Project: Control System Design and Simulation

The project should be submitted until Sunday, 10.07.2021, 23:59 on odtuclass. The preferred format is a pdf including all derivations, explanations and plots with the filename `lastname_firstname_studentID_Project.pdf` Do not forget to indicate the approximate amount of time spent for working on the project.

In addition to the project report, we will organize a synchronous session, where each student will give a presentation (5 minutes) about the project. This synchronous session will take place in the week after 10.07.2021.

Part 1: Control System Design

You are supposed to perform a controller design for ONE of the systems below:

- Inverted pendulum on a card
- Ball and beam system
- Lane keeping control system
- You can choose your own system if you want (I will check if it is suitable)

Summarize all the steps/computations/decisions/simulations you perform in a report.

a. Determine a suitable system model for the system you selected. Confirm the model with me before you go on.

b. Explain which of the controller design methods we studied in the lecture are applicable/not applicable to the system you selected.

c. Choose an appropriate design method and perform a controller design for the selected system:

- Discuss how you decide about the relevant parameters such as steady-state error, closed-loop dynamics, etc.
- Discuss possible limitations due to actuator saturation, plant properties, etc.
- Include possible disturbances in your model and study their effect on the feedback loop.

d. Validate your controller design by simulations in Simulink.

Part 2

The trajectory of the Apollo satellite given by the coordinates x, y is described be the following state space model. Hereby, the states are chosen as $x_1 = x$ and $x_3 = y$. It is assumed that the satellite is orbiting around the earth in a plane.

$$\begin{aligned}
\dot{x}_1 &= x_2 \\
\dot{x}_2 &= 2\,x_4 + x_1 - \mu^\star \frac{(x_1+\mu)}{(\sqrt{(x_1+\mu)^2 + x_3^2})^3} - \mu \frac{x_1 - \mu^\star}{(\sqrt{(x_1-\mu^\star)^2 + x_3^2})^3} \\
\dot{x}_3 &= x_4 \\
\dot{x}_4 &= -2\,x_2 + x_3 - \mu^\star \frac{x_3}{(\sqrt{(x_1+\mu)^2 + x_3^2})^3} - \mu \frac{x_3}{(\sqrt{(x_1-\mu^\star)^2 + x_3^2})^3}
\end{aligned}$$

The parameters are $\mu = 1/82.45$, $\mu^\star = 1 - \mu$ and the initial conditions are given by $x_1(0) = 1.2$, $x_2(0) = 0$, $x_3(0) = 0$ and $x_4(0) = -1.0494$.

a. Realize the model in Simulink and determine the numerical solution for different parameters of the solver (you can modify the "Configuration Parameters" in Simulink). Use the following settings as a reference and determine the xy plot for comparison:

- Maximum step size: auto
- Relative tolerance: 1e-5
- Solver: ode45 (variable step size)

Now try different variations of the Maximum step size, relative tolerance and solver (also try fixed step size). Report your findings and explain how they match our analysis in the lecture.

b. Implement your own solver based on the explicit Runge-Kutta method ($p = 4$) in Lecture 11.

(a) Implement and test the Runge-Kutta method for a fixed step size and determine a suitable value for the step size.

(b) Learn about the realization of a variable step size. The relevant chapter of the textbook is provided on odtuclass. Summarize the main implementation steps you need for a solver with variable step size

(c) Extend the Runge-Kutta method in part (a) by step-size adaptation. Use a suitable explicit method of order 3 for the error estimation (you can look for such method on the web).

(d) Test your solver using the Apollo satellite. Compare the computation time of the numerical solution for the method in (a) and the method in (c). You can use "tic" and "toc" in Matlab.

(e) Plot the step-sizes you observe when applying the method in (c). How can you interpret the change in the step sizes when looking at the trajectory of the satellite?