated in the manufacturer specific programming language.

B. Future Works

In regards to safety regulations when manipulating industrial robots, wireless safety and security needs to be ensured. Furthermore, the tablet does not include safety devices, such as an emergency button and an enabling device, which are mandatory when operating robots. One possibility to overcome these issues is to implement some kind of docking interface on the conventional teach pendant to the tablet.

Currently, only manipulation of robots can be done with the proposed system. Future work will concentrate on implementing intuitive programming paradigms including aspects of augmented reality to visualize the specified path in advance.

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