Control System In Uni-Wheel Mobile Robot using PID-Fuzzy

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***Abstract*— Research on Mobile robot controller inverted pendulum which aims to keep an upright position on the mass of the pendulum has been done. However, existing studies still have significant weaknesses which are fairly large oscillating motion when the robot moves to maintain balance, and also oscillations at almost reached the position of maximum slope of the pendulum. Therefore, the purpose of this research is to solve weaknesses by combining fuzzy and PID controller to minimize the oscillation movement. Input from the movement of the robot is determined by the data from accelerometer and gyroscope sensor that detects the tilt angle. The raw data from accelerometer and gyroscope sensor is filtered by the Complementary Filter to obtain the results of sensor data readings to more stable, little noise and more accurate while measure the data. Data that has been filtered by Fuzzy and PID, with each controller output is 50% to obtain the movement of the drive wheel of uniwheel robot more smooth when balancing itself. Based on experimental results, Fuzzy-PID algorithm more capable to keep uniwheel mobile robot in determined position from complementary filter.**

***Keywords*— accelerometer, gyroscope, filter complementary, Inverted Pendulum, fuzzy, PID .**

I. Introduction

The development of technology is currently growing rapidly along with the pace of time is increasingly unstoppable. Various innovations in this field is designed to help human life. One of these technologies in the field are robotics and automotive. Several automotive companies are now innovating to make personal vehicle (Personal Transporter) more practically used to minimize the time. one of them was uni-Wheel (Vehicle with One Wheel).

Many automotive industries are racing to add intelligence in vehicles made by combining artificial intelligence technology, such as the Uni-Wheel vehicle. Uni-Wheel is a vehicle with one wheel which can be driven by humans, Uni-Wheel vehicles can be balanced to the front and to the back of the vehicle imbalance is due to the intelligent controller that controls the balance of the vehicle [1]. Uni-Wheel is the development of a model of inverted pendulum (inverted pendulum) which maintain the balance of a pendulum upwards. Uni-Wheel vehicle requires a good control method and stable for the vehicle in order to maintain a position in a state perpendicular to the top of the earth's surface [2].

II. Related Works

Many researches that has been done in the field of inverted pendulum robotics. Some research titles that have a relationship with the uni-wheel mobile robot is "Real-time PID control of an inverted pendulum" made by Pasquale Buonocunto and Francesco Corucci, 2011. This study was conducted to balance a pendulum which is perpendicular to the top, as well as how to overcome the balance of the pendulum in order to stay upright and above [3]. Other research on mobile robot uniwheel created by Zhu Zhen, A. Al-Mamun and Phone Myint Naing, 2009 [4]. This research intend to test the design of Mechatronics robot one wheel to see the response of the sensor then get modeling.

However, existing research still have significant weaknesses which are fairly large oscillating motion when the robot moves to maintain balance, and also oscillations at almost reached the position of maximum slope of the pendulum. Therefore, this study intends to improve stability by combining fuzzy and PID controller to minimize the oscillation movement.

Input from the movement of the robot is determined by accelerometer and gyroscope sensor to detects the tilt angle when the inverted pendulum move to any directions. The raw data accelerometer and gyroscope sensor is filtered by the Complementary Filter to obtain the results of sensor data readings more stable, little noise and more accurate measurement data

III. Method

System planning is done to determine what components are needed by the robot in order to balance its position independently, either with weights or without weights. It is also given the interference from outside to determine the response characteristics of the sensor and DC motor in this inverted pendulum robot system.

From **Error! Reference source not found.** above can be seen that the system work if the chassis tilted at an angle + Θ or leaning forward, then the robot will move forward. Vice versa if -Θ or leaning back, the robot will move backward. Forward and backward movement is performed by the momentum of the robot system to balance the straight upright position when not given interruption until the time given disturbance.

According to figures illustrate how the inverted pendulum robot, the system is needed:

- An electronic system to support the performance of the robot.
- PWM control system for the movement of the motor
- Detection system and change the value of the amount of tilt angles with IMU sensor module
- Control system in the form of software on the Microcontroller
- The power supply such as a battery.

The over all of system describe by block diagram that can be seen in **Error! Reference source not found.** below.

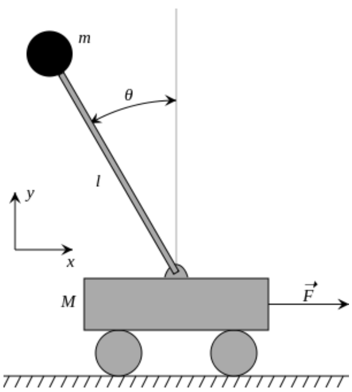


Fig. 1. Inverted pendulum robot movement.

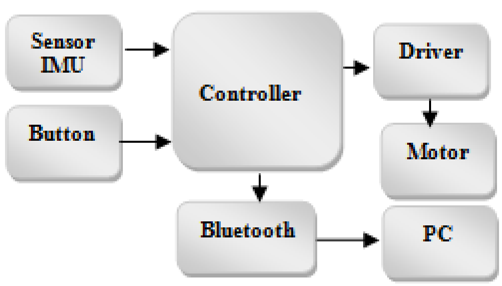


Fig. 2. Diagram of uni-wheel inverted pendulum robot

Broadly speaking, the system of the robot consists of input, controller, and output. On the input side consists of two sensor that read value of inclination angle and angular acceleration angle changes which consist of accelerometer sensor and gyroscope as a controller, use AVR ATmega16. This system uses the IMU sensor consists of an accelerometer and a gyroscope sensor which each have different characteristics. Accelerometer can read the amount of the angle of the acceleration process the angular displacement of the Earth's gravity, but it cannot read the change of angle angular velocity, by it that these sensors are paired together gyroscope sensor.

A. *PID Controller*

The expected goals of the course each tilt angle change will give a quick response to the jolt of a smooth style that does not cause the robot in case of a fall or move on. Mechanical Position therefore determined in equilibrium even without a controller. Moreover, it also set out the position set point for the angle of 0 degrees to gravity and also the limits of tolerance angle that can be reached by the robot from falling by the symbol + Θ to the value of the tilt angle when the robot mechanic leaning forward and symbols -Θ for value tilt angle when the robot mechanic leaning backward. The greatest value of the tilt angle of the robot is 45 °. Angle tolerance limits set by the value range of -20 ° to + 20 °. Magnitude of angle is determined upon consideration of the strength of torque motors to drive the wheels and pull the load of mechanical robot is quite heavy.

Designing the system in Uni-wheel mobile robot is done by using proportional method Integral Derivative (PID). **Error! Reference source not found.** shows the block diagram of PID control method.

By using feedback from sensors IMU (Inertial measurement unit) in which the sensor is preloaded Accelerometer and gyro. Accelerometer data is used to get the angle of Uni-Wheel. These values have been the benchmark in maintaining the balance of Uni-Wheel at a certain angle. However, in maintaining a good balance in the uni Wheel is not enough just to use the data Accelerometer, also needed data from gyro as the angular velocity. From both gyro and also accelerometer is known that has advantages and disadvantages of each other. Tilt angle calculated from the accelerometer has a slow response, while the tilt angle of the data integrated gyro having irregularities during a specific time period. Therefore, we can say that the accelerometer data is useful for long-term gyro while the data is useful for short term [5].

PID control helps improve the value of errors so the position of the uni-wheel to be balance. In the PID proportional component where there is proportional often called the G (s) = Kp, where k is a constant. If u = G (s) • E then u = Kp • E with Kp is a proportional constant. Kp valid as Gain (booster). Integral components of the system function to generate a response that has an error state (Error Steady State = 0). If a controller does not have an integrator element, a proportional controller is not able to guarantee the system output error becomes zero integral state it's often called Ki. While deverative components have properties such as a derivative operation. The sudden change in the controller input will result in a very big change, and fast. When the input is not changed, the controller output is also unchanged, whereas if the input signal is changed suddenly and ascending, generate output signals in the form of impulses. If the input signal changes slowly rises, output is precisely the great step function of magnitude heavily influenced by the speed of rise of the function is called with Kd constants.

B. Fuzzy Control

Formation of the membership function arranged by observing physical characteristics and sensors embedded in Uni-wheel mobile robot.

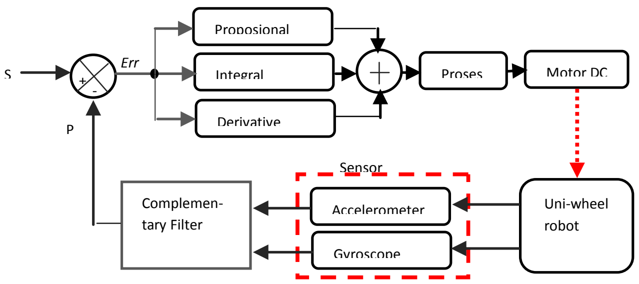


Fig. 3. Uni Wheel Diagram block

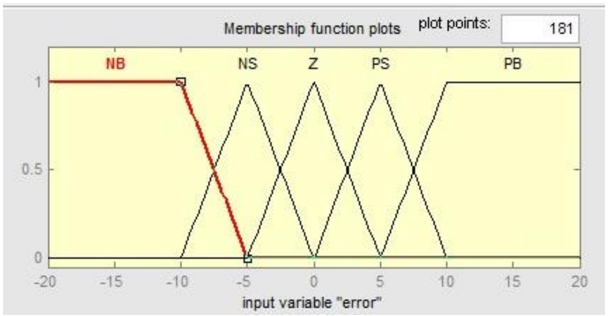
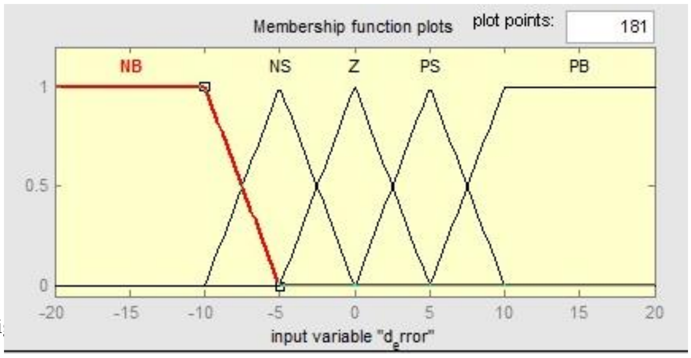


Fig. 4. Membership function of error



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This robot in a stable condition as described in the previous discussion is at 0 degrees inclination. In most circumstances falling or tilted position is 44 degree slope.

The membership functions are as follows:

1) Membership function Error

Error membership function consists of five parameters: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Big (PB). Its value has been determined from a minimum of -20 degrees to +20 degrees maximum tilt. The value of each membership function can be seen in **Error! Reference source not found.**.

2) Membership function d_error

D_error membership function consists of five parameters: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Big (PB). Its value has been determined from a minimum of -20 degrees to +20 degrees maximum tilt. The value of each membership function can be seen in **Error! Reference source not found.**.

C. Complementary Filter

The best way combining the data from the gyro and accelerometer are using Complementary Filter. Complementary Filter is designed so that the advantages of the sensor will be used to overcome the shortcomings of other sensors that complement each other. Filter Complementary task is to utilize an integrated angle of the gyro in a short time, and then the data obtained from the accelerometer is used for correcting the tilt angle during a long period of time. Balancing of the gyro sensor will also be constantly updated and improved. This will generate free estimate of deviation angle and quickly respond to shifting [6].

Mechanics

After all sections completed and then put together so the result describe in figure 6.

IV. RESULT

A. IMU Sensor

Testing the overall system is done in several stages, the first stage of testing the DC motor response system against heavy loads. The next stage is done on a trial and error tuning PID control system is installed to determine the value of the

Constants that are ideal for this inverted pendulum robot. Then the next stage test IMU sensor's response while maintain a balanced position both at rest without interruption until given interference from outside. The test is performed to determine whether the values of constants entered at balancing themselves fast or slow response. This process may take some time due to the characteristics of motors and sensors need to be adjusted to the heavy weight of the robot ranging from 12 kg.

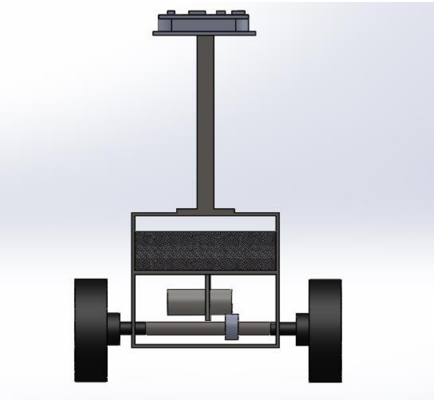

Fig. 6. Robot Mechanical

TABLE I. THE PRECISE LEVEL OF ACCELEROMETER SENSOR COMPARISON WITH PROTRACTOR

No.	The actual tilt angle with a protractor	Data tilt angle of the accelerometer
1	-47°	-47°
2	-40°	-40°
3	-35°	-35°
4	-30°	-31°
5	-25°	-25°
6	-20°	-20°
7	-15°	-15°
8	-10°	-10°
9	-5°	-5°
10	0	0
11	5°	5°
12	10°	10°
13	15°	15°
14	20°	20°
15	25°	25°
16	30°	30°
17	35°	35°
18	40°	40°
19	47°	47°

Initial testing precision sensor that results can be seen in Table 1.

From the table above shown that the level of precision sensor ADXL345 accelerometer are accurate. As for the error that exist due to rounding fragment of data generated various variable float data are converted into integers, shown in Figure 7.

Angle data that fluctuate can causing large error can be minimize by using LPF filter. Base on design of LPF filter, is obtained coefficients filter that can minimize noise level significantly. Coefficients filter (a) if its value increase so, the noise will be reduce. However, since this is closely connected with the time constant on the data sampling filter, the more magnified the value of the filter coefficients, it will prolong the time constant so that the data signal update time will be slower, see Figure 8.

Further testing is accessing gyroscope sensor via the I2C lines. Data of velocity angle measured is sent to the computer through a Bluetooth serial access and observe the hyperterminal software on a personal computer. Here are the results of data single axis x (movement pitch) obtained from the measurement of the angular velocity sensor L3G4200D gyroscope, see Figure 9.

According to Newton's second law, the greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object) and vice versa. When the initial state position IMU sensor module is in a certain angle and then moved to a stop at a certain angle, ideal final condition is the angular velocity is equal to zero. But in the actual conditions of the current stops, the angular velocity is not instantly changed to zero, but it takes time to reach a value of zero (finite acceleration).

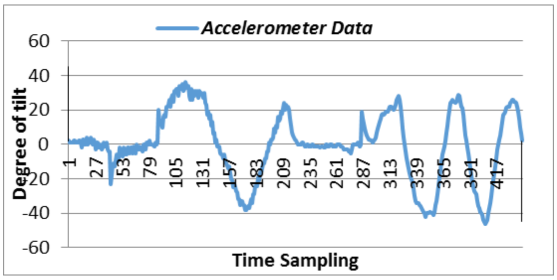

Fig. 7. Tilt angle measurement data with ADXL345 accelerometer sensor

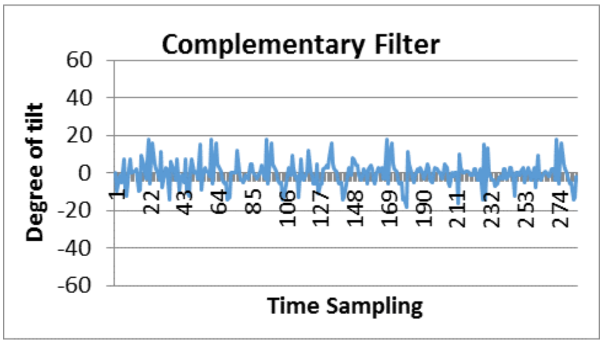

Fig. 8. Gyroscope data in an idle state

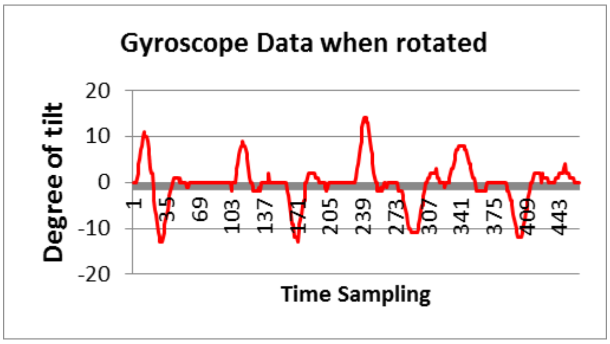

Fig. 9. Data Gyroscope in a state rotated

B. PID Tuning

Data from the chart above shown that the administration of the constants of different values, each data is still running to get a balanced position which is more subtle and oscillation caused by the angle less error. In Figure 10, 11 and Figure 12 shows that the value of the constant Kp Ki and Kd response PWM round too large. It shown that changes in the angle of the sensor resulted in the thrust of the motor is too large. Although the condition of the robot does not fall, but the inverted pendulum robot chassis oscillates too fast, it can cause the current to the motor also becomes unstable and can be fatal (track circuit has the potential to burn) at the DC motor driver when overheated.

Furthermore, in Figure 13 and Figure 14 for constants Kp = 600 Ki = 10 and Kd = 10 seemed calmer than before.

Results multiplier of constants Kp, Ki and Kd of the error angles produce a sufficient response to balance themselves, can even reach in the corner of a fairly extreme 19 ° tilt of this inverted pendulum robot. Thus for this test, set for tuning PID control parameters on the system balance inverted pendulum robot is set at Kp = 600, Ki = 10 and Kd = 10.

While the results of the complementary filter output itself is quite fast and not air noise with the filter coefficients (a) 0.97. The filter coefficients (a) is closely associated with time constan at the time of sampling the sensor signal which is given the symbol dt. With a value of 100 Hz or 0.01 seconds for the renewal of the actual data from the sensors can run fast as required at this inverted pendulum robot system.

C. Testing Fuzzy - PID

This test aims to obtain get PWM response to the transition or movement of the left and right motors when the robot maintain a good balance when maintaining balance independently and without load, then when balancing given a load. Input PID constants have been defined according to the value obtained when testing the previous parameter tuning.

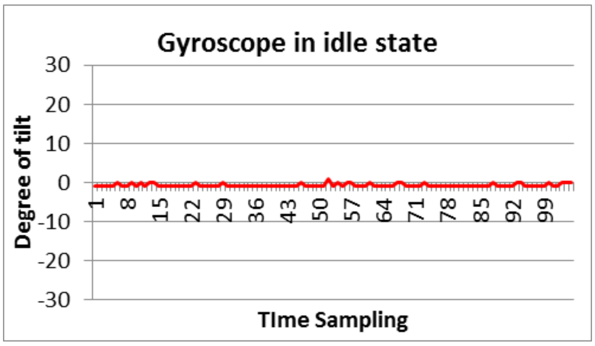

Fig. 10. PWM for kp=600, KI=10 and Kd=3000

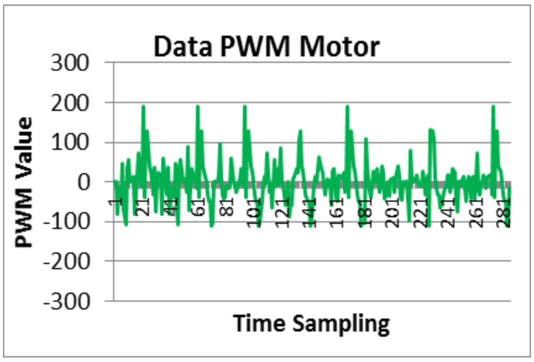

Fig. 11. IMU sensor for kp=600, KI=10 and Kd=3000

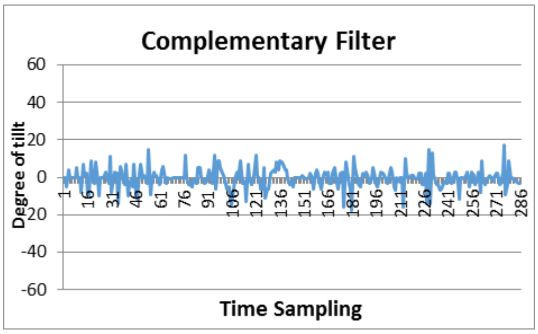

Fig. 12. IMU sensor for kp=600, KI=10 and Kd=10

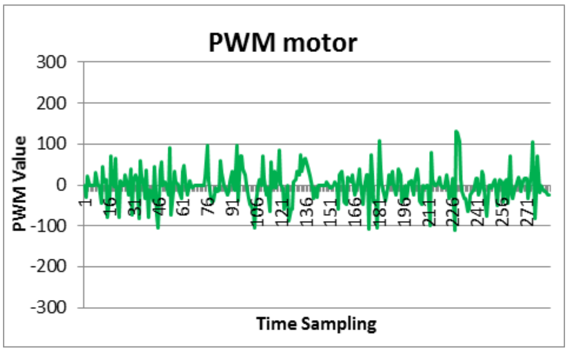

Fig. 13. PWM response for kp=600, KI=10 and Kd=10

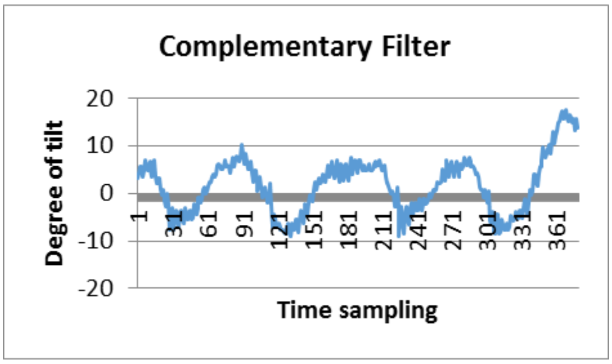

Fig. 14. Complementary response without load

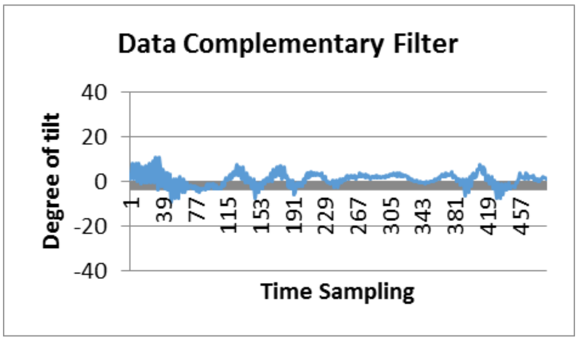

Fig. 15. Complementary Filter response when the robot maintain a balance with a load of 48 kg

In the figure 14 shown that the movement of the motor is in a stable condition although there is still a movement of oscillation with a span of about 1 second to move forward and backward to maintain a balanced position with the maximum angle reached 19 ° tilt, with the estimation time required to reach a stable position is approximately from 15 until 20 second

From Figure 15 it can be analyzed that the response of the motor and also the power of the motor torque capable of carrying loads up to 50 kg of the weight from user. Robots capable to running on a flat track at an average speed of 2 meters per second with a maximum angle until the state falling down with tilt angle is 10 °. The slow movement caused by the motor torque is set larger in order to be able to carry heavy loads. DC motor can be accelerated by reducing the motor torque force setting in the program, but, it would give the same response to the chassis and user load.

V. CONCLUSION

After doing the testing phase and the analysis it can be concluded as follows:

PID control by using complementary filter can work well for Uni- Wheel balancing robot control system. Tuning of control parameters to obtain the ideal conditions cases these research tools, the adjustable parameters is Kp = 600, Ki = 10, Kd = 10. This is because the characteristics response of the sensor and the power of movement from the motor must be aligned to the robot chassis when maintaining a balanced position. Accelerometer sensor readings can run stable with complementary filter. Accelerometer data which originally contained a fairly large noise, can be eliminated with the filter.

REFERENCES

[1] https://en.wikipedia.org/wiki/Self-balancing_unicycle.

[2] http://www.hindawi.com/journals/jcse/2012/194397/.

[3] P. Buonocunto, "Real-time PID control of an inverted pendulum. MSc in Computer Engineering", University of Pisa – Italy.

[4] Z. Zhen, A. Al-Mamun, and M. P. Naing. "Control-Centric Simulator For Mechatronics Design Case Study: Gyroscopically Stabilized Single Wheel Robot". 2009.

[5] S. Colton. The Balance Filter: A Simple Solution for Integrating Accelerometer and Gyroscope Measurements for a Balancing Platform, http://web.mit.edu/scolton/www/filter.pdf, 28 Juni 2015.

[6] S. Colton. The Balance Filter A Simple Solution for Integrating Accelerometer and Gyroscope Measurements for a Balancing Platform, Rev.1: Submitted as a Chief Delphi white paper. 2007.