

# BOĞAZİÇİ UNIVERSITY

# DEPARTMENT OF MECHANICAL ENGINEERING

# ME 537 – State Space Control Theory – Fall 2020

Midterm Exam Report

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**1)**

Given system:

|  |  |  |
| --- | --- | --- |
|  |  | (1) |

Is equal to:

|  |  |  |
| --- | --- | --- |
|  |  | (6) |

Introducing equation (3):

|  |  |  |
| --- | --- | --- |
|  |  | (3) |

|  |  |  |
| --- | --- | --- |
|  |  | (7) |

Introducing equation (4):

|  |  |  |
| --- | --- | --- |
|  |  | (4) |

Assuming is constant, it is possible to get:

|  |  |  |
| --- | --- | --- |
|  |  | (8) |

Substituting (7) and (8) into (6) :

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  | (9) |

Noting ;

|  |  |  |
| --- | --- | --- |
|  |  | (10) |

Combining (9) and (10), state space representation of the error dynamics is obtained as following:

|  |  |  |
| --- | --- | --- |
|  |  |  |

Comparing it with (6), the new set of equations include the third state, , as well.

**2)**

Lookahead is introduced by equation (5):

|  |  |  |
| --- | --- | --- |
|  |  | (5) |

|  |  |  |
| --- | --- | --- |
|  |  | (11) |

Using equations (9), (10) and (11);

|  |  |  |
| --- | --- | --- |
|  |  | (12) |

|  |  |  |
| --- | --- | --- |
|  |  | (13) |

Substitute (13) back to (12), and arrange the terms:

|  |  |  |
| --- | --- | --- |
|  |  | (14) |

By equations (13) and (14), error dynamics with lookahead are obtained:

**Design methodology for questions 3 and 4:**

While designing the system and are considered as outputs.

Following parameters are considered while choosing the pole locations:

* Open loop plant dynamics should not be modified much
* Placed poles should be realizable, their bandwidth should be in actuator limits

System is designed iteratively, after every pole placement following checks are performed to evaluate performance:

* Initial response of the system for some non-zero initial values, for this case no input is specified so road curvature is not considered.
* Road curvature is introduced by extending the definition of B, so that both and are supplied as inputs, then the system is excited with a step response for the second input.
* Finally, change of closed loop pole locations are inspected for various combinations of and

For the computations Python with libraries Numpy and python-control is used.

**Note**: Useful data for bandwidth of the actuator and manual steering performance is not found. So, a common sense inspect is used for evaluating the steering performance.

**3)** See the attached code, relevant calculations are under “Design by pole placement”.

**4)** See the attached code, relevant calculations are under “Design by LQR”.

**Results:**

For the problem there is a trade-off between steady-state error and stability margin of the closed loop system. Two systems one with pole placement other with LQR are obtained with acceptable responses by the iterative process described above.

After several attempts, the systems are designed to have an acceptable steady-state error; however, this means there is very little room for stability-margin. A different, more involved control approach can help in this case. Nitin R. Kapania, J. Christian Gerdes (2015), use a feedback-feedforward system to handle this issue. Another approach is to introduce an integral controller to the outer loop so that the steady-state error can be kept under control.