2020 Control Systems Final Project

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***Abstract*— A typical P controller is applied to stabilize a lunar lander after impact.**

I. Introduction

The block diagram of the system is shown in Figure 1. The plant (P) is the lander, the inputs (u) are the voltages of the left and right AMEID, the output (y) is the angle between the lander and the ground, and the reference (r) is 0 degree. A typical PID controller is applied. The tuning is elaborated in the next section.

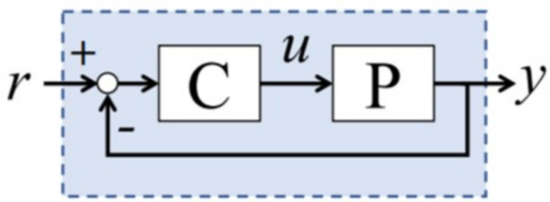

Fig. 1: Block diagram of the system

II. Control Design

1) Premises, assumptions and objectives
   Only free-falling, non-rotating cases are considered to avoid astronomical calculation. The following assumptions are made:
   a) The initial angle have a uniform distribution over $[0, \frac{\pi}{2}]$.
   b) There is no control saturation.

   Iterating through the angles 0, 0.01, ..., 1.57, an uncontrolled lander is found to make 88 stable landings. Our goal is to make the number of successful landings larger than this.
2) P controller
   Instinctively, a larger Kp is more capable of stabilizing the lander. However, when the lander leg is perpendicular to the ground, a large Kp (like 2000) performs poorly, while a small Kp (like 100) does well. Thus, a more systematic way of selecting Kp is needed. To make a rough selection, for each Kp candidates, the angles 0, 0.1, 0.2, ..., 1.5 are iterated through, and the number of stable outcomes are recorded. The candidates are 100, 200, ..., 10000. Plotting the number of stable outcomes versus the candidate value yields Figure 2. The candidates that produce the most stable outcomes are the ones around 1000. To make a more delicate selection, the angles 0, 0.01, 0.02, ..., 1.57 are iterated through, and the Kp candidates are 100, 200, ..., 2000. This results in Figure 3. The one creating the most stable outcomes is Kp = 1000. Thus, Kp is temporarily chosen as 1000.

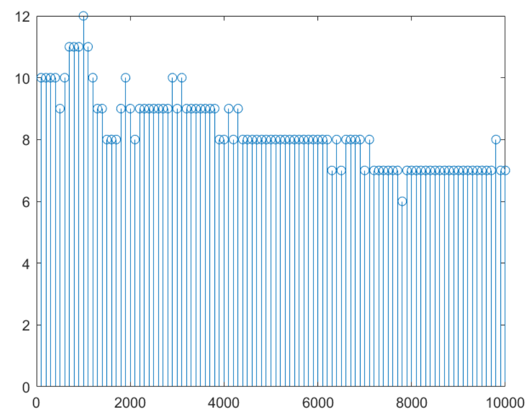

Fig. 2: Number of stable outcomes vs. Kp values. Angles = 0, 0.1, ..., 1.5, Kp = 100, 200, ..., 10000

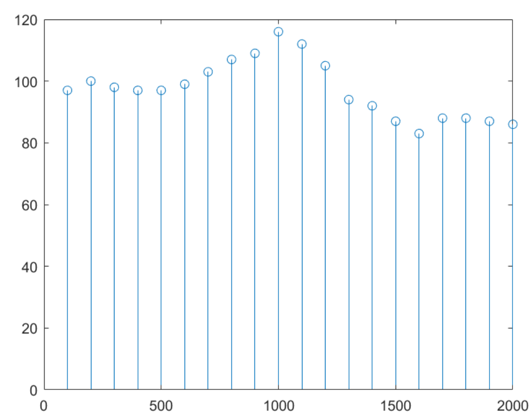

Fig. 3: Number of stable outcomes vs. Kp values. Angles = 0, 0.01, ..., 1.57, Kp = 100, 200, ..., 2000

3) D controller
   Theoretically, a D controller can suppress the oscillation and lead to a smaller settling time. A rough selection of Kd is done by a process similar to the selection of Kp, which iterates through the angles 0, 0.1, 0.2, ..., 1.5 while the Kd candidates are 0, 0.01, 0.02, ..., 1. The result is shown in Figure 4. The Kd values that make the most stable outcomes are the ones

smaller than 0.01. A more delicate selection of Kd is carried out by iterating through the angles 0, 0.01, 0.02, ..., 1.57 and the candidates being 0, 0.0001, 0.0002, ..., 0.01. Figure 5 shows the result. It appears that for Kd below 0.01, the difference in Kd does not greatly shift the outcome. Besides, the effect of adding a D controller is not significant. At the end of this section, Kp and Kd are tuned simultaneously to decide whether to add a D controller and to determine the ultimate values of Kp and Kd.

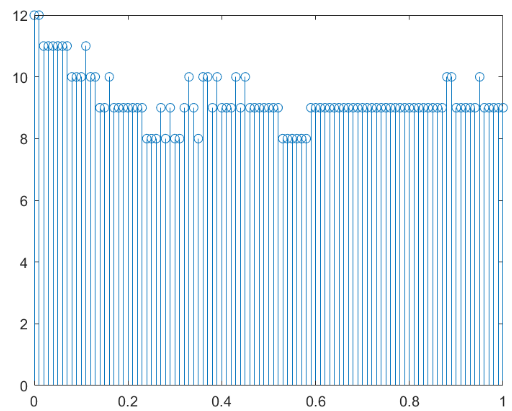

Fig. 4: Number of stable outcomes vs. Kd values. Angles = 0, 0.1, ..., 1.5, Kd = 0, 0.01, ..., 1

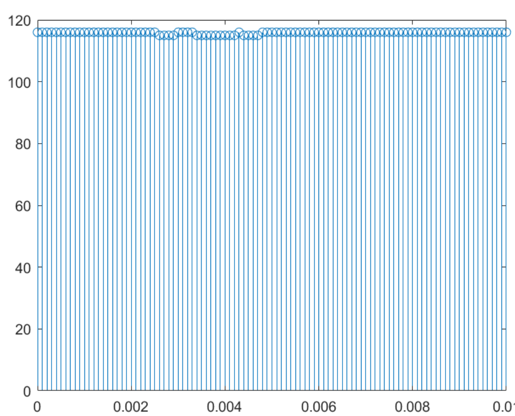

Fig. 5: Number of stable outcomes vs. Kd values. Angles = 0, 0.01, ..., 1.57, Kd = 0, 0.0001, ..., 0.01

4) I controller
The steady state angle need not be zero (although when the ground is flat and the landing status is stable, it will converge to zero). Therefore an I controller is not needed.

5) Tuning of the PD controller
Several values of Kp and Kd are tested for the number of stable outcomes using the method similar to the previous one. The result is displayed in Table I. When Kp = 1000, regardless of Kd value, the most stable outcomes are observed. This implies that when we let Kp be 1000, there is no need to add a D controller.

Kp \ Kd	0	0.0025	0.0050	0.0075	0.0100
900	109	109	110	110	110
950	114	114	115	115	115
975	115	115	115	116	116
1000	116	116	116	116	116
1025	115	115	113	114	114
1050	114	114	114	114	113
1100	112	112	111	111	112

TABLE I: Number of stable outcomes

III. Simulation Results

1) Under a safe initial condition
Under a safe initial condition, e.g. $[0, 11, 0.8, 0.8, 0.2]$, the lander lands successfully with or without the controller. The simulation results are shown in Figure 6, 7 and 8.

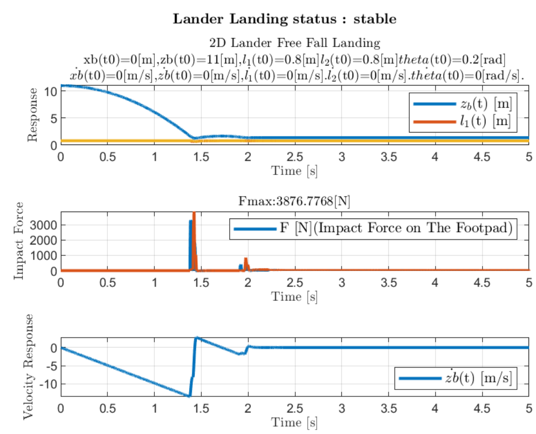

Fig. 6: Uncontrolled: under a safe initial condition

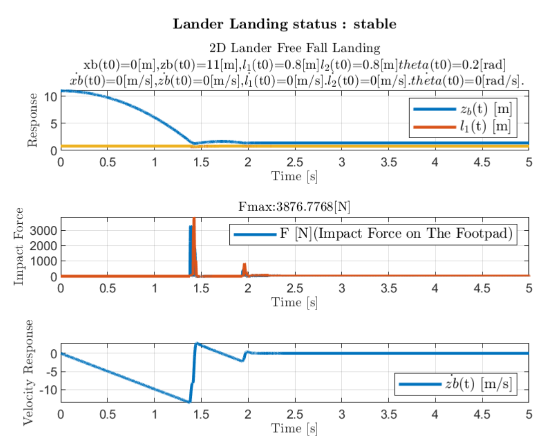

Fig. 7: Controlled: under a safe initial condition

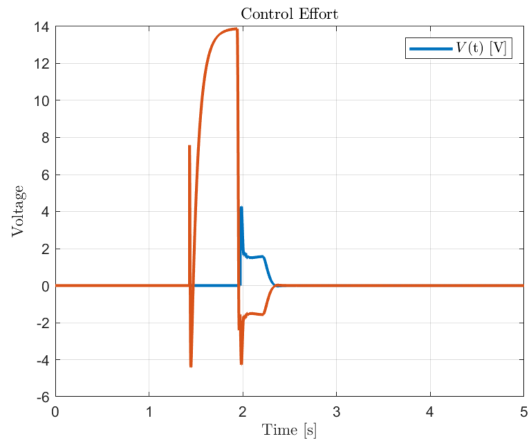

Fig. 8: Control effort under a safe initial condition

2) At the critical angle
As mentioned before, when the lander leg is perpendicular to the ground, the P controller may produce an unstable result. However, the effect of the controller under an unsafe initial condition compensates this, so the overall performance of a controlled lander is still better than an uncontrolled one. The simulation results are shown in Figure 9, 10 and 11.

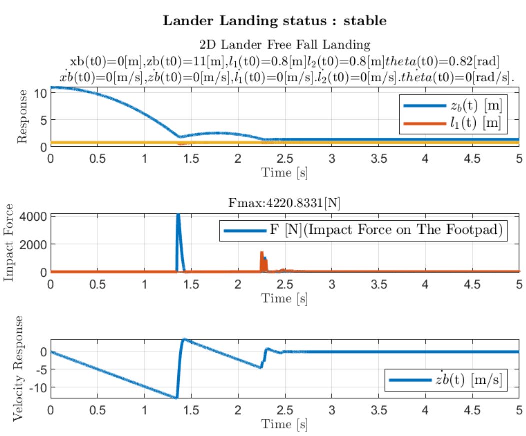

Fig. 9: Uncontrolled: at the critical angle

3) Under an unsafe initial condition
Under an unsafe initial condition, e.g. $[0, 11, 0.8, 0.8, 1.1]$, the uncontrolled lander fails to stabilize itself while the controlled one works well. The simulation results are shown in Figure 12, 13 and 14.

IV. Conclusion

A P controller is applied. The controller is not perfect, but it does improve the stability of the lander.

V. Acknowledgements

I would like to express my thanks to Professor Cheng-Wei Chen, who explains the ideas of control systems clearly and humorously, and to TA Yi-Lun Hsu, who kindly answers all of my questions.

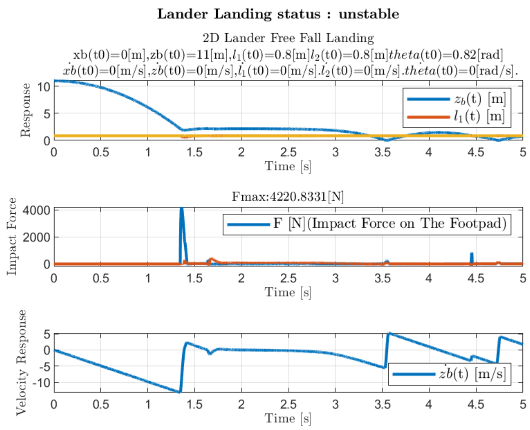

Fig. 10: Controlled: at the critical angle

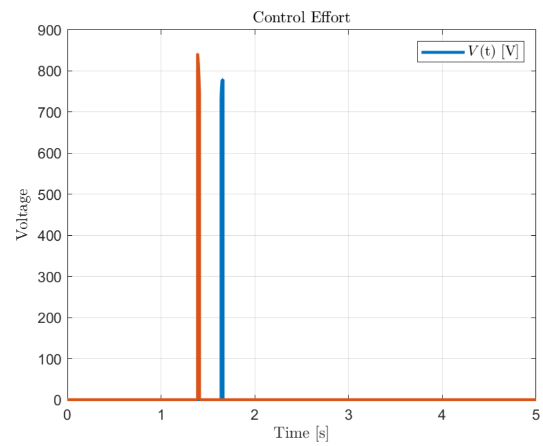

Fig. 11: Control effort at the critical angle

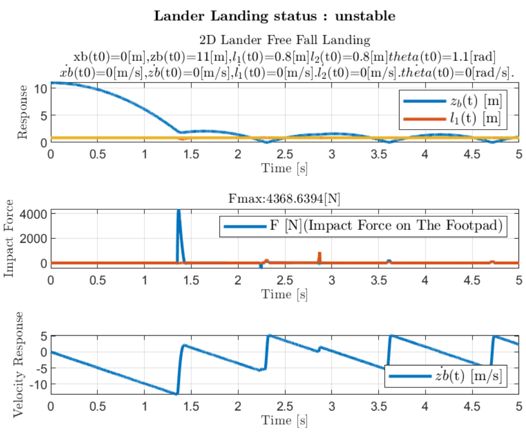

Fig. 12: Uncontrolled: under an unsafe initial condition

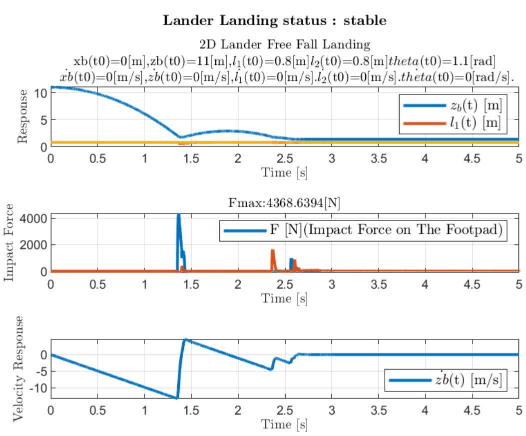

Fig. 13: Controlled: under an unsafe initial condition

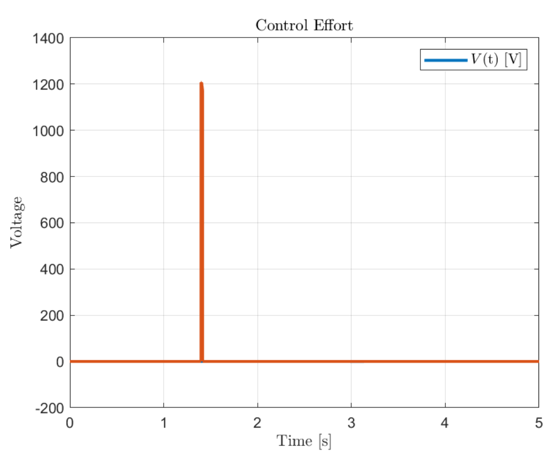

Fig. 14: Control effort under an unsafe initial condition