Design and Evaluation of Two-wheeled Balancing Robot Chassis

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***Abstract*—Two-wheeled balancing robot is one of interesting non-linear plant. The goal is to control the robot so that it can move with only two wheels. This paper elaborates the design and evaluation of its chassis. The chassis is constructed with Lego Mindstorm NXT and controlled by the AVR ATMega16 microcontroller. The system uses MX2125 accelerometer sensor from Parallax to evaluate the robot chassis. Two chassis design, i.e. model A and B are developed. From the experiments, it is shown that robot chassis design must address the mechanically stable issue. Therefore chassis model A is discarded. PD controller is recommended for this chassis model B. The chassis also considers the flexibility to mount such a load. Mounting load under the axis helps to stabilize the chassis. This makes the controller design easier. The load position opens the further research topic. Using Lego Mindstorm is very helpful in design and evaluation of mechatronics set up.**

Keywords-two-wheeled balancing robot; chassis, MX2125, the AVR microcontroller

I. INTRODUCTION

Two-wheeled balancing robot is interesting non-linear plant nowadays. It has been implemented as urban transportation through Segway [1]. The Segway is interesting application of this robot.

The main idea of this robot is to make the robot stands still with only two wheels. The controller must detect tilt position of the robot and give compensation signals to the plant.

This robot need robust controller design but some aspect such as robot chassis must be addressed carefully. Robot with center of gravity higher than the rotation axes makes the controller likely fail to control the robot. On the other hand, when the position of the center of gravity is to low, the controller almost has no role because the robot is already balance [2].

For this reason, it is interesting to evaluate the chassis for balancing robot to design good controller. This paper does not discuss design of the controller. It focuses on the chassis only.

The goal of this research is to evaluate the chassis design for balancing robot such that the controller design is not too complex. For the chassis is the main topic of this paper, the control algorithm uses PID controller, the most widely accepted control algorithm in industries. The discussion does not go further to find good parameter for PID controller. This constraint is important in order to make this paper focus on the chassis only.

Another important constraint is that the chassis is built with LEGO bricks. The DC motor is also from LEGO. Only the controller and the other circuitry are specially designed.

First, some similar project and chassis design are used as reference of this project. The next section is about chassis design phase. Following to this section is about MX2125 accelerometer and AVR microcontroller. The paper continues with experiments, discussion and conclusion.

II. REVIEW OF CHASSIS DESIGN

The two-wheeled robot can be considered as a cart with inverted pendulum [3]. The cart moves back and forth to make the stick stands. The controller must detect the position of the stick and send appropriate signal to maintain the stick position.

For this purpose, suitable chassis must be designed. The chassis should be light enough in order to give motor low load. This makes the motor more responsive. But, the chassis must be designed such that the center of gravity is not too high because it makes the system unstable.

Ref. [4] shows how the chassis of the balancing robot is design such that one can increase or decrease the load of the robot. This is very interesting approach for the design and evaluation of the chassis needs this feature. Here, the chassis is made of Perspex plate.

Constructing a two-wheeled robot with LEGO mindstorm is not new [5] [6] [7] [8]. Those show that LEGO bricks are very helpful to make the chassis. Beside, its modification can be made fast. All the above references show that the motor is also from LEGO. The center of gravity of these robots is above pivotal point.

Ref. [8] also shows experiment with increasing/decreasing load for the robot. The idea is to evaluate the controller performance under disturbance. This idea is similar to [4].

Another similar project, Quasimoro [9], places circuitry and all related electronics components below the wheel axes. It makes the system more stable and the controller works more easily. Figure 1 shows the design chassis of Quasimoro.

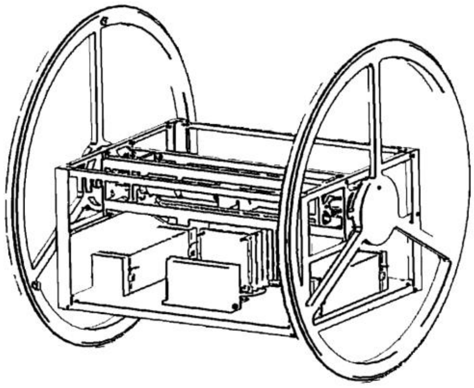

Figure 1. Quasimoro chassis [9]

Ref. [10] shows a balancing robot but the load is on top of the platform. The control system is very good since with the load position, the system is unstable. Figure 2 shows the robot from [10].

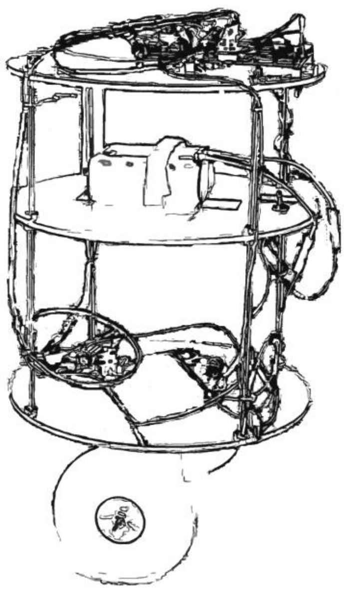

Figure 2. Balancing robot chassis from [10]

Another robot called BalanceBot from RidgeSoft [11] also place the batteries on top of the robot. Figure 3 shows the chassis.

The load position determines the center of gravity location. When the center of gravity is below the pivotal point, it helps the robot balance itself. The controller works not so hard for this condition.

The problem raised here is the motor response and load. The position of the center of gravity makes the motor drives more load. It makes the motor less responsive.

Placing the center of gravity above the pivotal point makes the robot more unstable but it makes the motor more responsive because of the load is small. Another interesting fact is that the chassis also serves as inverted pendulum [3].

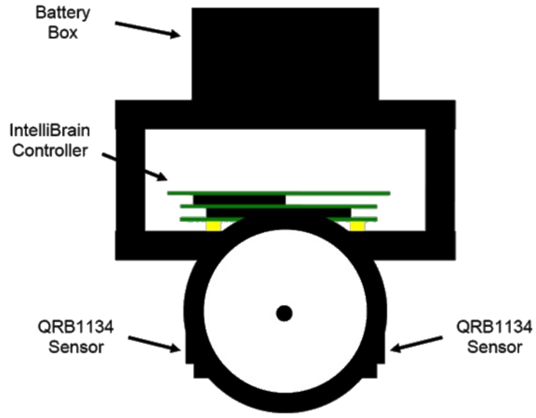

Figure 3. BalancingBot chassis from RidgeSoft [11]

III. CHASSIS DESIGN

There are two important things in the chassis design of the balancing robot, i.e. control and mechanical stability [12]. In chassis design, the mechanical stability aspect is considered.

The chassis consist of 3 parts, i.e. two wheels, platform and body. The body gives the biggest role in determining the center of gravity because the control circuit is mounted to the body.

The chassis must consider the place to mount the control circuit, batteries and sensor. The batteries serve as load of the robot. So it is important to think about batteries position.

Since there is such a trade off between center of gravity position and control algorithm complexity, this project focus on the center of gravity rather than the other. The control algorithm uses simple PID controller. The relationship between PID parameters and the center of gravity position will be evaluated.

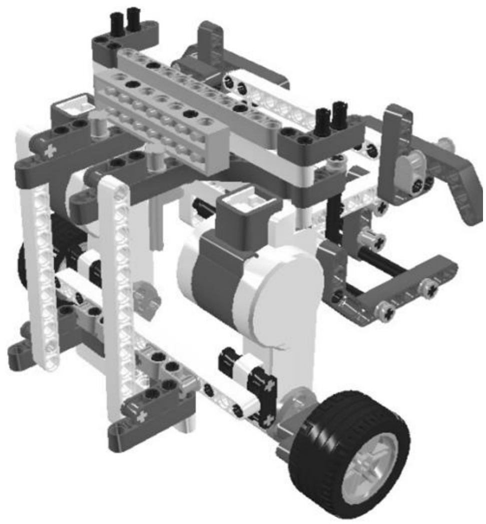

Figure 4. Chassis model A

Figure 4 shows the first model, i.e. model A. The first chassis design is not good. The batteries are mounted below and behind the chassis. This makes the robot in very unstable position. The center of gravity is far above the pivotal point, i.e. the wheel axis. Beside the center of gravity is also behind the z-axis of the robot. It makes the robot fall backward always. The control circuit does not help to solve this problem because it is too light.

Figure 5 shows the second chassis design, i.e. model B. Here, the batteries are mounted below the pivotal point. It makes the center of gravity is lower than the previous version, but it is still above the pivotal point. There are two reasons for this statement. First, the DC motor is actually above the pivotal point [13]. The motor rotation is transferred through gear system to the wheel axis. Second, the chassis has height where all circuits are mounted. Although the batteries are mounted below the axis, the center of gravity cannot go lower than the pivotal point.

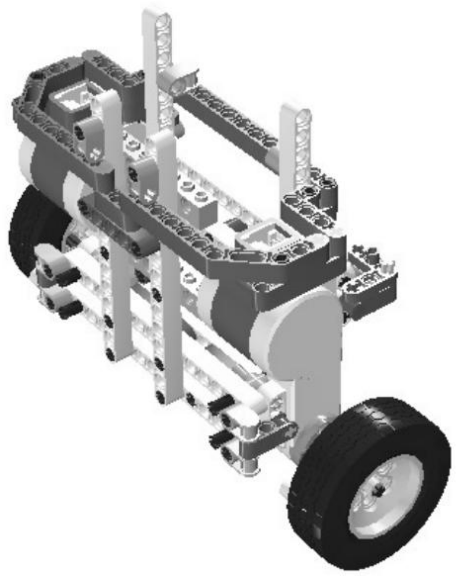

Figure 5.   Chassis model B

This chassis also addresses the possibility of changing the load position. This changing position is useful in evaluating the influence of load position to control the balancing robot.

The problem raised in this chassis is the height. Its height pushes the controller to have extra work. The speed of DC motor must be high in order to balance the robot.

IV. HARDWARE DESIGN

A. Sensor MMX2125

The system uses MX2125, the dual axis accelerometer, to detect inclination rate of the robot. The controller reads inclination rate from both axis, i.e. X and Y.

The two outputs from the MX2125 are in series with 220ohm before entering to the ATMega16. These resistors keep the current fed by the MX2125 not too high for the controller.

The MX2125 gives data in the form of pulse width. The period of the signal is constant, i.e. 10ms. In normal condition, the duty cycle is 50%. When there is acceleration rate, the duty cycle changes.

B. Controller Implementation

The control algorithm implemented for this experiment is PID controller. It is a simple and still acceptable controller in industries.

Once, the system uses either PI or PD controller. The PID is implemented when it is needed. The experimental set up is to change the PID controller parameters according to the load or center of gravity position.

The controller drives two DC motors from the LEGO NXT via H-bridge circuit. The driver uses optoisolator to protect the ATMega16 from high current.

V. EXPERIMENTS

Model A is not good chassis. First, the chassis is very unstable and it tends to fall backward. Second, it is very difficult to adjust the load position to make it balance. Therefore, the experiments use chassis model B.

Model B, which has the center of gravity lower than the model A, has more advantages. One can adjust the load position so that changing the center of gravity position can be made easily. The battery mounting is also under pivotal point so it helps the robot balance itself mechanically. It means this fulfills requirements in [12].

When the chassis is mechanically stable, now the controller must be designed to achieve control stability. It means when the center of gravity changes, the controller can balance the robot well.

The experiments use zero degree to indicate the balance position. It means the setting point for the robot is zero degree. So, the overshoot is the same as undershoot but the direction is opposite to each other. Positive degree means the robot tilt forward and the negative indicates the backward tilt.

First it uses P controller with Kp=8. The response of the robot from vertical axis, i.e. zero degree is shown in figure 6.

It is shown that the P controller can make the chassis balance around the setting point. Although there are overshoots, the controller can still balance the robot.

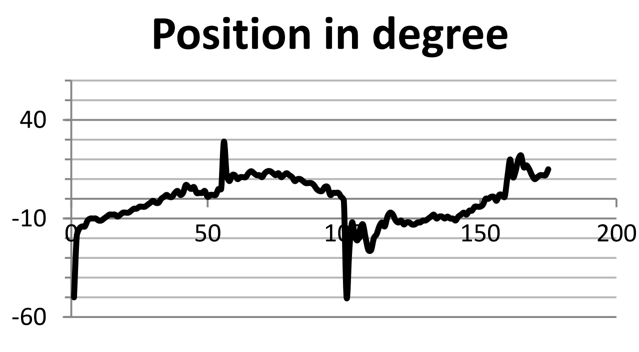

Figure 6.   P controller with Kp=8 for model B

If PD controller is used, the response is better since the Derivative controller can suppress the overshoot (see figure 7). This is verified by increasing Kd to 12 as shown in figure 8.

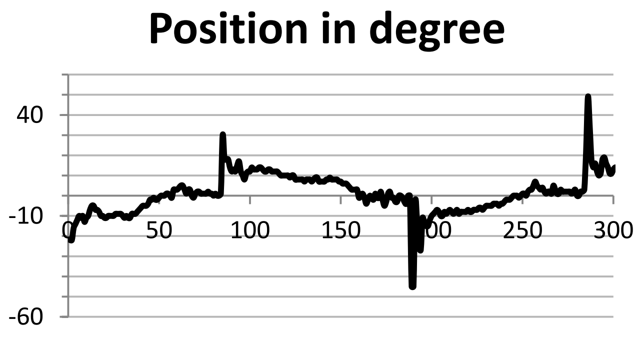

Figure 7. PD controller with Kp=8 Kd=8 for model B

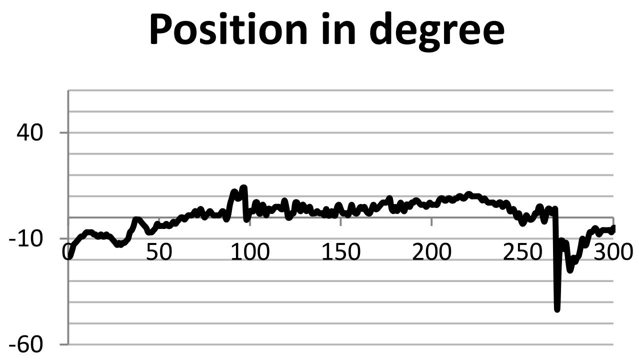

Figure 8. PD controller with Kp=8 Kd=12 for model B

When the Kd is increased, the overshoot is decreased. The stability, however, is almost the same.

Now 200 g load is mounted under the axis of the wheels. The black bar in figure 9 is the mounted load. This is the only load mounted to chassis for experiments.

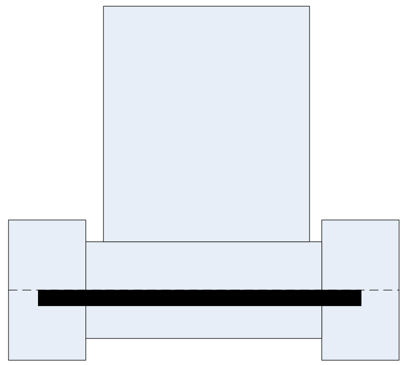

Figure 9. Position of the load

The load, however, lower the center of gravity position but the center of gravity position is still above the pivotal point. The objective of this set up is to see the influence of load to the PID controller parameter. This also leads to further research in chassis for balancing robot.

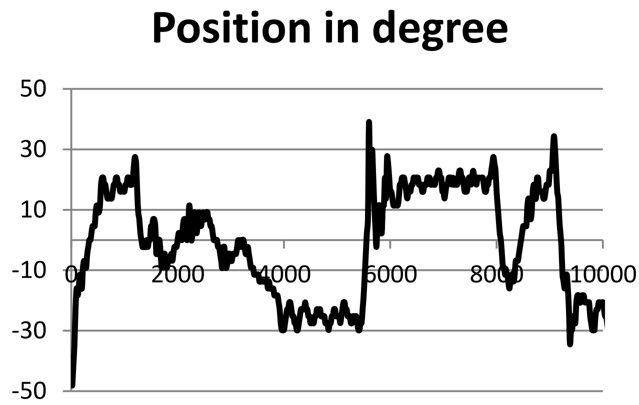

Figure 10. Response of the robot with Kp=6

Figure 11 also shows that the robot is oscillating around the equilibrium point, i.e. the setting point. The swing is less than ten degree. For small chassis this can be significant value but the greater the chassis, the smaller the oscillation.

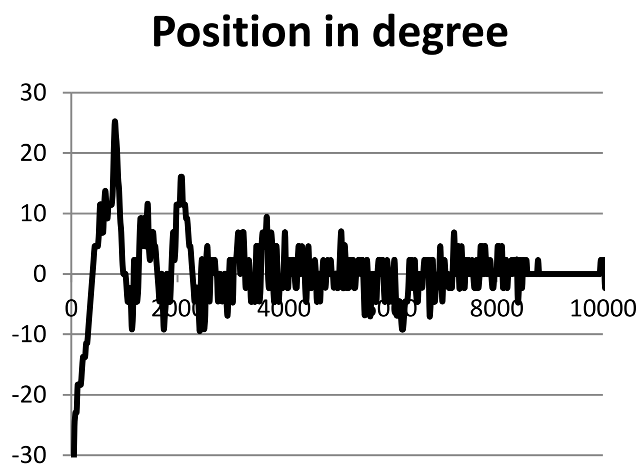

Figure 11. Response of the robot with Kp=8

The Kp cannot go further under 6 or above 8 because the robot becomes unstable. Although, no figures show for those Kp, the experiments have been conducted for these parameters.

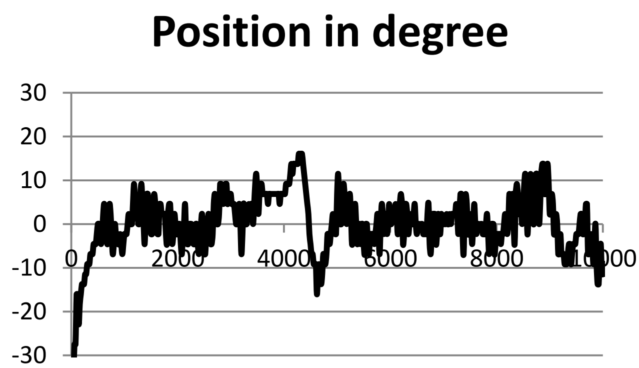

Figure 12. Response of the robot with Kp=8 and Kd=2

Figure 12 shows the experiment with Kp=8 and Kd=2. The derivative controller serves as good damper the overshoot in figure 11.

Experiments with PI controller show not satisfying results. The controller fails to balance the robot with minimal oscillation. Therefore, it is not recommended to use PI controller for this chassis. Figure 13 shows one of the experiments with PI controller.

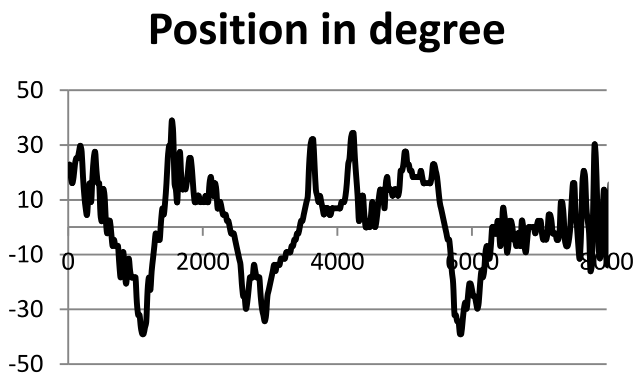

Figure 13. Response of the robot with Kp=8 and Ki=1

VI. DISCUSSION

Chassis design for balancing robot must address the mechanical stability. The center of gravity must lie at the Z-axis of the robot. The Z-axis is at the center of the body. When one fails addressing this issue, the chassis is useless as in model A.

Chassis model B considers the above issue in the design and implementation. The body is mechanically stable.

The center of gravity position for model B is still above pivotal point as inspired by [4]- [11]. This makes the DC motor more responsive. Although the experiment with changing load position is not conducted yet, the chassis model B support for this kind experiments.

The response of P controller is slightly good. The controller can balance the robot around the equilibrium point but the overshoot or oscillation is still big. To solve this problem, PD controller is used.

The PD controller successfully suppresses the overshoot. Figure 8 shows how the PD controller manipulates the chassis to balance at zero degree.

Mounting a small load at the bottom of the chassis is only preliminary experiments. When this experiments show good result, it can open for further research.

With P controller, Kp=8, the chassis with small load shows better result (compare figure 7 and 11). The load, however, helps the control to balance the robot. So it is interesting to do further research on the position of the load in order to get good performance.

Using PD controller for chassis with load shows good performance also. These experiments also verify for further research as mention above.

VII. CONCLUSIONS

Chassis design with LEGO bricks is very useful. When we cannot be sure about mechanics aspect of our design, LEGO makes it easier in building the mock up. Sure that mock up from LEGO cannot be used directly to real application, but it cut the design time.

It is important to address the flexibility in chassis design. The load position can be changed to see the overall performance of the system. This opens the further research, i.e. relationship between PID controller parameters and load position.

It is necessary to design a chassis that is mechanically stable. This helps in designing appropriate controller. If the chassis does not fulfill this requirement, the controller must compensate it and this is too costly.

This research recommends PD controller instead of P or PI controller for this chassis. PD controller can suppress the overshoot and oscillation. Figure 6 to 8 verify this statement.

This paper also includes the preliminary research about mounting load to the chassis to influence the stability. Indeed, the load can help the chassis to have greater stability.

When figure 6 and 11 are compared, it is shown that the P controller with the exactly the same parameter gives different performance. The chassis with the mounting load has small oscillation.

PD controller for chassis with mounting load can reduce the overshoot but the oscillation is little bit higher than P controller. This opens for the next research question concerning the mounting load.

This paper also does some experiments with PI controller. The results are not satisfying and only one of them is shown, i.e. figure 13.

It is interesting to evaluate the controller performance and parameters for different load position. This is the next research conducted for this project.

REFERENCES

[1] S. A. Shaheen and R. Finson, "Bridging the Last Mile: A Study of the Behavioral, Institutional, and Economic Potential of the Segway Human Transporter," *Transportation Research Board*, January 2003.

[2] D. C. Giancoli, *Physics: Principles with Applications*, 6th ed. NJ: Upper Sadle River, 2006.

[3] C. H. Chiu, W. R. Tsai, M. H. Chou, and Y. F. Peng, "Two-wheeled Robot Control Based on Self-tuning Output Recurrent CMAC," in *Proceedings of the International MultiConference of Engineers and Computer Scientists 2009*, vol. 1, Hong Kong, 2009.

[4] R. C. Ooi, "Balancing a Two-Wheeled Autonomous Robot," University of Western Australia, Final year thesis 2003.

[5] S. Hassenplug. (2002) Steve's Legway. [Online]. http://www.teamhassenplug.org/robots/legway/

[6] G. N. Goretkin. (2008, August) Balancing Robot.

[7] D. Parker. (2010, February) BONUS MODEL # 5 NXT Segway with Rider. [Online]. http://mindstorms.lego.com/en-us/News/ReadMore/Default.aspx?id=164739

[8] H. K. Byung, "Reconfigurable Computing Platform for Small-scale Resource-constrained Robot," University of Minnesota, PhD Dissertation

2010.

[9] A. Salerno, R. Perlin, and J. Angeles, "The embodiment design of a two-wheeled self-balancing robot," in *Proc. CDEN Design Conference*, Montreal, 2004.

[10] T. Larson. (2010) Balancing Robot. [Online]. http://www.tedlarson.com/robots/balancingbot.htm

[11] RidgeSoft. (2004) Building a Balancing Robot with the IntelliBrain Robotic Controller and Lego Bricks. Document.

[12] H. Khoswanto and D. Purwanto, "Kesetimbangan Robot Beroda Dua Menggunakan Fuzzy Logic," in *Seminar Nasional Basic Science*, Malang, 2010.

[13] K. Mokonopi, "Balancing a Two Wheeled Robot," University of Southern Queensland, Dissertation 2006.