Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 40 (2016) 407 – 412

www.elsevier.com/locate/procedia

13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use

Using Adaptive Model Predictive Technique to Control Underactuated Robot and Minimize Energy Consumption

Ahmad Albalasie[a,*], Guenther Seliger[a], Ahmed Abu Hanieh[b]

[a]*Technical University of Berlin, Pascalstr. 8-9, Berlin 10587, Germany*
[b]*Birzeit University, Birzeit, Palestine*

* Corresponding author. Tel.: +49 (0)30 / 314-21255; fax: +49 (0)30 / 314-22759. *E-mail address:* albalasie@mf.tu-berlin.de

Abstract

This paper presents an adaptive model predictive control scheme to control the underactuated and redundant robot, the robot has highly nonlinear coupling because of the existence of a passive axis. Adaptive model predictive control provides a framework to solve optimal discrete control problem for a nonlinear system under input saturation and state constraints. The optimal reference trajectory is computed by using Quasi-linearization (QL) approach to minimize the energy consumption for underactuated motion between two points. The challenge is to meet the performance requirements e.g. position accuracy, repeatability, and precision, combined with high speed capability. Numerical simulations are conducted to validate the control scheme. Simulation results show very good comparison and prove the adequateness of this control technique for underactuated industrial robots.

Peer-review under responsibility of the International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing

Keywords: adaptive model predictive control; underactuated motion; industrial robot; trajectory tracki

1. Introduction

Industrial robots are key factors in implementing the production on the desired scale, speed, quality, and cost. The President of the International Federation of Robotics (IFR) announced in September - 2014 “more than 200,000 industrial robots will be installed in 2014 worldwide, 15% more than in 2013” [1]. Furthermore, he stated “the accelerating demand for industrial robots will continue between 2015 and 2017, growth will likely continue at about 12% on average per year” [1]. This statement emphasizes the need for continuous and intensive research and development in the various fields associated with industrial robots.

Energy efficiency is a field of research in manufacturing and robotics engineering. Since the prices of resources in general and crude oil or gas in specific are increasing, the research focus on saving energy within your production processes became increasingly interesting for companies manufacturing or assembling goods. This emphasizes the great potential to reduce the energy consumption of industrial robots. Consequently minimizing the energy consumption (EC) for the robot is an important issue because also it is minimizing the $\mathbf{CO_2}$ emission in the production stage of a product’s life cycle, decreases the cost of the products and it increases the contribution value of the production.

Several methods have been developed and tested for implementing energy efficient processes in the last decade. Some of these methods are managerial and the others are technical. The managerial methods include: overall production optimization strategies, and strategic and intelligent use of the robot application. The technical methods consist of intelligent braking management systems, the temporal storage of energy in a capacitive buffers, and the optimizing of robot trajectories [2–6].

SAMARA is a prototype of industrial robot for material handling process. It has five degrees of freedom as shown in Fig.1. Furthermore, it uses redundant, underactuated configurations and constrained optimization algorithm to minimize the energy consumption during executing the handling operations [2,7,8,3,3].

Peer-review under responsibility of the International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing
doi:10.1016/j.procir.2016.01.080

Through the previous phase of the work, the second generation of SAMARA prototype has been designed and built at TU Berlin. This new type of robot was designed and path planned minimize the energy consumption with high speed capability and high payload ratio. SAMARA prototype was programmed using optimal path planning algorithm based on the evolutionary algorithm [7,8,3] or the quasi-linearization algorithm in order to minimize the energy consumption during a specific cycle time [2].

In particular, SAMARA has two phases of motion to execute the required tasks. The first phase is the null space phase where the end effector executes the pick and place tasks. Consequently, all the motors are active in this phase. The angular position, angular velocity, and the angular acceleration have been computed for the null space motion by using the analytical solution for each axis. The second phase is the underactuated motion where the end effector moves from point A in the station to point B in the conveyor belt or the vice versa as shown in Fig.2. In this case, the third axis is a passive i.e. un-motorized axis. Also, the boundary values for the underactuated motion are known. This problem is known in mathematics, and it is called two-point boundary value problem (TPBVP).

The handling robots have the property of a relative long movement distances between the processing points of the handling operation. Although these robots consumes high energy consumption in movements among the other robot types, the energy saving in such robots is still larger than the other ones [5].

This paper uses new kinematics for underactuated motion (UAM) [7] and new type of control to execute the pick and place tasks uses a novel method for solving a tracking problem by using the adaptive model predictive controller based on trajectory tracking (AMPCTT) to control underactuated industrial robot taking into account increasing the energy saving by using the (QL) as approach for trajectory planning. This paper is an extension work for a previous work which was developed by TU Berlin and Birzeit university researchers for trajectory planning of UAM [3].

Robots commonly have fast and nonlinear dynamics, the implementation of MPC remains fundamentally limited due to high demand in computational resource associated with optimization. Though most physical systems are inherently nonlinear in nature, the majority of MPC applications are based on the linear dynamic model, mainly to take the computational advantages of MPC.

There are two main types of MPCs. The first type is the linear MPC. It uses the linear model for describing the nonlinear dynamical model for the system at the specific operating point. On the contrary, the second class is the nonlinear MPC (NMPC) which uses a nonlinear model. The computational time for the linear MPC is less than NMPC because of its linearity. But if the nonlinearity of the system is too high, the linear MPC cannot work accurately. Otherwise, NMPC calculates more accurate results, but it consumed longer time in calculations which is not suitable in some applications in the mode of real time environment. Researchers studied the control by using MPC or NMPC based on tracking reference paths for different applications [9–13]. The problem of nonlinearity in the dynamic equations of the underactuated robots causes a problem in the performance, stability, and the other requirements such as: the accuracy, repeatability, and the precision. According to [14], "MPC predicts future behavior using a linear-time-invariant (LTI) dynamic model. In practice, such predictions are never exact, and a key tuning objective is to make MPC insensitive to prediction errors. In many applications, this is sufficient for robust controller performance. If the plant is strongly nonlinear or its characteristics vary dramatically with time, LTI prediction accuracy might degrade so much that MPC performance becomes unacceptable".

This paper suggests another solution for the previous problem by using the adaptive MPC (AMPC). AMPC has the ability to update the linearized model at each control interval, therefore a set of LTI approximation at each current operating condition is used to approximate the nonlinear model and this will improve the response of the robot [14].

Fig. 1 second generation of SAMARA robot

There are two concepts applied in this research to minimize the energy consumption:

- The robot uses new type of kinematics is the underactuated and redundant configurations. The benefit of this type of configuration is that the number of joints are more than the number of actuators, and it uses the principle of momentum conservation [7].
- Minimize the energy consumption by using any optimization algorithm for trajectory planning. To implement this idea the researchers at TU Berlin