CHAPTER VII

CONCLUSIONS

7.1 Summary

This thesis has proposed the new idea of bicycle robot control using gyroscopic stabilization effect. This idea encounters the nonlinear unstable bicycle system by modeling it into a set of linear model or piecewise affine model. Then, the piecewise quadratic stability theorem can be applied and used for searching for the globally quadratic Lyapunov function to guarantee the system stability. Furthermore, this condition can be extended with the ellipsoid cell boundings to derive the feedback stabilization gain. The effectiveness of the proposed method has been illustrated through simulation examples. To summarize the thesis, we highlight main topics in the following.

Chapter 1 briefly introduces the motivation behind the research. Next, the literature review is given to cover an overview of bicycle model and its control method as well as some application of PWA systems. Afterward, we present the thesis objective, scope and research contributions.

In Chapter 2, a basic knowledge with some important concepts of a bicycle; its nature and the effect of gyroscopic which can help stabilize the bicycle. An important tool to be used to derive the dynamic equation of the bicycle are included in this chapter. The overview of PWA system and its representation of matrix parameterization has been introduced. And it follows with the quadratic stability condition that uses for finding the quadratic Lyapunov function and the feedback control gain. In chapter 3, the parameter measurement and calculation on the experimental bicycle are performed. The major apparatus are the body of the bicycle itself and the gyroscopic flywheel. Some parameters are obtained by the real measurement and some are obtained through the CAD modeling program based on the real bike parameters.

Chapter 4 and 5 presents the detail steps in deriving the nonlinear dynamic model of an autonomous bicycle using gyroscopic effect and an approximation of this model to be the PWA model. The nonlinear dynamic model is derived by Lagrangian mechanics theory. The PWA model is approximated by the 3 proposed methods, i.e. trigonometric terms approximation, Least-square error approximation without boundary constraints, and Least-square error approximation with boundary constraints.

Finally, all information from the former chapters are gathered to formulate the quadratic stabilization problem. The unconstrained was selected as a PWA model to solve for the feedback stabilization gain. The graphical results are also shown in various initial conditions accompanied with the comparison of the response of the nonlinear model and the approximated PWA model.

The conclusion and future work guideline are briefly described at the end.

7.2 Future Work Guideline

1. *Control of autonomous bicycle with bicycle velocity feedback*
   The result of bicycle control in this thesis starts from the simpler case which does not tackle the problem of bicycle speed varying. As we saw in Chapter 2 that the bicycle gives a significant effect on the bicycle stability, so it is expected to be easier to utilize the speed to help stabilize the bicycle. However, the problem will be more complex in the bicycle modeling and the mutual effect to the bicycle roll angle by the gyroscopic effect and bicycle velocity.

2. *PWA Identification of an autonomous bicycle using gyroscopic effect*
   There are another methods for deriving the PWA model of the bicycle. The PWA model proposed in this thesis is derived by a simple technique and thus easy to debug. We recommend to proceed to the more advance technique that has been studied widely in [54], [55], [42], [56], [57], [58], [59], [60] and in Ph.D. thesis [61].

3. *An implementation on the real bicycle*
   To the best proof of this control strategy, an implementation on the real hardware is encouraged. From the author experience, since there is no ready bicycle robot for testing the control laws in the market and an individual work is quite a large burden to be busy working on the electronics and mechanics stuff, this future work is recommended to be done in a team.