1 Brief Course Description

ELEC4410 examines advanced analysis and design issues in linear feedback control systems. The course provides an in-depth introduction to the fundamental concepts of linear system theory using both transfer function and state equation system descriptions. Emphasis is placed on the design of feedback controllers and state estimators for pole-placement, robust regulation, tracking and disturbance rejection, in the context of real world industrial process applications.
2 Course Objectives
This course builds on ELEC4400 offering a more advanced discussion of control systems, introducing modern control techniques and practical implementation issues. In particular, students who successfully complete this course should have:

- An exposure to modern control design and analysis tools, such as internal model control, state feedback control, and observers.
- An in-depth introduction to the fundamental concepts of linear system theory, including internal stability, realisations, controllability and observability.
- A basic understanding of various factors which limit the achievable control system performance, such as time delays, non minimum phase zeros, and open loop unstable poles.
- Experience in several lab implementations of control systems.
- An initial exposure to various control implementation issues, including sampled data systems, actuator saturation, and anti-windup schemes.
- An initial exposure to more advanced control system topics, such as multiple-input multiple-output systems, optimal control, and Kalman Filters.
- Knowledge of case studies of successful modern control implementations.
- Exposure to experimental modelling using system identification techniques.

3 Contact Details
3.1 Lecturers

<table>
<thead>
<tr>
<th>Lecturer</th>
<th>Email</th>
<th>Room</th>
<th>Phone</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Julio Braslavsky</td>
<td><a href="mailto:julio@ee.newcastle.edu.au">julio@ee.newcastle.edu.au</a></td>
<td>EAG02</td>
<td>4921 5740</td>
<td>Thursdays, 15:00–17:00</td>
</tr>
<tr>
<td>James Welsh</td>
<td><a href="mailto:james.welsh@newcastle.edu.au">james.welsh@newcastle.edu.au</a></td>
<td>EAG15</td>
<td>4921 6087</td>
<td>Mondays, 13:00–15:00</td>
</tr>
</tbody>
</table>

3.2 Other Contacts

Faculty Student Service Office, Faculty of Engineering and Built Environment, Room EF101, Phone: 49216065

The Dean of Students, Dr Jennifer Archer. Phone: 49215806, Fax: 49217151
resolutionprecinct@newcastle.edu.au

Various services are offered by the University Student Support Unit:

4 Topics
Internal model control (16 hours), fundamental limitations in control design (5 hours), system identification (2 hours), state space system theory (21 hours), state space control design (14 hours), optimal estimation (5 hours), industrial case study (2 hours).

5 Assumed Knowledge
ELEC4400.

It is also assumed that students have an active knowledge of linear algebra and Laplace transforms as well as an elemental knowledge of complex variables and linear ordinary differential equations.
6 Course Contents

1. Introduction and motivation to ELEC4410
2. Mathematical description of systems
   2.1 A taxonomy of systems
   2.2 Linear time invariant systems
   2.3 Discrete-time systems
3. Control design via affine parameterisations
   3.1 Affine parameterisation for stable systems
   3.2 PID synthesis via the affine parameterisation
   3.3 Affine parameterisation for systems with time delays
   3.4 Undesirable closed-loop poles
   3.5 Saturation and anti-windup
   3.6 Affine parameterisation for unstable systems
   3.7 Affine parameterisation for MIMO systems
4. Fundamental limitations in control design
   4.1 Sensors, actuators, perturbations and model errors
   4.2 Structural limitations
      i. Delays
      ii. Unstable poles
      iii. Non-minimum phase zeros
   4.3 Design tradeoffs in the step response
      i. Interpolations constraints
      ii. Design specifications
      iii. Design limitations
5. Elements of system identification
   5.1 Introduction
   5.2 Least squares model fitting
6. Introduction to state space system theory
   6.1 Solution of LTI state equations
      i. Discretisation
      ii. Discrete-time state equations
   6.2 Realisations
   6.3 Equivalent state space equations
   6.4 Stability
      i. External and internal stability
      ii. Lyapunov Theorem
   6.5 Controllability
   6.6 Observability
   6.7 Canonical forms
   6.8 Discrete-time state equations
      i. Controllability after sampling
7. Control design via state space methods
   7.1 State feedback
   7.2 Regulation and tracking
      i. Robust tracking: integral action
   7.3 State estimation
   7.4 Feedback from estimated states
      i. The Separation Principle
      ii. Design considerations
   7.5 MIMO state feedback
   7.6 MIMO state estimation
   7.7 MIMO feedback from estimated states
8. Introduction to optimal control
   8.1 The basic optimal control problem
   8.2 The Kalman Filter

7 Teaching Modes

The material is presented based on a lecture format, including case studies, and is supplemented with Tutorials, Computer Simulations and Laboratories to reinforce student learning.

8 Lecture Times

<table>
<thead>
<tr>
<th>Activity</th>
<th>Day</th>
<th>Time</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td>Monday</td>
<td>11:00–12:00</td>
<td>EAG01</td>
</tr>
<tr>
<td>Tutorial</td>
<td>Wednesday</td>
<td>08:00–11:00</td>
<td>EF14/ES204</td>
</tr>
<tr>
<td>Lecture</td>
<td>Thursday</td>
<td>13:00–15:00</td>
<td>EAG01</td>
</tr>
</tbody>
</table>

First lecture July 18th. Last lecture November 3rd.
9 Grading Policies

The composition of the final mark is as follows:

- Assignments 15%
- Labs 10%
- Quiz 15%
- Exam 60%

The Quiz will be held on Wednesday, 14th September 2005, 08:00–10:00, in EF14. It will be open book — you are welcome to bring lecture notes and/or reference books. It will cover the material of the first eight weeks (up to and including Wednesday, 7th September 2005), with emphasis on lecture and tutorial material.

Students are required to obtain a minimum of 40% in the final exam to pass the course.

10 Assignments

There will be 10 Individual Assignments and one Group Assignment. They contribute to the final mark in the following proportion:

- Individual Assignments 10%
- Group Assignment 5%

All assignment solutions must be clear and neat, with the pages stapled together. Illegible or messy solutions will not be marked.

NOTE: Students need to submit all assignments with an assignment cover sheet. These cover sheets can be downloaded from the School’s website or obtained from the School’s Discipline Offices in Buildings EA and ES.

Individual Assignments: Homework problem sets will be given each week during the tutorial sessions as a way for students to master the course topics. Each week, one problem in the set will be chosen and marked as an assignment, which will be due at the beginning of the tutorial session in the following week. Marked problems will be returned at the tutorial sessions. Solutions to all the problems in the set will be posted after the due date.

Group Assignment: Students, working in groups of 2, will be required to review an article of their choice based on a specified topic or theme within the context of control systems, subject to the approval of the lecturer. Students are to write an executive summary (> 500 words) and make a 10 minute presentation based on the paper they choose to review.
Assignment Schedule:

<table>
<thead>
<tr>
<th>Individual Assignments</th>
<th>No.</th>
<th>Assigned</th>
<th>Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>July 20</td>
<td>July 27</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>July 27</td>
<td>August 3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>August 3</td>
<td>August 10</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>August 10</td>
<td>August 17</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>August 17</td>
<td>August 24</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>August 24</td>
<td>August 31</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>August 31</td>
<td>September 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September 7</td>
<td>No assignment</td>
<td>(upcoming Quiz)</td>
</tr>
<tr>
<td>8</td>
<td>September 21</td>
<td>October 12</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>October 12</td>
<td>October 19</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>October 19</td>
<td>October 26</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group Assignment</th>
<th>Part</th>
<th>Assigned</th>
<th>Due</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summary</td>
<td>July 18–22</td>
<td>September 19</td>
</tr>
<tr>
<td></td>
<td>Presentation</td>
<td>July 18–22</td>
<td>October 12, 19, 26</td>
</tr>
</tbody>
</table>

11 Laboratory Exercises

Students are required to complete a 10 points of laboratory exercises. The table below summarises the laboratories and their weighting in points. Laboratory 1, Simple Servomechanism Control is compulsory i.e. all students must complete this laboratory exercise. Students may choose to do any of the other laboratory exercises to meet the 10 point requirement. Students are permitted to work in groups of 3. Note that exceeding the 10 points will not result in extra marks towards the final assessment.

<table>
<thead>
<tr>
<th>Laboratory Exercises</th>
<th>No.</th>
<th>Title</th>
<th>Weighting</th>
<th>Date Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Simple Servomechanism Control</td>
<td>2</td>
<td>August 31</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Resonant Servomechanism Control</td>
<td>8</td>
<td>October 26</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Deadbeat Servomechanism Control</td>
<td>4</td>
<td>October 26</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>State Feedback and Observer Servomechanism Control</td>
<td>4</td>
<td>October 26</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Air Heater Control</td>
<td>4</td>
<td>October 26</td>
<td></td>
</tr>
</tbody>
</table>

For more information regarding the laboratory work please see the separate document titled 'Laboratory Guide for ELEC4410'.
## 12 Lecture and Tutorial Timetable

<table>
<thead>
<tr>
<th>MONDAY</th>
<th>TUESDAY</th>
<th>WEDNESDAY</th>
<th>THURSDAY</th>
<th>FRIDAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul 18</td>
<td>Class 1</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>§1 Introduction to ELEC4410</td>
<td>20</td>
<td></td>
<td>21 Class 3</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Class 2</td>
<td>Revision: Transfer functions, PID control, inversion by feedback</td>
<td>§2 Mathematical description of systems.</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Class 4</td>
<td>26</td>
<td>27 Class 5</td>
<td>28 Class 6</td>
</tr>
<tr>
<td>§3 §3 Introduction to IMC. Affine parameterisation for PID synthesis</td>
<td>Tutorial: §3 Affine parameterisation, PID synthesis</td>
<td>§3 IMC for systems with time delay. Undesirable closed-loop poles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aug 1</td>
<td>Class 7</td>
<td>2</td>
<td>3 Class 8</td>
<td>4 Class 9</td>
</tr>
<tr>
<td>§3 Undesirable closed-loop poles (continuation)</td>
<td>Tutorial: §3 IMC for systems with delay. Undesirable poles</td>
<td>§3 Saturation and IMC with anti-windup. IMC for unstable systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Class 10</td>
<td>9</td>
<td>10 Class 11</td>
<td>11 Class 12</td>
</tr>
<tr>
<td>§3 IMC for MIMO systems</td>
<td>Class 11</td>
<td>Tutorial: §3 IMC with anti-windup. IMC for unstable systems</td>
<td>§4 Design limitations in control. Design considerations</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Class 13</td>
<td>16</td>
<td>17 Class 14</td>
<td>18 Class 15</td>
</tr>
<tr>
<td>§4 Limitations in the step response</td>
<td>Tutorial: §4 Design limitations</td>
<td>§5 Elements of system identification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Class 16</td>
<td>23</td>
<td>24 Class 17</td>
<td>25 Class 18</td>
</tr>
<tr>
<td>§6 State space system realisations</td>
<td>Class 17</td>
<td>Tutorial: §5 Solution of state equations. Realisations</td>
<td>§6 Revision of Linear Algebra. Equivalent state space equations</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Class 19</td>
<td>30</td>
<td>31 Class 20</td>
<td>32 Class 21</td>
</tr>
<tr>
<td>5</td>
<td>Class 22</td>
<td>6</td>
<td>7 Class 23</td>
<td>8 Class 24</td>
</tr>
<tr>
<td>§6 Controllability</td>
<td>Class 23</td>
<td>§6 Tutorial: Stability, controllability.</td>
<td>§6 Observability. Canonical forms</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Class 25</td>
<td>13</td>
<td>14 Class 26</td>
<td>15 Class 27</td>
</tr>
<tr>
<td>Tutorial: Observability, Canonical forms</td>
<td>Class 26</td>
<td>Quiz</td>
<td>§6 Discrete equations. Talk: Industrial Control by Sam Crisafulli</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Class 28</td>
<td>20</td>
<td>21 Class 29</td>
<td>22 Class 30</td>
</tr>
<tr>
<td>§7 State feedback</td>
<td>Class 29</td>
<td>§6 Discrete equations. §7 State feedback</td>
<td>§7 Regulation and tracking, state estimation.</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Recess</td>
<td>27</td>
<td>28 Recess</td>
<td>29 Recess</td>
</tr>
<tr>
<td>Reccess</td>
<td>4</td>
<td>5 Recess</td>
<td>6 Recess</td>
<td>7</td>
</tr>
</tbody>
</table>
13 Plagiarism

University policy prohibits students plagiarising any material under any circumstances. A student plagiarises if he or she presents the thoughts or works of another as one's own. Without limiting the generality of this definition, it may include:

- copying or paraphrasing material from any source without due acknowledgment
- using another's ideas without due acknowledgment
- working with others without permission and presenting the resulting work as though it was completed independently.

Plagiarism is not only related to written works, but also to material such as data, images, music, formulae, websites and computer programs. Aiding another student to plagiarise is also a violation of the Plagiarism Policy and may invoke a penalty.

For further information on the University policy on plagiarism, please refer to the Policy on Student Academic Integrity at the following link:

The University has established a software plagiarism detection system called Turnitin. When you submit assessment items please be aware that for the purpose of assessing any assessment item the University may:

- reproduce this assessment item and provide a copy to another member of the University
  and/or
- communicate a copy of this assessment item to a plagiarism checking service (which may then retain a copy of the item on its database for the purpose of future plagiarism checking)
- submit the assessment item to other forms of plagiarism checking.

14 Extension of Time for Assessment Items, Deferred Assessment and Special Consideration for Assessment Items or Formal Written Examinations

Students are required to submit assessment items by the due date, as advised in the Course Outline, unless the Course Coordinator approves an extension of time for submission of the item. University policy is that an assessment item submitted after the due date, without an approved extension, will be penalised. Any student:
1. who is applying for an extension of time for submission of an assessment item on the basis of medical, compassionate, hardship/trauma or unavoidable commitment

or

2. whose attendance at or performance in an assessment item or formal written examination has been or will be affected by medical, compassionate, hardship/trauma or unavoidable commitment; must report the circumstances, with supporting documentation, to the appropriate officer on the prescribed form.

Please go to the Policy and the on-line form for further information, particularly for information on the options available to you, at:

15 Changing your Enrolment

The last date to withdraw without financial or academic penalty (called the HECS Census Date) is, for semester 2 courses, August 31 2005.

Students may withdraw from a course without academic penalty on or before the last day of semester and prior to the commencement of the formal exam period. Any withdrawal from a course after the last day of semester will result in a fail grade.

Students cannot enrol in a new course after the second week of semester/trimester, except under exceptional circumstances. Any application to add a course after the second week of semester/trimester must be on the appropriate form, and should be discussed with the School Office.

To change your enrolment online, please refer to
http://www.newcastle.edu.au/study/enrolment/change-enrol.html

16 Web Address for Rules Governing Undergraduate Academic Awards


17 Web Address for Rules Governing Postgraduate Academic Awards


18 Students With A Disability Or Chronic Illness

The University is committed to providing a range of support services for students with a disability or chronic illness.

If you have a disability or chronic illness which you feel may impact on your studies, please feel free to discuss your support needs with your lecturer or course coordinator.

Disability Support may also be provided by the Student Support Service (Disability). Students must be registered to receive this type of support. To register please contact the Disability Liaison Officer on 49215766, or via email at: student-disability@newcastle.edu.au

As some forms of support can take a few weeks to implement it is extremely important that you discuss your needs with your lecturer, course coordinator or Student Support Service staff at the beginning of each semester. For more information related to confidentiality and documentation please visit the Student Support Service (Disability) website at:
www.newcastle.edu.au/services/disability
19 Alteration of this Course Outline

No change to this course outline will be permitted after the end of the second week of the term except in exceptional circumstances and with Head of School approval. Students will be notified in advance of any approved changes to this outline.