16th INTERNATIONAL CONFERENCE
Dynamical Systems – Theory and Applications
December 6-9, 2021, On-line

Motion tracking of a rigid-flexible link manipulator in a controller failure condition

ELŻBIETA JARZĘBOWSKA[1*], KRZYSZTOF AUGUSTYNEK[2], ANDRZEJ URBAŚ[3]

1. Warsaw University of Technology, 00-665 Warsaw, Nowowiejska 24, Poland, [0000-0003-1407-7546]
2. University of Bielsko-Biala, 43-309 Bielsko-Biala, Willowa 2, Poland, [0000-0001-8861-4135]
3. University of Bielsko-Biala, 43-309 Bielsko-Biala, Willowa 2, Poland, [0000-0003-0454-6193]
* Presenting Author

Abstract: The paper presents its contribution to tracking control of systems in failure work conditions. The example we examine is a three degrees-of-freedom planar manipulator with rigid and flexible links, for which one of actuators fails during its work. The work task for the manipulator is defined by the programmed constraints. The CoPCoD method is used to derive the reference motion dynamics and the tracking control after one of manipulator failure.

Keywords: manipulator, reference motion dynamics, underactuated systems, tracking control

1. Introduction

Modern mechanical and mechatronic systems like robots, aircraft, satellites and space platforms, underwater vehicles and human servicing systems are designed for delivering work, services, for exploration and military purposes, to mention some of the applications only. Efforts of engineers and researchers aim excellent functionality, durability and reliability of these systems. Also, there are domains where failure is not an option, like space exploration and service delivery or health related devices. The growing demands for reliability lead to the active research in dynamics, nonlinear control theory and optimal control, and others. At the same time, failures are constantly associated with engineering activities. Failures can be costly in work time, equipment or the whole mission, e.g. a space mission, lost. The question thus arises, in all engineering branches, of how to minimize failure costs. From the dynamics and control theory side, an active research dedicated to underactuated systems continues. A fully actuated system, i.e. the one enjoying the number of control inputs equal to the number of degrees of freedom, does its mission as long as the actuators work properly. In case of failure, questions arise of how to minimize risks and danger of damages to the workplace and continue a predefined task up to bringing the system to some rest position, if possible. A system which is not fully actuated refers to as underactuated. An interest in design and control of underactuated systems is driven by two main questions, i.e. can we control underactuated system models (USM) using our current control techniques and whether there are any new control techniques for USM that can solve reliability problems in practice. These questions motivate a lot of current research in USM.

The literature on USM is quite vast, see e.g. [1]. Most of these papers tackle work conditions where there are no other motion limitations and demands, i.e. constraints. The constrained USM dynamics and control are presented in [2,3] for rigid models of underactuated systems. In [4] a dynamics approach to modeling, i.e. the automated computational procedure for constrained dynamics (CoPCoD) is presented. It works for rigid and flexible multibody systems which are fully actuated. Tracking control of USM is still a challenge topic, see e.g. [5-7].

2. Mathematical model of a rigid-flexible link manipulator

A model of three link, three degrees-of-freedom planar manipulator is presented in Fig.1. It is assumed that link 2 can be treated as rigid or flexible. The flexible link is discretised using the Rigid Finite Element Method (RFEM). The motion of the manipulator is forced by means of three driving torques. The aim of the paper is to propose an algorithm for control the manipulator when certain drives stop working due to failure. The algorithm is implemented in three main steps:

- Calculation of reference time courses of joint coordinates for the assumed programmed constraints, in this case the following DAE system is solved:

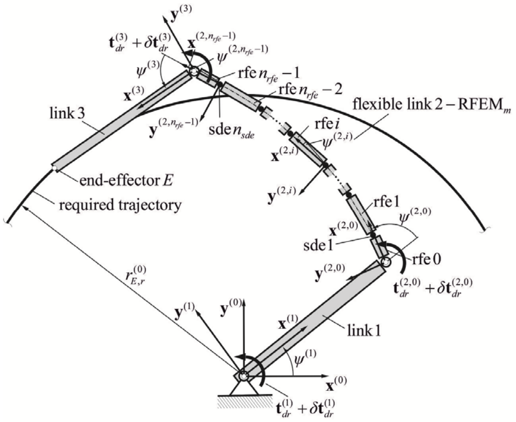

Fig. 1. Model of a rigid-flexible link manipulator

$$\left[\underbrace{\mathbf{M}_i\Big|_{i\in i_c} + \sum_{j\in i_{d_c}} \mathbf{M}_j \frac{\partial \dot{q}_j}{\partial \dot{q}_i}}_{\mathbf{K}}\right]\ddot{\mathbf{q}} = \left[\underbrace{\mathbf{h}_i + \mathbf{Q}_i + \sum_{k=1}^{n_{dof}} \dot{q}_k \frac{\partial \mathbf{Q}_k}{\partial \dot{q}_i} + \sum_{j\in i_{d_c}} \left(\mathbf{h}_j + \mathbf{Q}_j + \sum_{k=1}^{n_{dof}} \dot{q}_k \frac{\partial \mathbf{Q}_k}{\partial \dot{q}_j}\right)\frac{\partial \dot{q}_j}{\partial \dot{q}_i}}_{\mathbf{\Gamma}}\right], \tag{1}$$

where all symbols are explained in detail in [4].

- Application of the reference time courses to flexible drives to realize trajectory tracking.
- Compensation of the tracking errors due to the drive failure using the appropriate controller. As a result the analyzed manipulator is transformed from fully actuated to underactuated which is associated with additional numerical challenges.

References

[1] LIU Y., YU H.: A survey of underactuated mechanical systems. *IET Control Theory & Applications* 2013, **7**(7):921–935.

[2] JARZĘBOWSKA E., SZEWCZYK A.: An Emergency tracking controller design for a manipulator after its actuator failure, *Proc. ASME, IDETC/CIE,* August 2-5, 2015, Boston, MA, USA. https://doi.org/10.1115/DETC2015-47304

[3] JARZĘBOWSKA E.: Tracking control design for underactuated constrained systems. *Robotica* 2006, **24**(5):591-593.

[4] JARZĘBOWSKA E., URBAŚ A., AUGUSTYNEK K.: Analysis of influence of a crane flexible supports, link flexibility, and joint friction on vibration associated with programmed motion execution. *Journal of Vibration Engineering & Technologies* 2020, **8**:337–350.

[5] NERSESOV S.G., ASHRAFIUON H., GHORBANIAN P.: On the stability of sliding mode control for a class of underactuated nonlinear systems. *Proc. of the 2010 American Control Conference*, Baltimore, USA, 3446–3451, 2010.

[6] ZHONG-PING J.: Controlling Underactuated Mechanical Systems: A Review and Open Problems. *in Lecture Notes in Control and Information Sciences book series* 2010, **407**: 77-88.

[7] HE B. , WANG S. A, LIU Y.: Underactuated robotics: A review. *International Journal of Advanced Robotic Systems* 2019, https://doi.org/10.1177/1729881419862164.