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COMPARING THE SIMULATED AND REAL ENERGY CONSUMPTION OF INDUSTRIAL ROBOTS

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Abstract

Pick and place robot applications in industry are often characterised by high energy consumption. Between 2020 and 2022, electricity costs increased by 150% in several European countries. In order to reduce these costs and prevent global climate change, the energy efficiency of these applications must be optimised. Robot manufacturers provide software tools that can also predict energy consumption. This makes these tools very attractive, even in the early stages of developing these applications. Normally, the energy required to move the robot is predicted. In this case, the energy consumption of the robot controller must also be added. The aim of this work is to compare the total energy consumption of the robot system with the energy consumption of the manipulators (i.e. the simulated energy values of the robot software). To express it more precisely, the ratio of these two major factors is of interest. The ABB software RobotStudio and the robot IRB1100, also from ABB, were used. For compatibility, an ABB EM/S3.16.1 energy meter is connected between the power source and the robot controller, which communicates with the output unit via the KNX bus. The energy consumption of two different motion sequences at five different speeds, ranging from the movement of a single axis to a more complex pick-and-place application, was measured both practically and by simulation. The results of this work show that there is a relationship between the measured values and the simulated energy consumption. In the future, it is planned to extend the test to other robot manufacturers with robots of the same class.

Keywords: Industrial Robots; Automation; RobotStudio; KNX; Energy efficiency

1. Introduction

The design of robotic applications is very important and therefore an essential part of the design [1], [2]. For years, the use of simulation software such as ABB's RobotStudio has improved for the design of such systems [3]. In terms of energy efficiency, the ability of software to estimate power consumption of the robot is of great importance [4] from designing and planning of pick and place applications. Although most robot simulation tools can provide a sufficiently accurate model in many respects, as with all simulations, they can never be a fully accurate representation of a real system [5].

It can therefore be assumed that there is a specific distinction between the real robot application and the simulated one. Since the simulated power usage of the system is one of the most widely used and more important tools of RobotStudio and as there is no reliable data how accurate the simulated energy consumption is, this thesis will examine the difference between the energy consumption calculated by RobotStudio and the real energy consumption of an ABB robot.

2. Problem Statement

Even when companies have no interest in becoming more energy efficient for the sake of environmental or at least economical concerns, the European Union is forcing them more and more with legal provisions to be so [6]. This is thereby how the EU defines the term energy efficiency: The Ratio of output, service, goods or energy yield to energy input [7]. Before taking any steps to improve the energy efficiency of an industrial plant, it is necessary to identify all areas where significant amounts of energy are used. To identify these spots, it is required to determine the energy consumption of each sub system of the process. The easiest way to achieve this is to use energy meters for each system. In practice few or none energy meters are being implemented to evaluate the energy use hence it only can be estimated or in other cases, simulations of the process are conducted [8].

Because of the permanent use of industrial applications for example a robot cell, relatively small modifications in the system can lead to significant changes in the energy efficiency of this application [9]. Therefore, it is necessary that simulations provide a reliable source of accurate data when they are used to design a robot cell in terms of energy consumption. RobotStudio is a widespread program in the industry and also used for research projects [4] to simulate these kind of robot cells. As mentioned one of the most important aspects of optimizing energy efficiency is viewing the simulated power consumption of industrial robots in RobotStudio. But how accurate are these calculations in comparison to the real consumption of a Robot? This thesis is answering this question by investigating the gap of the calculated electricity consumption of a simulated industrial robot and the measured electricity consumption of a real industrial robot.

3. Materials and Methods

This is accomplished by simulating different motion sequences of a robot in RobotStudio and performing the exact same processes with the equal robot in reality where the power is measured by an electricity meter. The main goal of this thesis is to find out if the simulated energy consumption of a industrial robot in RobotStudio is accurate or by how much it deviates from the real consumption. It is not examined how energy can be saved in a robot application or how it is consumed. In the first part of the paper it is explained with which energy meter and how the measurement of the consumed energy of the real ABB IRB1100 robot is performed and how the data from the energy meter is read out. In the second part the data from the different measurements are presented and discussed.

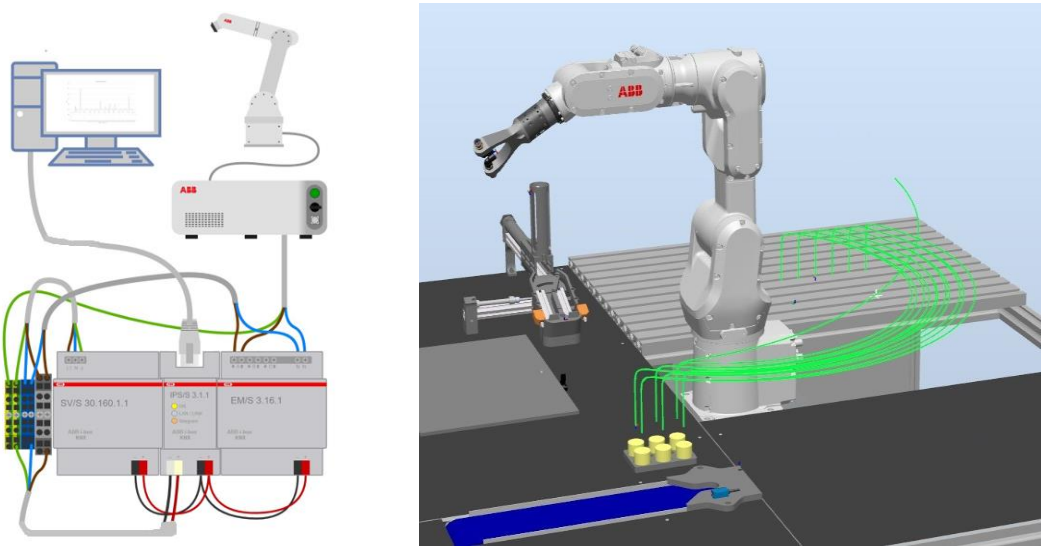


Fig. 1. Schematic representation of the energy meter set-up. The path of the simulated PnP movement

The energy meter that is used to measure the real energy consumption of the robot is the ABB EM/S3.16.1. It is capable of measuring three phase of either 250 V or 450 V alternating current with 16 or 20 Ampere [14]. This is sufficient as the IRB1100 robot that is used is controlled by the Omnicore C30 controller, which has an interrupt fuse for currents in excess of 10A [10]. The connection bus which the EM/S3.16.1 is using is the KNX. KNX was originally developed for home and building control and is the successor to the European Installation Bus (EIB). It is the only open standard worldwide in this field and is recognized in the EU as well as internationally [11].

At the level of the OSI-Model the functionalities of KNX can be assigned to different layers. At the first layer, the physical layer KNX is offering four different alternatives where the TP (Twisted Pair) - which has similarities to the RS-485 standard - is the most used. The three other ones are KNX PL (Power Line), KNX RF (Radio Frequency) and KNX IP (Internet Protocol). The latter one was used in this project where KNX telegrams are wrapped into IP packets so that a conventional LAN network can be used [12].

Therefore, also the ABB IPS/S3.1.1 had to be used to create the connection between the energy meter with the KNX Bus and the PC in the IP Network which was used to read in the measured data. Additionally, as it is shown in the figure 1 the ABB SV/S 30.320.1.1 was used to generate the power for the KNX Bus at 320 mA and monitor the KNX system voltage. The SV/S is supplied with the normal 230 V, 50 Hz voltage source from the electrical enclosure which also provides the 24 V for the IPS/S interface. Apart from these two connections the electrical enclosure is seen as a black box since the only relevant parts where the energy consumption is examined are the ABB Omnicore C90 XT Controller and the ABB IRB 1100 Manipulator as shown in figure 1.

To be able to connect the EM/S over the IPS/S to the computer the XKNX python library was used [13]. After connecting the IPS/S over the LAN with the computer the used python program with the xknx library searches for KNX/IP devices in the network and builds a IP-Tunnel to the corresponding sensor selected by the IP Address. For the first measurements the sensor was not connected directly to the computer but via a wireless access point what lead to a slightly lower scanning rate.

The EM/S is capable of measuring the consumed power in Watt every 0.2 seconds which is enough for slower robot movements at around 250 mm/s but the device reached its limits when the robot speed was increased to more than 1000 mm/s as can be seen further below at the results. The lowest current that can be measured is 25 mA what was in this case accurate enough to measure the power consumption [14].

4. Methods

As mentioned the counterpart of the real movement of the robot is a simulation of the movement in RobotStudio from ABB. To compare the energy consumption of the simulation and the real robot in a useful way it is necessary to ensure that they both are making the exact same movements. To have a better understanding what RobotStudio is measuring, in the beginning simple movements were chosen to determine the differences between simulation and reality. One of the simplest movements that was first picked is the circular path between two points that can be reached by only moving the first axis of the robot by 180 degrees and back. For this kind of movement, the moveJ (J for Joint) command is the most suitable. The forth and back motion of the first axis was performed with three different velocities: 200, 1000 and 5000 mm/s.

The second motion sequence was a little more complex task. At a pick and place (PnP) application six imaginary objects where moved around about 100 degrees as can be seen in figure 2. This was again performed with three different velocities: 2000, 4000 and 7000 mm/s. The PnP offset motion over the yellow cylinders the robot was for safety reasons only moved at 200 mm/s.

In RobotStudio, the energy consumption is computed in the signal analysis and can be exported as a Microsoft Excel file. Different values can be recorded here. For this project only the engine power in Watt and the engine energy in Joule are relevant. The data measured by the EMS was stored by the python program as a .csv file. Each of the three velocities for the two different motion sequences where measured five times to obtain a more accurate average value afterwards. The measurement was started by hand and afterwards the motion sequence was started. It was not practically possible to start both at the same time how RobotStudio is doing it in the simulation.

5. Results

Two pieces of information where looked for. Firstly, how many joules does the robot consume for the entire motion sequence and secondly, how many watts does it consume to move the axis. Since the energy meter is only measuring the current power in watt the joules for the sequence where calculated by numerically integrating the measured watts. This can be seen in equation 1 with t as the current time and W the measured watt. n stands for the current measuring and N for the total number of measurements. For this calculation, it was assumed that the duration of the procedure is the same in both the simulated and the real world.

$$\sum_{n=0}^{N}(t_{n+1}-t_n)\cdot\frac{W_{n+1}+W_n}{2} \tag{1}$$

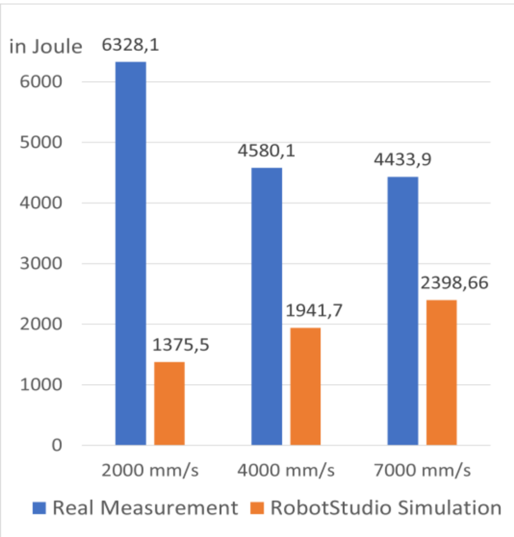
The watt refers to the average value during the movement. The joules for the whole sequence. The calculated joules for the 180 ° rotation and for the PnP application can be seen in figure 3 and 4. For the simple 180 ° rotation it was also possible to get an average watt consumption for the movement of the first axis. These values are also shown in Figure 3. Calculating an average watt usage was no longer possible for the more complex PnP motions sequence at the higher speeds of 4000 and 7000 mm/s especially because of the positive and negative acceleration of the different axes of the robot. In figure 5 the first half of the motion sequence at 4000 mm/s is illustrated with the measured values and the simulated values on top of them.

6. Discussion

The first thing that can be easily seen is that there is a significant contrast between the measured values of the consumed energy and the simulated ones by RobotStudio. The biggest difference of almost 1100 % more joule for the measurements than for the simulation can be seen in the slow 180 degree movement (figure 3). This huge gap can be explained by the difference of around 138 watt for the rotation movement. Since due to the low speed the rotation takes so long (more that 30 sec back and forth), the gap between the simulation and reality is increasing and increasing every second.

For the higher velocities the difference in the measured watt stays more or less the same (186 W at 1000 mm/s and 177 W at 5000 mm/s) but as the motion sequence is much shorter the gap in the calculated joule is also much smaller. This deviation of around 140 to 180 watt can be seen as an absolute error and could possibly originates that RobotStudio does not take the consumption of the controller or Flex-Pendant into account. Or it is also possible that the simulation has certain other inaccuracies (friction, different masses, other physical resistances) or modelling errors that lead to this deviation. An interesting observation that supports this assumption is that when the robot is in a wait position the simulated power consumption is about 5,14 W but at the same time the energy consumption - the joules - is not rising. Another thing to note in figure 3, is that while the simulated energy increases at higher speeds, the energy calculated from the measured values decreases. In figure 4 for the pick and place sequence the trend of the 180 ° rotation continues. At higher velocities the gap between the simulated and measured values is getting smaller while the simulated energy increases and the measured consumption decreases. A couple of things have to be noted here. Firstly as it shows in figure 5 the sampling rate of the energy meter was probably not high enough to accurately read the robot’s consumption. Where the simulated values have clear peaks, the measured ones are more like a rectangular signals. For the highest velocity this was even more decisive. Also for this reason, in order to reduce this constraint, several measurements were carried out what again led to the next challenge to synchronize these different measurements. Since the movement sequence could not be started always at the same time, the first peak was used to overlay the five measurements and calculate the average value. Thirdly, it was observed that the simulated values could also go negative, whereas the measured values couldn’t. This is probably due to the robot braking at higher speeds and RobotStudio simulates this differently to how it was measured.

The smaller differences between 4000 mm/s and 7000 mm/s in figure 4 comes likely from the fact that according to the simulation the higher velocities of 7000 mm/s can’t be reached in this motion sequence. It was not possible in this project to determine how these speeds correspond to the ones in real world.



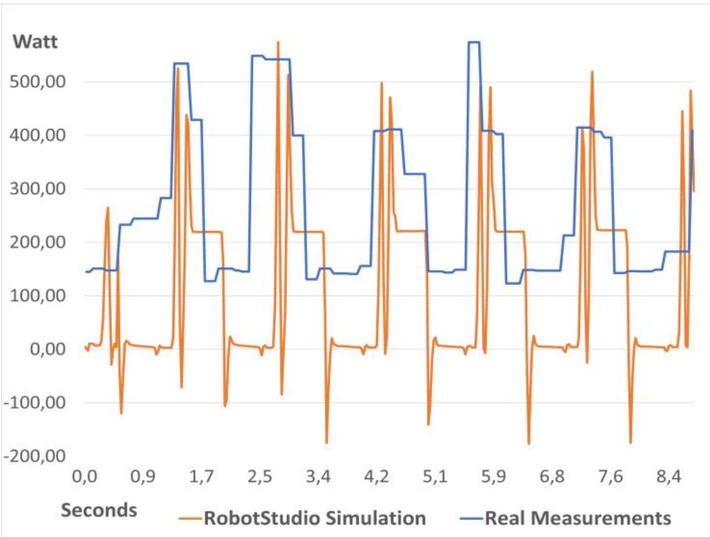


Fig. 2. Measurements of the energy consumption of the PnP application. Figure 5: Illustration of the measured and the simulated power of the PnP application.

7. Summary and Outlook

Pick and Place robot applications Since years the use of simulation software to plan robot application is a standard. RobotStudio from ABB is an example of this software. The tool to visualize the consumed energy of the robot in the simulation is essential to design these applications in an energy efficient manner. To determine how accurate these values are the ABB EM/S3.16.1 energy meter was used to compare them to real measurements from the same robot station. The energy meter was connected to an PC with the KNX IP bus and read out with the xknx python library. Two different motion sequences where examined, one 180 ° rotation and a pick and place application each at three different speeds. Significant differences were observed between the simulated and the measured energy consumption.

As a result of a possible absolute error (which does not increase at higher speeds) between the simulated and measured watts required to move an axis, the difference in energy consumption increased the longer the movement lasted. This observation could be made for the simpler 180 ° rotation and for the more complex Pick and Place sequences. For following projects an energy meter with a higher sampling rate would be necessary to measure high dynamic applications more precisely. It would also be interesting having the possibility to make these kind of comparison between the simulation and the real world with bigger industrial robots where much more energy is needed and also the potential for savings is much higher.

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