Research Driven Robotics Education

Подготовка кадров в области робототехники в Норвежском научно-техническом университете

Антон Ширяев
Professor, PhD
Department of Engineering Cybernetics, NTNU

NTNU

Department of Engineering Cybernetics / Studies

Studies at the Department of Engineering Cybernetics

Programmes of Study

- Master in Cybernetics and Robotics (5 years)
- Master in Cybernetics and Robotics (2 years on top of a Bachelor degree)
- Master in Industrial Cybernetics (2 years on top of a Bachelor degree)
- PhD in Engineering Cybernetics (3 years on top of a Master degree)

Courses

All courses at Department of Engineering Cybernetics

Hint: Choose tick for **Taught in English** to only see courses offered in English.

Contact

E-mail: studinfo@itk.ntnu.no

Ph. D. studies

- PhD in Engineering Cybernetics
- Starting, progress, completion and forms of the PhD-studies at IME.
- Introduction seminar for PhD-students
- PhD opportunities at NTNU
- For doctoral students and staff at NTNU
- DION - The interest organization for doctoral candidates at NTNU

NTNU

Studies / All courses / Courses A - Z

Under each course you will find information about exams, schedules and faculty.

Courses NTNU Gjøvik

Courses NTNU Ålesund

Courses for exchange students

Teaching location

- ☐ Gjøvik
- ☐ Trondheim
- ☐ Ålesund

Filter

- ☐ With multimedia
- ☐ Taught in English
- ☐ Phd courses

Course start

- ☐ Autumn
- ☐ Spring
- ☐ Summer

Show exam date for

Search for **courses**

Search courses

Autumn 2016/Spring 2017

Faculty of Information Technology, Mathematics and Electrical Engineering

Department of Engineering Cybernetics

Code	Course name	Location	Exam date
TTK4210	Advanced Control of Industrial Processes	Trondheim	
TK8103	Advanced Nonlinear Systems	Trondheim	
TK8109	Advanced Topics in Guidance and Navigation	Trondheim	

TTK4101	Instrumentation and Measurements	Trondheim	
TTK4115	Linear System Theory	Trondheim	2016-12-02
TTK4200	Mathematical Modelling of Physical Systems	Trondheim	2016-12-16
TTK4160	Medical Imaging	Trondheim	2016-12-07
TTK4195	Modeling and Control of Robots	Trondheim	
TTK4170	Modelling and Identification of Biological Systems	Trondheim	2016-11-28
TTK4130	Modelling and Simulation	Trondheim	
TK8116	Multivariate Data and Meta Modelling: Preparing for Big Data Cybernetics	Trondheim	
TTK4150	Nonlinear Control Systems	Trondheim	2016-12-10
TK8102	Nonlinear State Estimation	Trondheim	
TK8115	Numerical Optimal Control	Trondheim	
TTK4135	Optimization and Control	Trondheim	
TTK4205	Pattern Recognition	Trondheim	2016-12-15
TTK4145	Real-time Programming	Trondheim	
			2016-

- ⦿ Autumn
- ○ Spring
- ○ Summer

TTK4605	Applied Parameter and State Estimation	Trondheim	2016-11-30
TTK4100	Computerized Control, Introduction	Trondheim	2016-12-12
TTK4230	Control Systems	Trondheim	2016-12-07
TTK4105	Control Systems	Trondheim	
TTK4220	Dynamics in Social Systems	Trondheim	2016-12-12
TTK4235	Embedded Systems	Trondheim	
TTK4155	Embedded and Industrial Computer Systems Design	Trondheim	2016-12-06
TTK4900	Engineering Cybernetics, Master's Thesis	Trondheim	
TTK4555	Engineering Cybernetics, Specialization Course	Trondheim	2016-11-30
TTK4550	Engineering Cybernetics, Specialization Project	Trondheim	
TTK4551	Engineering Cybernetics, Specialization Project	Trondheim	
TK8107	Estimation in Nonlinear Systems	Trondheim	
TTK4190	Guidance and Control of Vehicles	Trondheim	2016-12-07
TTK4240	Industrial Electrotechnics	Trondheim	2016-12-19
TTK4175	Instrumentation Systems	Trondheim	

TTK4147	Real-time Systems	Trondheim	12-17
TTK4165	Signal Processing in Ultrasound Imaging	Trondheim	
TTK4215	System Identification and Adaptive Control	Trondheim	2016-11-29
TTK4225	Systems Theory, Introduction	Trondheim	2016-11-29
TK8112	The Theory of Concurrency in Real-Time Systems	Trondheim	
TK8108	Topics in Fisheries and Aquaculture Cybernetics for PhD students	Trondheim	
TK8111	Topics in System and Control Theory	Trondheim	
TTK4625	UNIK, Specialization Course	Trondheim	2016-11-30
TK8105	Ultrasound imaging in Heterogeneous, Non-Linear Tissue	Trondheim	
TTK4600	Understanding Technology, Innovation and Product Development	Trondheim	2016-11-30

Norwegian University of Science and Technology

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Information on the program

- The department accepts
  - about 150 students for 5 year MSc program
  - about 20 students from colleges outside of NTNU for 2 year MSc program
- ¾ of courses in the program are compulsory and ¼ are volunteered
- Specialization in robotics is taught on the last two years
- The main courses are
  - 4th year: <u>Robot Modeling and Control</u>; Nonlinear Control Systems
  - 5th year: <u>Advanced Topics in Robotics</u>; Advanced Topics in Guidance and Navigation; Autonomous Systems; Identification

Principles and content

- Студенты должны познакомится с различными подразделами (topics) робототехники
- Студенты должны поделать эксперименты на оборудовании (и иногда можно что-то поломать)
- Студенты должны увидеть, что просто и можно купить, и что не просто и купить невозможно или очень дорого
- Упор делается
  - на разработку математических моделей,
  - на решение задач идентификации,
  - на разработку алгоритмов поиска движений и синтеза систем управления
- Work in contact with active researchers!

Equipment

- ABB IRB 140, 1600, 4600 + any available software (MultiMove, Force Control for assembly, machining)
- KUKA LWR4+
- Educational robots from EdRob and Quanser
- Self-designed and developed (locomotive) machines/robots

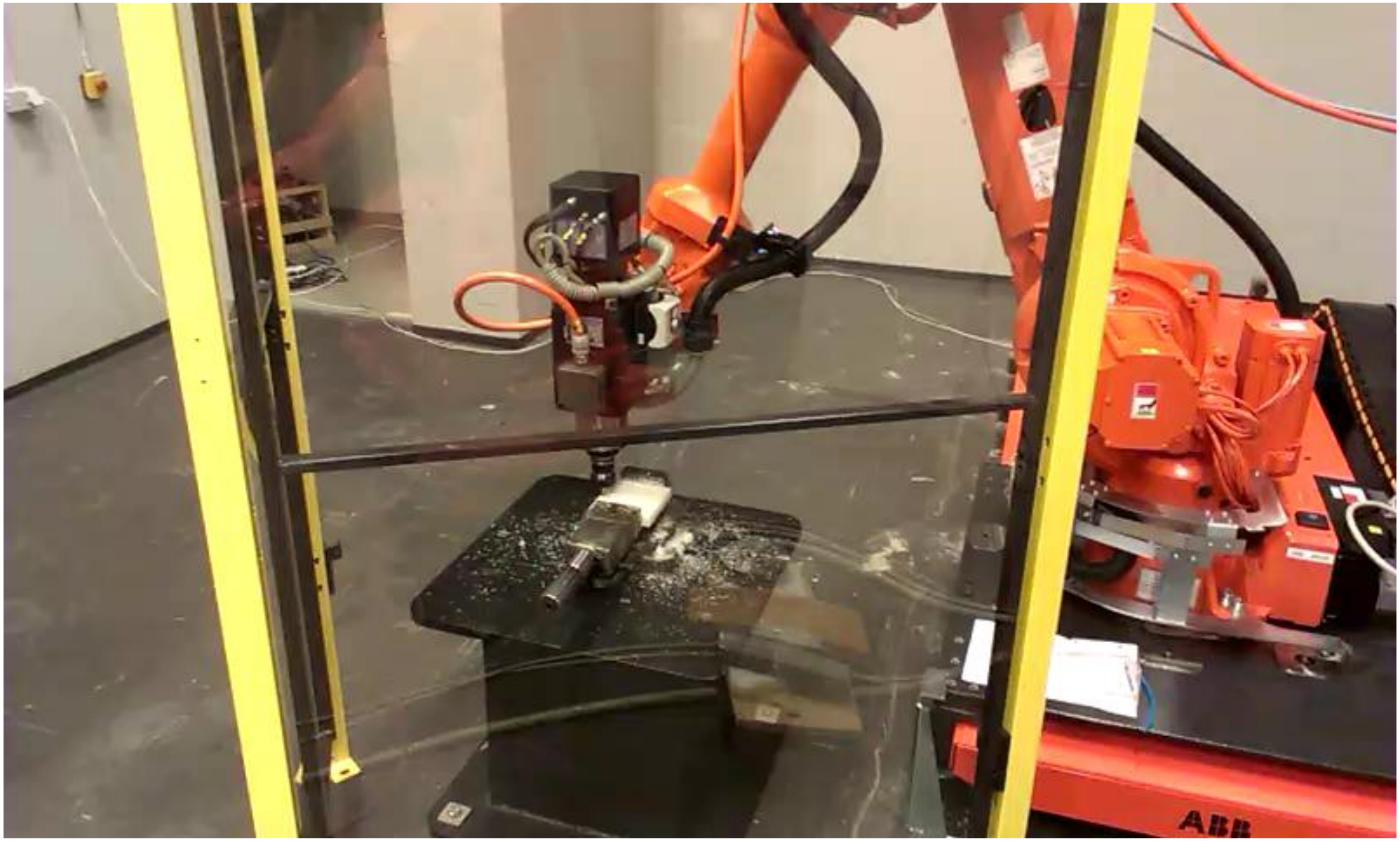
- Robotiq adaptive grippers
- Schunk servo-electric 2-finger parallel grippers
- Spindles

- Metrological equipment
- Cameras
- Force/torque sensors

Examples of student reports

- Issues in Trajectory planning and controlling an industrial Robot's Tool position for accurate passage through sharp Corners of a nominal Path (Eirik Strandbråten)
- Slip Prediction Based on Manipulator Motion (Arne Ranvik)
- 2-D Passive Compass Biped Walker: Analysis and Robustness of Stable Gait (Torleif Anstensrud)
- Analyzing Motions of Unicycles and Car-Like Vehicles (Stian Tvetmarken)
- Stabilization of Gaits for the SemiQuad Robot (Henrik Breivik)
- Path-searching for Rolling Motion of the Two-Link Acrobot With Curved Links (Øystein Henriksen)
- Stabilization of Brachiation Locomotion in a Monkey Robot (Stian Askeland)
- Path Planning, Dynamic Trajectory Generation and Control Analysis for Industrial Manipulators (Torstein Myhre)
- Planning and Control of Locomotion for a Quadruped: Studying the Curvet Gait (Stian Lode)

Movies



Project: Integrated Motion Planner and Feedback Controller for Robot Manipulators

IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY, VOL. 25, NO. 1, JANUARY 2017 101

On Orbital Stabilization for Industrial Manipulators: Case Study in Evaluating Performances of Modified PD+ and Inverse Dynamics Controllers

Stepan S. Pchelkin, Anton S. Shiriaev, Anders Robertsson, Leonid B. Freidovich, *Senior Member, IEEE*, Sergey A. Kolyubin, Leonid V. Paramonov, and Sergey V. Gusev, *Senior Member, IEEE*

***Abstract*— Orbital stabilization is one of the available alternatives to the classical asymptotic stabilization, known as the reference tracking control, which is typically considered and implemented for controlling motions of industrial robot manipulators. Since asymptotic orbital stability means convergence of solutions of a closed-loop system to an orbit of a reference trajectory, instead of tracking it as a function of time, new feedback designs can potentially improve performance with respect to several key criteria for industrial manipulators such as absolute path accuracy for tool's motions and robustness to uncertainties in the model. The main outcomes of this paper are a new class of controllers that achieve asymptotic orbital stabilization of motions and a novel analytical method for analysis and redesign of system's dynamics using an excessive set of easy-to-compute transverse coordinates. The contributions have been**

I. Introduction

A. Motivation

ORBITAL stabilization is one of a few alternatives to the classical reference tracking control task. Searching for such alternatives in robotics has been strongly motivated by the facts that the reference tracking problem formulation is rather loose and implicitly responds to several demanding characteristics of an industrial robot motion controller and that new feedback design methods have the potential to improve requested performances. Among others, the absolute accuracy

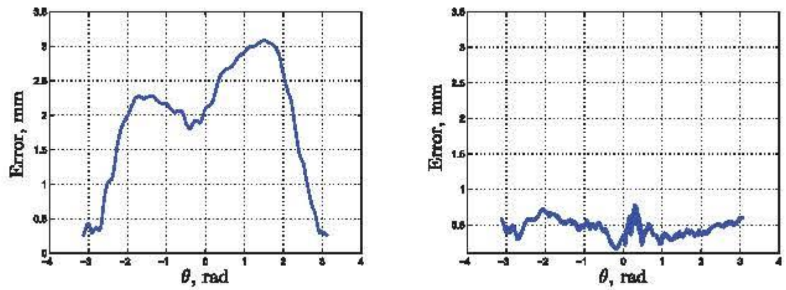


Fig. 15. Left: records of the steady-state TCP path error versus the path variable θ achieved by the standard ABB controller in the experiment to follow the reference with a maximal constant angular velocity that completes the circle in 1.15 s. Right: records of the steady-state TCP path error versus the path variable θ for the closed-loop system with the modified PD+ controller that completes the circle in 0.92 s [rescaled plot of Fig. 13 (left)].

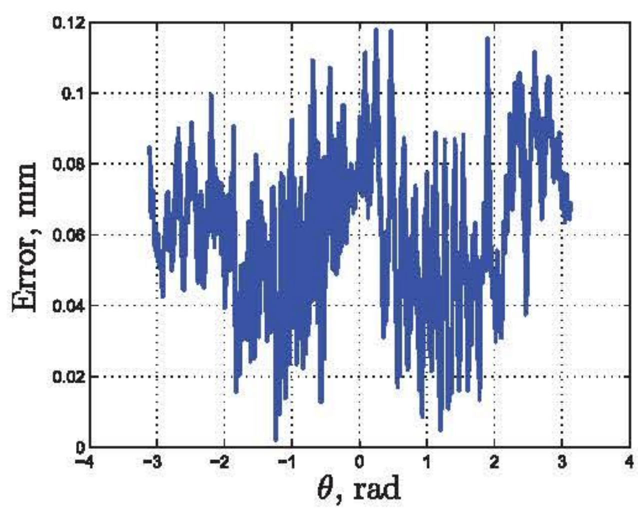


Fig. 16. Steady-state path error for modified PD+ control, which is achieved experimentally. The motion generator $h(\theta)$ is chosen as $h(\theta) = 0.1 + 0.05e^{-2\theta^2}$.

and the linearization of the system dynamics written this new coordinates takes the following decoupled for

$$\frac{d}{dt}[\delta s] = 1, \quad \frac{d}{dt}[\delta x_\perp] = A_\perp(t)\delta x_\perp \qquad (4$$

where $A_\perp(t)$ is a $(2n-1)\times(2n-1)$ smooth T-perio matrix function.

2) If the periodic linear system represented in (40), whi is the dynamics of $\delta x_\perp$ known as transverse lineari tion, is asymptotically stable, then the periodic soluti $x = x^*(t)$ of system (11) is asymptotically orbita stable.

The proof of Statement 1 can be found in [18], wh Statement 2 is a reformulation of Theorem 1.

It is worth emphasizing that in the local coordinates $[s, x$ the periodic solution $x = x^*(t)$ becomes

$$s = s^*(t), \quad x_\perp = x_\perp^*(t) \equiv 0, \quad t \in [0, T]. \qquad (4$$

Statement 2: Given a smooth dynamical system (11), nontrivial T-periodic solution $x = x^*(t)$ and the coordina $[s, x_\perp]$ introduced in Statement 1, consider a smooth sca function $z = z(x)$ that equals to zero on the periodic soluti

$$z(x)|_{x=x^*(t)} \equiv 0. \qquad (4$$

Then the partial derivative of the function $z(x)$ with resp to the new variable s evaluated at any point of the orbit of t solution $x = x^*(t)$ is zero and, in particular

$$\left.\frac{\partial}{\partial s} z(x(s, x_\perp))\right|_{x=x^*(t)} \equiv 0. \qquad (4$$

Furthermore, the variation of the function $z(x)$ in a vicinity

Project: Gait Synthesis and Control for Underactuated Walkers

IEEE TRANSACTIONS ON ROBOTICS, VOL. 29, NO. 3, JUNE 2013 589

Stable Walking Gaits for a Three-Link Planar Biped Robot With One Actuator

Pedro X. Miranda La Hera, *Member, IEEE*, Anton S. Shiriaev, *Member, IEEE*, Leonid B. Freidovich, *Senior Member, IEEE*, Uwe Mettin, *Member, IEEE*, and Sergey V. Gusev, *Senior Member, IEEE*

***Abstract*—We consider a benchmark example of a three-link planar biped walker with torso, which is actuated in between the legs. The torso is thought to be kept upright by two identical torsional springs. The mathematical model reflects a three-degree-of-freedom mechanical system with impulse effects, which describe the impacts of the swing leg with the ground, and the aim is to induce stable limit-cycle walking on level ground. The main contribution is a novel systematic trajectory planning procedure for solving the problem of gait synthesis. The key idea is to find a system of ordinary differential equations for the functions describing a synchronization pattern for the time evolution of the generalized coordinates along a periodic motion. These functions, which are known as virtual holonomic constraints, are also used to compute an impulsive linear system that approximates the time evolution of the subset of coordinates that are transverse to the orbit of the continuous part of the periodic solution. This auxiliary system, which is known as transverse linearization, is used to design a nonlinear exponentially orbitally stabilizing feedback controller. The performance of the closed loop system and its robustness with re-**

I. Introduction

We deal with the case of a planar biped walker that, to the best of our knowledge, was originally introduced in [1], and reflects a version of the compass biped that includes upper body [2]–[4]. The main motivation to consider such an example is to seek solutions to the problems of stabilizing and generating dynamic walking gaits, which are of common interest for passive, fully actuated, and underactuated walkers [5].

The elemental difference with the model of [1] is to consider the biped to be actuated only in between the legs. This consideration leads to a system with two passive links, i.e., point feet and torso, in which posture is maintained upright by torsional springs. This modification makes the problems of gait synthesis and control design more complex, but it represents a more general example of hybrid mechanical systems with sev-

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- МОН РФ
- Companies