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CENTRALE NANTES

MASTER OF SCIENCE, TECHNOLOGY AND HEALTH

CONTROL AND ROBOTICS

ADVANCED ROBOTICS

YEAR 2

PROGRAMME SUPERVISORS:
OLIVIER KERMORGANT, OLIVIER-HENRI ROUX

Établissement public sous tutelle du ministère de l'Enseignement supérieur, de la Recherche et de l'Innovation

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CONTROL AND ROBOTICS – ADVANCED ROBOTICS

YEAR 2 - AUTUMN SEMESTER

CORE COURSES

Research Methodology

Advanced Modeling of Robots

Sensor Based Control of Complex Robots

Cultural and Communication English

French Language

ELECTIVE COURSES

Humanoid Robots

From Human Motion to Humanoid Control

Optimal Kinematic Design

Advanced Visual Geometry

Autonomous Vehicle

Research Methodology

CONTROL AND ROBOTICS – ADVANCED ROBOTICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Ina TARALOVA

Objectives

At the end of the course the students will be able to:

- Research the background and perform a bibliographic review of a specified subject;
- Identify key aspects of research work;
- Use a range of techniques to research and collect information;
- Demonstrate an understanding of how research may be evaluated;
- Plan and prepare a research proposal;
- Deliver a satisfactory written report, including correct citation of related works and analysis;
- Understand the job of researchers and faculty staff.

Course contents

This course aims to provide the students with the necessary skills and tools to carry out and present a research topic. It presents the jobs of researchers and university staff, in research institutions, labs and in R&D departments in companies, and how to apply for them.
This course includes also the bibliographical study for the master thesis topic.

- Setting goals and defining the objectives of the master thesis;
- Bibliographical research and collecting information;
- Written communication: reports, theses, journal & conference papers;
- Oral communication: research presentations, attending conference & presenting a paper;
- Presentation of the researcher position, and university staff;
- The research institutions in EMARO+ countries;
- How to apply for a faculty position in research institutions in Europe and worldwide;
- Seminars will be organized to present the latest technological developments of advanced topics.

This module is assessed via the bibliography report and defense based on the master thesis topic.

Course material

- J. Collis, R. Hussey, Business Research A Practical Guide for Undergraduate and Postgraduate Students, 2nd Edition, Basingstoke: Palgrave, 2003,
- M. Polonsky, D. Waller, Designing and Managing a Research Project, Sage, 2005

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	EXAM
English	5	16 hrs	0 hrs	6 hrs	0 hrs	1 hrs

ADVANCED MODELING OF ROBOTS

CONTROL AND ROBOTICS – ADVANCED ROBOTICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Sébastien BRIOT

Objectives

This course presents advanced modelling techniques (geometric, kinematic and dynamic) of robots (tree structure robots, parallel robots, and hybrid robots) composed of rigid links.

At the end of the course the students will be able to:

- Understand the fundamentals of the mathematical models of robots and their applications in robot design, control and simulation.
- Analyse the mobility of parallel robots and understand the notion of operation modes
- Analyse, identify and illustrate the serial and parallel (including the constraint) singularities of parallel robots
- Identify the geometric and dynamic parameters of a robot
- Use the best methods to develop the required models of a given architecture
- Apply the given techniques to other systems such as mobile robots or passenger cars
- Use the convenient numerical schemes for numerical integration.
- Use modelling, optimization, and signal processing tool box software packages (Matlab, Adams).

Course contents

- Description of complex mechanical systems (tree-structured or closed loop systems),
- Geometric and kinematic models of closed-loop structure robots, constraints equations, mobility analysis, singularity analysis (introduction to DHm convention of tree-structured and closed loop systems)
- Workspace analysis of full-mobility and lower-mobility parallel robots
- Calibration of geometric parameters
- Reminder of dynamics principles (Newton-Euler, Euler-Lagrange, Principle of virtual works) for open and closed-loop mechanism systems
- Dynamic modelling of rigid tree-structure robots: the inverse and direct dynamic problems, the base inertial parameters, computation of the ground forces.
- Dynamic modelling of rigid parallel robots without and with actuation redundancy: the inverse and direct dynamic problems, the base inertial parameters, computation of the ground forces.
- Analysis of the degeneracy conditions of the dynamic model of rigid parallel robots, and singularity crossing
- Identification of dynamic parameters

Practical Work: Exercises will be set, involving modelling, identification and simulation of robots. Advanced technical papers from recent international conferences will be analysed and reviewed.

Course material

- S. Caro, lecture notes on “Geometric and Kinematic Modelling of Serial and Parallel Robots”
- W. Khalil, E. Dombre, Modelling, identification and control of robots, Hermes Penton, London, 2002.
- J. Angeles, Fundamentals of Robotic Mechanical Systems, Springer-¬-Verlag, New York, 3rd edition, 2007
- Merlet, J. P., 2006, Parallel Robots (Solid Mechanics and Its Applications), Springer, New York, Vol. 128.
- S. Briot, lecture notes on “Advanced Dynamic Modelling of Robots”
- S. Briot and W. Khalil, Dynamics of Parallel Robots, Springer.

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	**EXAM**
English	**5**	**24 hrs**	**0 hrs**	**16 hrs**	**0 hrs**	**2 hrs**

Sensor Based Control of Complex Robots

CONTROL AND ROBOTICS – ADVANCED ROBOTICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Olivier KERMORGANT

Objectives

This course presents the fundamentals of the modelling and control techniques used in sensor-based control of complex robots. By complex robots, we mean multi arms systems (including Humanoid robots), parallel robots. Topics will include classical kinematic and dynamic robot control (computed torque control) expressed in joint, Cartesian and sensor space (i.e visual servoing) more generally. A special focus will be placed on redundant robot control using task priority formalisms.

At the end of the course the students will be able to:

- Understand the different properties of visual servoing schemes.
- Use the most convenient methods to obtain the required models,
- Understand practical applications of the mathematical modelling of kinematic visual features.

Course contents

The following subjects will be covered:

- Kinematic control of robots
- Computed torque control
- Position/Force control
- Sensor based control
- Vision based control (Interaction matrix, 2D, 3D, Hybrid)
- Advanced Vision based control (Omnidirectional, Fisheye, Vision/force, etc)
- Visual servoing applications (manipulators, mobile robots, aerial robots, parallel robots, humanoids etc)
- Point-based and region-based image moments
- Redundancy and task priority
- Unilateral constraints in sensor space (object visibility, obstacle avoidance)
- Multi points control of robots

Practical Work: Exercises will be set, which will involve modelling some visual features, and simulation of different control laws.

Course material

- W. Khalil, E. Dombre: Modeling, identification and control of robots, Hermes Penton, London, 2002.
- F. Chaumette, S. Hutchinson, Tutorial, Visual servo control PART I: Basic approaches, IEEE Robotics and Automation Magazine, December 2006
- F. Chaumette, S. Hutchinson, Tutorial, Visual servo control PART II: advanced approaches,

IEEE Robotics and Automation Magazine, March 2007
- Visual Control of Robots: High Performance Visual Servoing, P.I. Corke, Robotics and Mechatronics Series, 2, John Wiley & Sons Inc (November 1996), Language: English
- O. Kanoun, F. Lamiraux, P.-B. Wieber, Kinematic control of redundant manipulators: generalizing the task-priority framework to inequality task, IEEE Trans. on Robotics, 2011

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	**EXAM**
English	**4**	**20 hrs**	**0 hrs**	**12 hrs**	**0 hrs**	**2 hrs**

CULTURAL AND COMMUNICATION ENGLISH

CONTROL AND ROBOTICS – ADVANCED ROBOTICS
YEAR 2 – AUTUMN SEMESTER

LEAD PROFESSOR: Spencer HAWKRIDGE

Objectives

Team-building and Communicational English:

- Understand the general concepts of team-building
- Build a team-building project
- Understand and nurture the creative process
- Enhance self-belief and self-empowerment

Behavioral skills in an inter-cultural environment:

- Strengthen self-confidence and capacity for interaction
- Develop active listening and reformulation skills
- Develop networking skills

Course contents

Cultural and Communicational English: exercises to explore in practice the areas of culture and communication
Field-related or inter-cultural project (for example, construct content for inter-cultural teambuilding activities; example WIOBOX website etc).

Course material

Written and televised press, information and digital tools, general documents business environment and company strategies.
Internet conferences (Ted Talks, etc.), our own educational materials on Hippocampus (Moodle).

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	EXAM
English	4	0 hrs	32 hrs	0 hrs	0 hrs	0 hrs

French Language

CONTROL AND ROBOTICS – ADVANCED ROBOTICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Silvia ERTL

Objectives

The objective is to familiarize the learner with the French language and French culture through an entertaining task-based communicative language teaching, focused on speaking combined with:

- Phonetics
- Self-correcting exercises on our learning platform
- Learning Lab activities
- Project work
- Tutoring

Course objectives include the acquisition and reinforcement of vocabulary, syntax, and pronunciation by both traditional means and through the use of digital resources. Students will learn general French, develop language skills of oral and written comprehension and expression.

After completing this course (32 hours + personal work), the students will be able to communicate in spoken and written French, in a simple, but clear manner, on familiar topics in the context of study, hobbies etc. Another important goal of this course is to introduce the student to French culture.

At the end of the course (2 semesters), complete beginners can achieve an A1 level and some aspects of the A2 of The Common European Framework of Reference for Languages. More advanced students may aim for B1/B2 levels. Those who already completed the first year of the French course will be prepared for working in a French business environment.

Course contents

Two different tracks are proposed: track 1 for students newly arrived at Centrale Nantes and track 2 for students who have completed the first year of the French course.

Track 1:
Full range of practical communication language exercises: reading comprehension, listening comprehension, written expression, oral expression.
Learners will be able to use the foreign language in a simple way for the following purposes:

1. Giving and obtaining factual information:
- personal information (e.g. name, address, place of origin, date of birth, education, occupation)
- non-personal information (e.g. about places and how to get there, time of day, various facilities and services, rules and regulations, opening hours, where and what to eat, etc.)

2. Establishing and maintaining social and professional contacts, particularly:
- meeting people and making acquaintances
- extending invitations and reacting to being invited

- proposing/arranging a course of action
- exchanging information, views, feelings, wishes, concerning matters of common interest, particularly those relating to personal life and circumstances, living conditions and environment, educational/occupational activities and interests, leisure activities and social life

3. Carrying out certain transactions:

- making arrangements (planning, tickets, reservations, etc.) for travel, accommodation, appointments, leisure activities
- making purchases
- ordering food and drink

Track 2:
This track follows on directly from the first-year French course, developing and completing the concepts studied thus far. The main themes are: housing, health and work. These topics will help prepare students for their future work environment. For example, housing is explored in the form of a search for accommodation upon arrival in a new city.

Course material

Preparation manuals, our own tailor-made documents, written and televised press, internet, general civilization documents, digital tools, our own educational materials on Hippocampus (Moodle).

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	**EXAM**
French	4	0 hrs	32 hrs	0 hrs	0 hrs	0 hrs

Humanoid Robots

CONTROL AND ROBOTICS – ADVANCED ROBOTICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Christine CHEVALLEREAU

Objectives

At the end of the course the students will be able to:

- define walking robot stability considering the static and dynamic condition,
- define a control law for a walking robot,
- analyse the stability of a control strategy,
- synthesize and implement the motion of a simple walking robot,
- define a control law for a manipulation task

Course contents

This course presents the fundamentals of control of humanoids for locomotion and manipulation. The students will learn the most common solutions used for stable motion synthesis and control.

The course covers the following:

- biped locomotion: kinematics and dynamics, modelling of contact with the ground
- motion synthesis for bipeds: optimization method, simplified models
- passive robots: properties, stability analysis (Poincaré map), extension
- control methods for postural stabilization, walking, and running: ZMP, on line adaptation, stability analysis, foot placement
- humanoid: whole motion control (redundancy)
- manipulation and grasping
- under-actuated hand

Practical Work:
Exercises will be set, which will involve biped modelling, definition of optimal motion, simulation of passive robots, experiments on an under-actuated hand.

Course material

- C. Chevallereau, G. Bessonnet, G. Abba et Y. Aoustin Bipedal Robots, ISTE Wiley, CAM Control Systems, Robotics and Manufacturing Series,
- E. R. Westervelt, J. W. Grizzle, C. Chevallereau, J-H Choi, Feedback Control of Dynamic Bipedal Robot Locomotion, and Benjamin Morris, Taylor & Francis/CRC Press, 2007.
- M. Vukobratovic, B. Borovac, D. Surla, D. Stokic, Biped Locomotion: Dynamics, Stability, Control and Application, Springer-Verlag, 1990.
- Marc Raibert, Legged Robots That Balance, MIT Press, 2000

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	**EXAM**
English	**4**	**20 hrs**	**0 hrs**	**12 hrs**	**0 hrs**	**2 hrs**

FROM HUMAN MOTION TO HUMANOID CONTROL

CONTROL AND ROBOTICS – ADVANCED ROBOTICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Sophie SAKKA

Objectives

This course outlines the necessary steps allowing for a software simulation of captured human motion to control a humanoid robot. It presents the fundamental knowledge on the mechanics of the human body considered as open kinematic chains of rigid bodies.
At the end of the course the students will be able to:

- Measure human motion using optical motion capture system
- Model and simulate human dynamics
- Imitate hand, arm and whole-body human motion (kinematics) using a humanoid robotic system
- Understand the security and ethical issues of interacting with human beings

Course contents

The following subjects will be discussed:

Human kinematics and dynamics modelling from non-invasive measures:
- Non-invasive measurement of human movement, experimental process
- Experimental, hardware and software artefacts
- Musculoskeletal system
- Human models for robotics applications, approximations
- Simulation of human dynamics from optical motion capture

Imitation of human motion using a humanoid robot:
- Kinematics - application to manipulation, upper and whole-body movements
- Dynamics - application to whole-body humanoid motion generation
- Autonomous behaviour

Course material

- W. Khalil, E. Dombre: Modeling, identification and control of robots, Hermes Penton, London, 2002.
- S. Kajita, H. Hirukawa, K. Harada, K. Yokoi: Introduction à la commande des robots humanoïdes, Springer, 2009.

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	EXAM
English	4	20 hrs	0 hrs	12 hrs	0 hrs	2 hrs

OPTIMAL KINEMATIC DESIGN

CONTROL AND ROBOTICS – ADVANCED ROBOTICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Philippe WENGER

Objectives

This course presents advanced tools and methodologies for the kinematic design of new robots. Both serial and parallel kinematic architecture will be covered. The students will learn how to manage a general kinematic design problem in robotics.

At the end of the course the students will be able to:

- Set an optimal design problem in robotics, taking into account multi-objective criteria,
- Evaluate the kinematic performance of serial and parallel robots,
- Know how to design a cuspidal or a non-cuspidal robot
- Find the best suitable robot for a given task
- Find the best placement of the robot's base,
- Design parallel kinematic robots with given mobility and motion type.

Course contents

- Formalization of relevant criteria for the performance evaluation of robots (accessibility, feasibility of trajectories, dexterity, cuspidality etc),
- Methods for the calculation of robot workspace and of the maximal regions of feasible trajectories, taking into account joint limits and obstacles,
- Classification of cuspidal robots (non-singular posture changing robots) and geometric conditions for a robot to be cuspidal/non-cuspidal
- Optimal design and placement of serial-type robots in cluttered environments,
- Methods for designing parallel kinematic robots (architecture design, geometric design, coping with singularities and operation modes),
- Application examples in typical industrial cases,
- Application examples for the design of innovative robots.

Exercises will be set, which will involve the optimal kinematic design of typical robotic manipulators (serial and parallel). Simulation and verification using Robotic-CAD systems.

Course material

- J. Angeles, Fundamentals of Robotic Mechanical Systems, Springer-Verlag, New York, 2002,
- P. Wenger: "Performance Analysis of Robots", in Robot Manipulators: Modeling, Performance Analysis and Control, E.Dombre, W.Khalil (ed.), ISTE, London, 2006.
- J.P. Merlet, Parallel Robots, Second Edition, Springer, 2006.

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	**EXAM**
English	**4**	**20 hrs**	**0 hrs**	**12 hrs**	**0 hrs**	**2 hrs**

ADVANCED VISUAL GEOMETRY

CONTROL AND ROBOTICS – ADVANCED ROBOTICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Vincent FREMONT

Objectives

This course presents the fundamentals of advanced vision-based perception algorithms. Vision is one of the most promising senses to be used in robotics, providing important geometrical information on the surroundings of the robot. In this way, two-view geometry extended to multiple-view geometry will be investigated in order to address the difficult problems of relative pose estimation, 3D registration, pose and velocity estimation, and SLAM (simultaneous localization and mapping).

Depth cameras will also be introduced as they are used more and more in robot perception.

At the end of the course the students will be able to:

- Understand what can be done from visual geometry
- Develop algorithms for visual odometry
- Develop algorithm for SLAM applications
- Perform 3D registration

Course contents

- Projective geometry
- Epipolar geometry (Homography, Essential and fundamental matrix)
- Multi view geometry
- Visual odometry
- Pose and velocity estimation
- 3D registration
- Visual SLAM (Mono, stereo)
- RGB-D cameras

Practical Work: Exercises will be set, which will involve pose and velocity estimation, visual odometry, visual SLAM, RGB-D cameras

Course material

- Multiple View Geometry in Computer Vision, Richard Hartley, Andrew Zisserman, Barnes & Noble, 2nd edition 2004
- Three-Dimensional Computer Vision, Olivier Faugeras, MIT Press, November 1993
- An invitation to 3D vision: from images to geometric models, Yi Ma, Stefano Soatto, Jana Kosecka, S. Shankar Sastry, Springer, 2010
- Visual Odometry, Part I - The First 30 Years and Fundamentals, Scaramuzza, D., Fraundorfer, F., IEEE Robotics and Automation Magazine, Volume 18, issue 4, 2011.
- Visual Odometry: Part II - Matching, Robustness, and Applications, Fraundorfer, F., Scaramuzza, D., IEEE Robotics and Automation Magazine, Volume 19, issue 1, 2012
- Simultaneous localization and mapping: part I, Durrant-Whyte, H.; Australian Centre for Field Robotics, Sydney Univ., NSW; Bailey, Tim, IEEE Robotics & Automation Magazine,3(2):99-

110, June 2006
- Simultaneous localization and mapping (SLAM): part II, Bailey, Tim; Australian Centre for Field Robotics, Sydney Univ., NSW; Durrant-Whyte, H., IEEE Robotics & Automation Magazine, 13(3): 108 -117, Sept. 2006

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	**EXAM**
English	**4**	**20 hrs**	**0 hrs**	**12 hrs**	**0 hrs**	**2 hrs**

Autonomous Vehicle

CONTROL AND ROBOTICS – ADVANCED ROBOTICS
YEAR 2 - AUTUMN SEMESTER

LEAD PROFESSOR: Eric LE CARPENTIER

Objectives

This course presents the fundamentals of perception for intelligent and autonomous vehicles. Topics will include mapping, decision making process, autonomous navigation and platooning.

At the end of the course the students will be able to:

- Have an overview of an intelligent vehicle's capabilities
- Estimate the risk and the situation
- Put in place a decision-making process
- Understand the global architecture of an autonomous vehicle and platoons

Course contents

The following subjects will be covered:

- Introduction to IV and ITS application
- Bayesian framework
- Decision process
- SLAM
- Autonomous navigation (ADAS, IPAS)
- Platooning

Practical Work: Exercises will be set, which will involve autonomous vehicle platoons, SLAM, Bayesian framework and decision process

Course material

- Eskandarian Azim, Handbook of Intelligent Vehicles, Springer London Ltd Edition, 2012, 1630 pages,
- Cheng Hong, Autonomous Intelligent Vehicles, Theory, Algorithms, and Implementation, Series:
- Advances in Computer Vision and Pattern Recognition, Springer, 2011, 147 pages
- Yaobin Chen, Lingxi Li, Advances in Intelligent Vehicles, 1st Edition, Academic Press, Dec 2013
- Multiple View Geometry in Computer Vision, Richard Hartley, Andrew Zisserman, Barnes & Noble, 2nd edition 2004
- Three-Dimensional Computer Vision, Olivier Faugeras, MIT Press, November 1993
- An invitation to 3D vision: from images to geometric models, Yi Ma, Stefano Soatto, Jana Kosecka, S. Shankar Sastry, Springer, 2010
- Visual Odometry, Part I - The First 30 Years and Fundamentals, Scaramuzza, D., Fraundorfer, F., IEEE Robotics and Automation Magazine, Volume 18, issue 4, 2011.
- Visual Odometry: Part II - Matching, Robustness, and Applications, Fraundorfer, F., Scaramuzza, D., IEEE Robotics and Automation Magazine, Volume 19, issue 1, 2012

- Simultaneous localization and mapping: part I, Durrant-Whyte, H.; Australian Centre for Field
- Robotics, Sydney Univ., NSW; Bailey, Tim, IEEE Robotics & Automation Magazine, 3(2):99-110, June 2006
- Simultaneous localization and mapping (SLAM): part II, Bailey, Tim; Australian Centre for Field
- Robotics, Sydney Univ., NSW; Durrant-Whyte, H., IEEE Robotics & Automation Magazine, 13(3): 108 -117, Sept. 2006

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	**EXAM**
English	**4**	**20 hrs**	**0 hrs**	**12 hrs**	**0 hrs**	**2 hrs**

YEAR 2 - SPRING SEMESTER

Master Thesis / Internship

MASTER THESIS / INTERNSHIP

CONTROL AND ROBOTICS – ADVANCED ROBOTICS

YEAR 2 - SPRING SEMESTER

LEAD PROFESSOR: Olivier KERMORGANT

Objectives

- Be exposed to and adapt to an industrial or research environment
- Put in practice the scientific and technical skills acquired in the previous semesters
- Strengthen interpersonal and communication skills
- Be part of or manage a project
- Organize tasks, analyze results and build deliverables

Course contents

Students should be pro-active and career-oriented in the search for their thesis/internship. The topics are validated by the program supervisor to ensure an adequate Master level. The thesis/internship is evaluated through the submission of a written report and an oral defense.

Course material

- Turabian Kate Larimore, Booth Wayne Clayton, Colomb Gregory G., Williams Joseph M., & University of Chicago press. (2013). A manual for writers of research papers, theses, and dissertations: Chicago style for students and researchers (8th edition.). Chicago (Ill.) London: University of Chicago Press.
- Bui Yvonne N. How to Write a Master's Thesis. 2nd ed. Thousand Oaks, Calif: Sage, 2014.
- Evans David G., Gruba Paul, et Zobel Justin. How to Write a Better Thesis. 3rd edition. Carlton South, Vic: Melbourne University Press, 2011.

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT	**EXAM**
English	30	0 hrs	0 hrs	0 hrs	0 hrs	0 hrs