1. General Information

1a. Submitted by the College of: ENGINEERING

   Date Submitted: 7/21/2016

1b. Department/Division: Mechanical Engineering

1c. Contact Person

   Name: Jesse B. Hoagg

   Email: jhoagg@engr.uky.edu

   Phone: 218-0641

   Responsible Faculty ID (if different from Contact)

   Name:

   Email:

   Phone:

1d. Requested Effective Date: Semester following approval

1e. Should this course be a UK Core Course?   No

2. Designation and Description of Proposed Course

2a. Will this course also be offered through Distance Learning?:   No

2b. Prefix and Number: ME 672

2c. Full Title: Nonlinear Systems &Control

2d. Transcript Title:

2e. Cross-listing:

2f. Meeting Patterns

   LECTURE: 3

2g. Grading System: Letter (A, B, C, etc.)

2h. Number of credit hours: 3

2i. Is this course repeatable for additional credit?   No

   If Yes: Maximum number of credit hours:

   If Yes: Will this course allow multiple registrations during the same semester?

2j. Course Description for Bulletin: This course presents methods for analyzing and controlling nonlinear dynamic systems. The major topics are: 1) fundamental properties of nonlinear ordinary differential equations such as existence and uniqueness; 2) Lyapunov stability theory; and 3) nonlinear feedback control techniques such as backstepping, feedback linearization, and Lyapunov-based design.

2k. Prerequisites, if any:

2l. Supplementary Teaching Component:

3. Will this course taught off campus?   No

    If YES, enter the off campus address:

4. Frequency of Course Offering: Spring,

    Will the course be offered every year?:   Yes

    If No, explain:

5. Are facilities and personnel necessary for the proposed new course available?:   Yes

    If No, explain:

6. What enrollment (per section per semester) may reasonably be expected?:   10

7. Anticipated Student Demand

    Will this course serve students primarily within the degree program?:   Yes

    Will it be of interest to a significant number of students outside the degree pgm?:   Yes

    If Yes, explain: The material in ME 672 is highly relevant to graduate students whose research involves nonlinear control system design or analysis, and these topics span multiple engineering disciplines (e.g., electrical engineering, mechanical engineering, chemical engineering).

8. Check the category most applicable to this course: Traditional – Offered in Corresponding Departments at Universities Elsewhere,

    If No, explain:

9. Course Relationship to Program(s).

    a. Is this course part of a proposed new program?:   No

    If YES, name the proposed new program:

    b. Will this course be a new requirement for ANY program?:   No

    If YES, list affected programs:

10. Information to be Placed on Syllabus.

    a. Is the course 400G or 500?:   No

    b. The syllabus, including course description, student learning outcomes, and grading policies (and 400G-/500-level grading differentiation if applicable, from **10.a** above) are attached: Yes

Distance Learning Form

Instructor Name:

Instructor Email:

Internet/Web-based: No   3

Interactive Video: No

Hybrid: No

1. How does this course provide for timely and appropriate interaction between students and faculty and among students? Does the course syllabus conform to University Senate Syllabus Guidelines, specifically the Distance Learning Considerations?

2. How do you ensure that the experience for a DL student is comparable to that of a classroom-based student's experience? Aspects to explore: textbooks, course goals, assessment of student learning outcomes, etc.

3. How is the integrity of student work ensured? Please speak to aspects such as password-protected course portals, proctors for exams at interactive video sites; academic offense policy; etc.

4. Will offering this course via DL result in at least 25% or at least 50% (based on total credit hours required for completion) of a degree program being offered via any form of DL, as defined above?

If yes, which percentage, and which program(s)?

5. How are students taking the course via DL assured of equivalent access to student services, similar to that of a student taking the class in a traditional classroom setting?

6. How do course requirements ensure that students make appropriate use of learning resources?

7. Please explain specifically how access is provided to laboratories, facilities, and equipment appropriate to the course or program.

8. How are students informed of procedures for resolving technical complaints? Does the syllabus list the entities available to offer technical help with the delivery and/or receipt of the course, such as the Information Technology Customer Service Center (http://www.uky.edu/UKIT/)?

9. Will the course be delivered via services available through the Distance Learning Program (DLP) and the Academic Technology Group (ATL)?   NO

If no, explain how student enrolled in DL courses are able to use the technology employed, as well as how students will be provided with assistance in using said technology.

10. Does the syllabus contain all the required components?   NO

11. I, the instructor of record, have read and understood all of the university-level statements regarding DL.

    Instructor Name:

ME 672
Nonlinear Systems & Control

Instructor: Prof. Jesse B. Hoagg
Office: 271 Ralph G. Anderson Building
Email: jhoagg@engr.uky.edu
Phone: (859) 218-0641

Course Description
This course presents methods for analyzing and controlling nonlinear dynamic systems. The major topics are: 1) fundamental properties of nonlinear ordinary differential equations such as existence and uniqueness; 2) Lyapunov stability theory; and 3) nonlinear feedback control techniques such as backstepping, feedback linearization, and Lyapunov-based design.

Prerequisites
Knowledge of linear dynamic systems (e.g., EE 611) is helpful but not required.

Student Learning Outcomes
After completion of this course, the student will be able to:
1) Examine existence and uniqueness of a solution to a nonlinear ordinary differential equation (ODE)
2) Examine how the solution to an ODE depends on initial conditions and parameters
3) Use Lyapunov's direct and indirect methods to analyze the stability properties of an equilibrium of a nonlinear ODE
4) Estimate the region of attraction for a local asymptotically stable equilibrium
5) Apply LaSalle's invariance principle
6) Apply instability analysis methods
7) Analyze the stability properties of an equilibrium of a nonlinear time-varying ODE
8) Design nonlinear feedback controllers using Lyapunov-based design techniques, backstepping, feedback linearization, and sliding mode control
9) Analyze the stability properties of a closed-loop system obtained using nonlinear feedback control methods

Lecture Hours
Tuesday, Thursday 12:30pm to 1:45pm

Office Hours
Tuesday, Thursday 2:00pm to 3:30pm, and by appointment

Required Material
Textbook: Hassan K. Khalil, *Nonlinear Systems*, 3rd edition, Prentice Hall, 2002.

Other References
1) J.-J. E. Slotine and W. Li, *Applied Nonlinear Control*, Prentice Hall, 1991.
2) S. Sastry, *Nonlinear Systems*, Springer, 1999.
3) A. Isidori, *Nonlinear Control Systems*, 3rd edition, Spring, 1995.
4) W. H. Haddad and V. Chellaboina, *Nonlinear Dynamical Systems and Control*,
   Princeton University Press, 2008.
5) E. D. Sontag, *Mathematical Control Theory*, Springer, 1998.

Office Policy
I encourage students to seek help if they have questions. I am available for questions during my office hours and by appointment. Additionally, I have an *open-door policy*, that is, if my door is open, then you are welcome to stop by and ask questions. However, if my door is closed, then I am not available for questions.

Email Policy
I will respond to all emails within 24 hours. I welcome general questions through email; however, I prefer that you come to my office for technical questions.

Course Activities and Assignments
Classroom activities for this course consist primarily of lectures; however, students are encouraged to ask questions during lectures.

The required assignments for this course are:
   1) One midterm exam worth 100 points
   2) One final exam worth 100 points
   3) Nine graded homework assignments worth 10 points per assignment
Thus, there are a total of 290 points available for assignments and exams in this course. Students can expect to spend approximately 8 to 10 hours per week (outside of normal course meetings hours) working on homework and studying course material.

Midterm and Final Exams
The midterm exam is administered during a normal scheduled course meeting time and in the normal classroom. The date of the midterm exam will be announced at least 2 weeks before the exam is held. Tentatively, the midterm exam is scheduled for Tuesday March 19, 2013 from 12:30pm to 1:45pm.

The final exam is administered during the final exam period scheduled by the Office of the Registrar. The final exam is scheduled for Thursday May 2, 2013 from 1pm to 3pm.

No make-up exams will be given except in the case of an excused absence (please see the Excused Absences section of this syllabus.). In this case, the student must make a reasonable attempt to notify the instructor before the scheduled exam is missed.

Unless otherwise stated, exam problems are graded based on the correctness of your work. For example, a correct answer without any work may receive zero credit.

If you want to have an exam re-graded, then you must submit a re-grade request, which consists of the graded exam and a typed letter explaining why you request a re-grade. A re-grade request must be submitted within 2 weeks of the date that graded exams were distributed to the class. If you request a re-grade, then the entire exam is re-graded.

Homework Assignments

Homework is assigned approximately once every 10 calendar days, and each homework assignment is due approximately 10 calendar days after it is assigned. Each homework assignment has the exact due date and time printed on it.

Each homework assignment consists of approximately 5 to 10 long-answer problems related to the material covered during lecture. The solution of these problems requires an understanding of the material covered in lecture. Some problems require Matlab.

Your solutions to each homework assignment must be submitted in hardcopy. Electronic submission of homework solutions will not be accepted unless approved by the instructor in advance of the due date and time.

Homework submissions must be legible and adhere to the following rules:
- Homework must be neat and professional in appearance
- Unless otherwise stated in the problem, hand-written solutions are acceptable
- Unless otherwise stated in the problem, all plots must be computer generated and the axes should be labeled with an appropriate name and with the correct units
- Each page must contain your name, the course name, and the homework assignment number
- Each problem should begin on a new page
- All pages of the homework must be stapled and arranged with problems in the correct numerical order
- All work must be shown; homework is graded on the correctness of your work rather than the correctness of your answer
- Answers must be boxed
- No paper with frayed edges (e.g., torn from a notebook) should be used
- Diagrams must be drawn using a straightedge

Failure to adhere to any of the above rules may result in a reduction of score by up to 30% on the assignment.

Homework Grading

Each homework problem will be graded on a scale of 0 to 5. Five will be awarded for problems with a correct solution; 4 will be awarded for problems with an incorrect solution, where the problem is conceptually understood and the mistakes are minor; 1 to 3 will be awarded for problems with an incorrect solution; and 0 will be awarded for problems that are not attempted in good faith.

Late homework is not accepted and receives zero credit except in the case of an excused absence. Please see the Excused Absences section of this syllabus.

Course Grading

Course grades are determined based on the percent of the total available points (i.e., 290 points) that are earned by the student. Earning 80% to 100% of the total available points is an A; 70% to 80% is a B; 60% to 70% is a C; and below 60% is an E.

Tentative Course Material and Schedule

The following table provides an outline of the course material and schedule. This outline is subject to change at the instructor's discretion.

Course Material	Week(s) Covered	Homework Assignment	Textbook Chapters
Models and behavior of nonlinear systems	1		1, 2
Mathematical preliminaries	1, 2	1	
Existence and uniqueness of solutions	2	1	3
Continuous dependence on initial conditions and parameters	3	2	3
Lyapunov stability theory	4, 5	2, 3	4
Instability	6	3	4
Invariance principle	6	3	4
Linearization and stability analysis	7	4	4
Stability for time-varying systems	8	5	4
Midterm Exam	**To be announced (tentatively 3/19/2013)**		
Introduction to feedback control	9	6	12
Control Lyapunov functions and Sontag's controller	10	6	
Backstepping control	11, 12	7	14
Sliding mode control	12	7	14
Feedback linearization control	13, 14, 15	8, 9	13
Final Exam	**1pm to 3pm on Thursday May 2, 2013**		

Attendance Policy
Students are responsible for all material covered during lectures. Attendance is strongly recommended; however, attendance will not be taken during lecture.

Classroom Conduct
Students are expected to conduct themselves in a professional and courteous manner. While this course consists primarily of lectures, students are encouraged to ask questions during lectures. There is no talking during class unless contributing to class discussion. There is no eating during class. Please ensure that cell phones do not ring during class.

Excused Absences
Students need to notify the professor of absences prior to class when possible. *Senate Rules 5.2.4.2* defines the following as acceptable reasons for excused absences: (a) serious illness, (b) illness or death of family member, (c) University-related trips, (d) major religious holidays, and (e) other circumstances found to fit "reasonable cause for nonattendance" by the professor.

Students anticipating an absence for a major religious holiday are responsible for notifying the instructor in writing of anticipated absences due to their observance of such holidays no later than the last day in the semester to add a class. Two weeks prior to the absence is reasonable, but should not be given any later. Information regarding major religious holidays may be obtained through the Ombud (859-257-3737, http://www.uky.edu/Ombud/ForStudents_ExcusedAbsences.php.

Students are expected to withdraw from the class if more than 20% of the classes scheduled for the semester are missed (excused) per University policy.

Per *Senate Rule 5.2.4.2*, students missing any graded work due to an excused absence are responsible: for informing the Instructor of Record about their excused absence within one week following the period of the excused absence (except where prior notification is required); and for making up the missed work. The professor must give the student an opportunity to make up the work and/or the exams missed due to an excused absence, and shall do so, if feasible, during the semester in which the absence occurred.

Verification of Excused Absences
Students may be asked to verify their absences in order for them to be considered excused. *Senate Rule 5.2.4.2* states that faculty have the right to request "appropriate verification" when students claim an excused absence because of illness, or death in the family. Appropriate notification of absences due to University-related trips is required prior to the absence when feasible and in no case more than one week after the absence.

Academic Integrity
Per University policy, students shall not plagiarize, cheat, or falsify or misuse academic records. Students are expected to adhere to University policy on cheating and plagiarism in all courses. The minimum penalty for a first offense is a zero on the assignment on which the offense occurred. If the offense is considered severe or the student has other

academic offenses on their record, more serious penalties, up to suspension from the University may be imposed.

Plagiarism and cheating are serious breaches of academic conduct. Each student is advised to become familiar with the various forms of academic dishonesty as explained in the Code of Student Rights and Responsibilities. Complete information can be found at the following website: http://www.uky.edu/Ombud. A plea of ignorance is not acceptable as a defense against the charge of academic dishonesty. It is important that you review this information as all ideas borrowed from others need to be properly credited.

Senate Rules 6.3.1 (see http://www.uky.edu/Faculty/Senate/ for the current set of *Senate Rules*) states that all academic work, written or otherwise, submitted by students to their instructors or other academic supervisors, is expected to be the result of their own thought, research, or self-expression. In cases where students feel unsure about a question of plagiarism involving their work, they are obliged to consult their instructors on the matter before submission.

When students submit work purporting to be their own, but which in any way borrows ideas, organization, wording, or content from another source without appropriate acknowledgment of the fact, the students are guilty of plagiarism.

Plagiarism includes reproducing someone else's work (including, but not limited to a published article, a book, a website, computer code, or a paper from a friend) without clear attribution. Plagiarism also includes the practice of employing or allowing another person to alter or revise the work, which a student submits as his/her own, whoever that other person may be.

With regard to homework assignments, homework submitted must be a student's individual work. Students may discuss homework problems with each other at a conceptual level, but students may not discuss the detailed solution of homework problems. Students are allowed to use any available printed resources for homework assignments as well as exam preparation, <u>except</u> solutions to homework assignments or exams from previous semesters of this course. Any resources used for homework assignments must be properly acknowledged.

When a student's assignment involves research in outside sources or information, the student must carefully acknowledge exactly what, where and how he/she has employed them. If the words of someone else are used, the student must put quotation marks around the passage in question and add an appropriate indication of its origin. Making simple changes while leaving the organization, content, and phraseology intact is plagiaristic. However, nothing in these Rules shall apply to those ideas, which are so generally and freely circulated as to be a part of the public domain.

Please note that any assignment you turn in may be submitted to an electronic database to check for plagiarism.

Accommodations Due to Disability

If you have a documented disability that requires academic accommodations, please see me as soon as possible during scheduled office hours. In order to receive accommodations in this course, you must provide me with a Letter of Accommodation from the Disability Resource Center (DRC). The DRC coordinates campus disability services available to students with disabilities. It is located on the corner of Rose Street and Huguelet Drive in the Multidisciplinary Science Building, Suite 407. You can reach them via phone at (859) 257-2754 and via email at drc@uky.edu. Their web address is http://www.uky.edu/StudentAffairs/DisabilityResourceCenter/.