PROPOSAL OF A NEW PG ELECTIVE COURSE

Title of the Course: Computational Foundations of Cyber Physical Systems

1. Credit requirement: (L-T-P: 3-1-0, Credit: 4)
2. Please select the committee for Approval: PGPEC
3. Name of the Dept: CSE
4. Please Specify the Level of the Subject: PG level
5. Semester: Autumn
6. Whether the subject will be offered as compulsory or elective: Elective
7. Prerequisite(s) for the subject, if any (Please give the subject numbers and names): None
8. **Course Objective**

   Cyber-physical systems, which consist of physical systems tightly integrated and/or controlled by software, are ubiquitous in many safety critical domains, including automotive, avionics, railways, healthcare, atomic energy, power, and industrial automation. The principles of design and implementation of cyber-physical systems are remarkably different from that of other embedded systems because of the tight integration of real valued and dense time real time systems with software based discrete automated control. The objective of this course is to develop an exposition of the challenges in implementing a cyber-physical system from a computational perspective, but based equally on the principles of automated control. The course aims to expose the student to real world problems in this domain and provide a walk through the design and validation problems for such systems.

9. **Study Materials**
   (a) "Principles of Cyber-Physical Systems" - Rajeev Alur
   (b) "Handbook of Networked and Embedded Control Systems" - Dimitrios Hristu-Varsakelis and William S. Levine (editors)
10. **References**
    (a) "Foundations of Cyber-Physical Systems" - Andre Platzer
11. **Syllabus (with Lecture wise break-ups)**
    (a) **What are Cyber-Physical Systems? [2 hours]**
        i. Cyber-Physical Systems (CPS) in the real world
        ii. What are the special design considerations for CPS?
        iii. Basic principles of design and validation of CPS
    (b) **Principles of Automated Control Design (basic control theory) [10 hours]**
        i. ODEs, Lipschitz continuity: existence of solutions, equilibria, Stability criteria
        ii. Eigenvalues, pole placement, introduction to PID control
        iii. Stability Analysis: Lyapunov Functions (CLFs, MLFs), stability under slow switching
        iv. Tutorial: Control Design using Simulink [2 hours]
    (c) **Engineering Challenges in Implementing a CPS [15 hours]**
        i. From continuous control laws to software based control systems [1 hour]
        ii. Architectural Platforms for implementing CPS [6 hours]
            A. ECU Architectures and Real Time Operating Systems
            B. Network (e.g. WirelessHart) and Bus Protocols (e.g. Flexray)
            C. Sense and Actuation (fault tolerant algorithms for sense and actuation)
        iii. Principles of CPS Implementation [6 hours]
            A. From features to software components
            B. Mapping software components to ECUs: Real Time Scheduling strategies

C. Performance Analysis - effect of scheduling, bus latency, sense and actuation faults on control performance
   D. Methods for Robust CPS implementation
iv. Tutorial: Control, Bus and Network Scheduling using Truetime [2 hours]

(d) **Safety and Security Assurance of Cyber-Physical Systems [18 hours]**

   i. Advanced Automata based modeling and analysis: [4]
      A. Basic introduction and examples
      B. Timed and Hybrid Automata
      C. Definition of trajectories, zenoness
      D. Formal Analysis: Flowpipe construction, reachability analysis
   ii. Analysis of CPS Software: [4]
      A. Weakest Pre-conditions,
      B. Bounded Model checking
   iii. Tutorials [4]
      A. Control Verification using Matlab Toolbox S-Taliro
      B. Hybris Automata Modeling : Flowpipe construction using Flowstar, SpaceX and Phaver tools
      C. CPS SW Verification: Frama-C, CBMC
   iv. Secure Deployment of CPS [6]
      A. Attack models
      B. Secure Task mapping and Partitioning
      C. State estimation for attack detection

(e) **CPS Case studies and Tutorials [4 hours]**

   i. Automotive and Avionics : SW controllers for ABS, ACC, Lane Departure Warning, Suspension Control etc, Flight (pitch, yaw, roll) Control Systems
   ii. Heathcare : Artificial Pancreas
   iii. Mass Transportation : European Train Control Systems (ETCS)

12. **Names of the faculty members of the Department/Centers/School who have the necessary expertise and will be the willing to teach the subject (Minimum two faculty members should be willing to teach the subject)**

   (a) Soumyajit Dey (expressed interest)
   (b) Pallab Dasgupta (expressed interest)
   (c) Anupam Basu (expressed interest)

13. **Do the contents of the subject have an overlap with any other subject offered in the Institute?** Yes

   (a) **Approximate percentage of overlap:**
      i. 10% overlap with Embedded Systems and Computer Architecture courses
      ii. 10% overlap with Control Theory courses
      iii. 10% overlap with Formal Systems course
   (b) **Reasons for offering the new subject in spite of the overlap :** The principles of design and implementation of cyber-physical systems relies on underlying foundations of control theory, embedded platform architectures, and software control. These are individually covered in different courses with little or no scope of explaining the relationship between these artifacts towards the implementation of a CPS. For example, the effect of message delays and software errors on the control performance of a CPS is not addressed in any of these courses. Indeed the understanding of the inter-dependence between control, platform issues and software is the key towards safe and secure designs of CPS, and must therefore be treated as a separate course as proposed here.