Pertanika J. Sci. & Technol. 25 (S): 181 - 188 (2017)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

# Multisensor Automatic Balancing Model for DARwIn-OP on Uneven Terrain

**Muhamad Khuzaifah Ismail*, Meng Cheng Lau, Mohammad Faidzul Nasrudin and Haslina Arsha**

*Center for Artificial Intelligence Technology, Universiti Kebangsaan Malaysia, 43630 Bangi, Selangor, Malaysia*

## ABSTRACT

The walking of a humanoid robot needs to be robust enough in order to maintain balance in a dynamic environment especially on uneven terrain. A walking model based on multi-sensor is proposed for a Robotis DARwIn-OP robot named as Leman. Two force sensitive resistor (FSRs) on both feet equipped to Leman to estimate the zero moment point (ZMP) alongside with accelerometer and gyrosensor embedded in the body for body state estimation. The results show that the FSRs can successfully detect the unbalanced walking event if the protuberance exists on the floor surface and the accelerometer and gyrosensor (Inertial Measurement Unit, IMU) data are recorded to tune the balancing parameter in the model.

*Keywords:* Balance, Humanoid, Multisensor, Walking model, ZMP

## INTRODUCTION

The design and implementation of gait generation for stable steady state humanoid walking is a complex problem due to the high dimensional control space as well as unstable motion on dynamic terrain. Humanoids must have a walking gait that models a human gait in order to operate stably. Recently, a number of humanoid robots with the complex sensory system have been developed e.g. ASIMO, HRP, LOLA, NAO and HUBO in order to operate in dynamic environment (Ha, Tamura, Asama, Han, & Hong, 2011) following a number of successful researches performed in artificial intelligence, motion planning, robot manipulation, communication and image processing. To maintain the robot in balance is one of the challenges that need to be

ARTICLE INFO

*Article history:*
Received: 15 August 2016
Accepted: 18 May 2017

*E-mail addresses:*
khuzaifah@gmail.com (Muhamad Khuzaifah Ismail),
mclaubee@gmail.com (Meng Cheng Lau),
mfn@ukm.edu.my (Mohammad Faidzul Nasrudin),
haslinarshad@ukm.edu.my (Haslina Arshad)
*Corresponding Author

ISSN: 0128-7680 

addressed. One of the approaches to solving the balancing problem is to define the trajectories of the legs which naturally steered the torso of the robot in order to reduce the ankle torque needed to compensate its motion. Then by measuring the zero moment point (ZMP) of the robot to ensure a stable state by keeping the ZMP within a predefined stability region. A robot uses a few sensors like gyrosensor and accelerometer for body state estimation to keep balanced when walking. There are not enough information supplied to the robot about the environment it is currently operating causing the robot to operate in an undesirable way, causing errors and affects its stability, furthermore decreases the efficiency of the robot's operation. In this paper, we focus on the FSR feasibility with the standard ZMP algorithm and sensor fusion for stable walking.

A humanoid robot is required to have a stable and dynamic walking bipedal locomotion to perform task successfully. In order to achieve stability, gyroscope and accelerometer are used (Alias et al., 2013). One of the problems with gyro-sensor and accelerometer is that the feedback is very noisy. The input data need to smoothen for use in active control of walking motion (Baltes, McGrath & Anderson, 2004). A robot needs to initiate its walking step dynamically relying on natural forces, gravity and required walking control. This dynamic walking control should be robust to adapt with any situation and automatically readjust the walking gait to suit the current situation and surrounding thus eliminating pre-programmed gait (Daut, Azyze, Sanhoury, Nafis, & Amin, 2013).

## MATERIALS AND METHODS

### ZMP for Bipedal Robot

Zero Moment Point (ZMP) concept was introduced by Vukobratovic as a control law for stable dynamic walking motion (Allgeuer & Behnke, 2014). ZMP is the point on the surface of the foot where a resultant force R can replace the force distribution shown in Figure.1. ZMP can be calculated from a group of contact points ***Pi*** for *i* = 1,...,N with each force vector, ***fi*** associated with the contact point,

$$ZMP = \frac{\sum_{i=1}^{N} Pifiz}{\sum_{i=1}^{N} fiz} = \frac{\sum_{i=1}^{N} Pifiz}{fz} \tag{1.1}$$

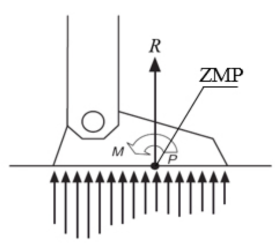


*Figure 1.* Definition of Zero Moment Point (ZMP)

If the floor is assumed horizontal, the torque reduces to 0 at the ZMP as,

$$\tau_x = \tau_y = 0 \tag{2.2}$$

The ZMP can never leave the support polygon for robot to stabilize. This is useful when pressure sensors are attached to the feet as center of pressure can be calculated and ZMP can be directly measured. The standard version of Leman did not equipped with FSRs disabling it to measure the ZMP position.

## Sensor Fusion for Attitude Estimation

Attitude estimation is the construction of full 3d orientation estimation of a body relative to some global fixed frame based on a finite history of sensor measurement. The body is often a robot (Allgeuer & Behnke, 2014). With low cost sensors and processors available, it is crucial that any estimation algorithm are able to run efficiently without sacrificing robot response. An open source generic C++ estimator that fulfilled the purpose for balancing (Shaari, Razali, Miskon, & Isa, 2013). has been implemented on Leman providing estimation for accelerometer and gyrosensor. The attitude estimator was formulated that internally relied on the concept of fused angles most notably in the areas of state estimation and walking originally built for ROS middleware of Nimbro-OP, a teen size humanoid robot by University of Bonn.

**Robot Specification.** Leman is a Robotis DARwIn-OP humanoid robot which weighs about 4kg and 45 cm tall. A 20-DOF (degree of freedom) standard version of DARwIn-OP is actuated by 20 Robotis's MX-28 servo motors. The high computational power FitPC2 single board computer embedded in the upper body part of Leman featuring 1.6GHz Intel Atom Processor and 1GB of RAM. To active balancing, a three axis gyro-sensor and a three-axis accelerometer IMU are included in the torso of Leman (Vukobratovic & Juricic, 1969). Leman is a robot competing in various robotic competition. In order to complete the tasks in the events, Leman has been modified by adding a pair of grippers on its hand and replaced its feet with 2 FSR feet unit as shown in Figure.2. All higher level processing is calculated in the main controller and send to the sub-controller with an ARM Cortex M3 processor running at 72MHz for low-level servo control (Shaari et al., 2013).

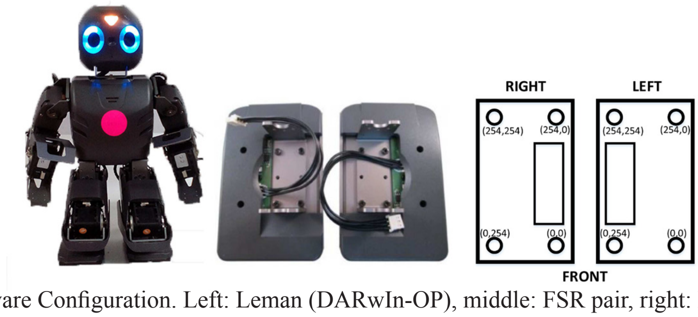


*Figure 2.* Hardware Configuration. Left: Leman (DARwIn-OP), middle: FSR pair, right: FSR mapping

**Model-based Walking Control.** Leman's walking framework is built based on hierarchy by considering dependency and modularity of its platform. The framework is written in C++ and running on Ubuntu 9.10. Similar to human walking pattern, humanoid robots walks in two phases, single support phase (passing) and double support phase (contact) as illustrated in Figure. 3. In the double support phase, both feet are on contact to the ground. As one leg lifts off the ground, it enters single support phase. The lifted leg then positioned on desired point and the cycle repeats as it enter double support phase again.

In order to create the stable walking phases, we need to design a robust walking gait. However, a robotic application on the unknown environment needs to be planned carefully due to high latency and short time for communication (Vukobratovic & Juricic, 1969).In an event of failure, a robot needs to restore itself to its original state. This function usually requires a human operator. Hence, a sensory feedback model needs to be developed to manipulate and analyses the data gathered from its surrounding to reinitialize the robot.

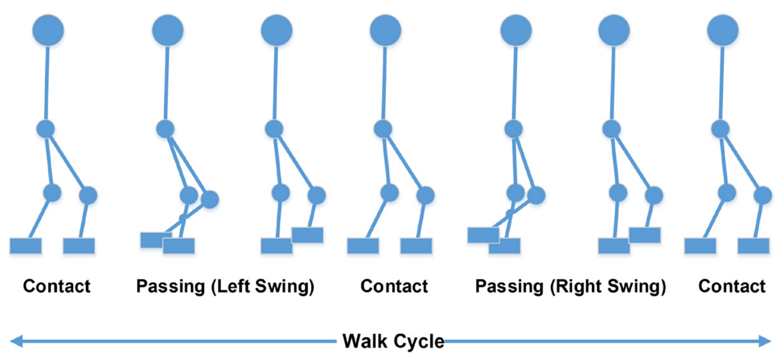


*Figure 3.* Walk cycle of Leman

In this paper, we propose a multisensory feedback control model as shown in Fig. 4 to overcome the balancing problem by using the FSRs and IMU. The set point, *sp* is the desired ZMP values that we obtained empirically based on our experiments. The ZMP value in *x* and *y* planes are measured from the FSRs feedback in a closed control loop with the existence of protuberances. Then output values are calculated that is proportional to the current error value, *e* through a simple *P* controller. The walking gait will be generated using Leman's inverse kinematic by the walking controller to calculate the joint trajectories based on the FSRs feedback.

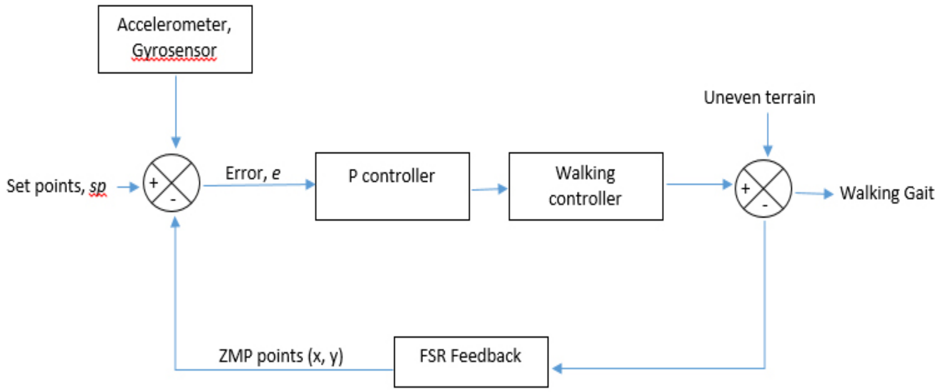


*Figure 4.* Multisensory feedback control loop model

## RESULTS AND DISCUSSION

We conducted a preliminary experiment to test the feasibility of the FSR for unbalanced event detection. The other sensory data e.g. gyroscope and accelerometer feedbacks were recorded in this experiment, but they are not discussed in this paper. The experiment was done in two conditions as shown in Figure. 5. During the experiments, Leman walked for 150 centimeters straight on the tiled floor. We placed three yellow bumps (cardboards with thickness vary from 0.8 to 1.0 centimeters) to create protuberances on the floor surface. We conducted three trials for each condition and data from sensors are recorded as plotted in Figure. 6 and Figure. 7.

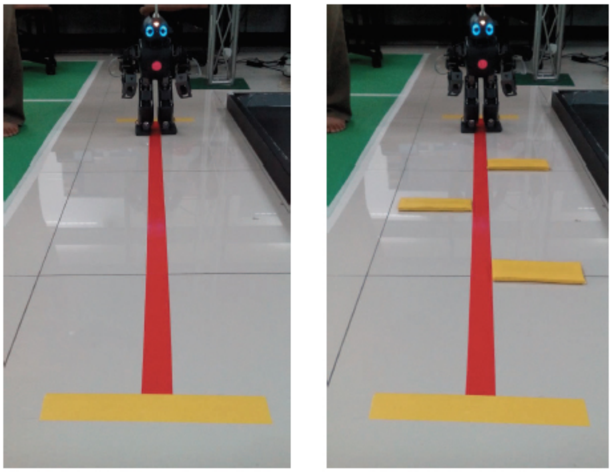

*Figure 5.* Experimental setup. Left: even floor surface, Right: uneven floor surface

Figure. 5 shows the result of X and Y axes of the right and left ZMP during Lemans operation on both experiments. In the even floor condition, the result shows a consistent pattern which can be used as a baseline to analyses the unbalanced event. Figure. 6 shows the ZMP results of X and Y axes of Leman's walking on the uneven surface. The result shows three inconsistent phases as highlighted in the bounding boxes. Based on our observation during the experiments, the inconsistencies of the FSRs data are perceived from the off-balance events due to the prearranged protuberances that caused on ground contact at the landing phases. From Figure. 6, we can conclude that the FSRs are able to detect 100% of the prearranged protuberances in our experiments.

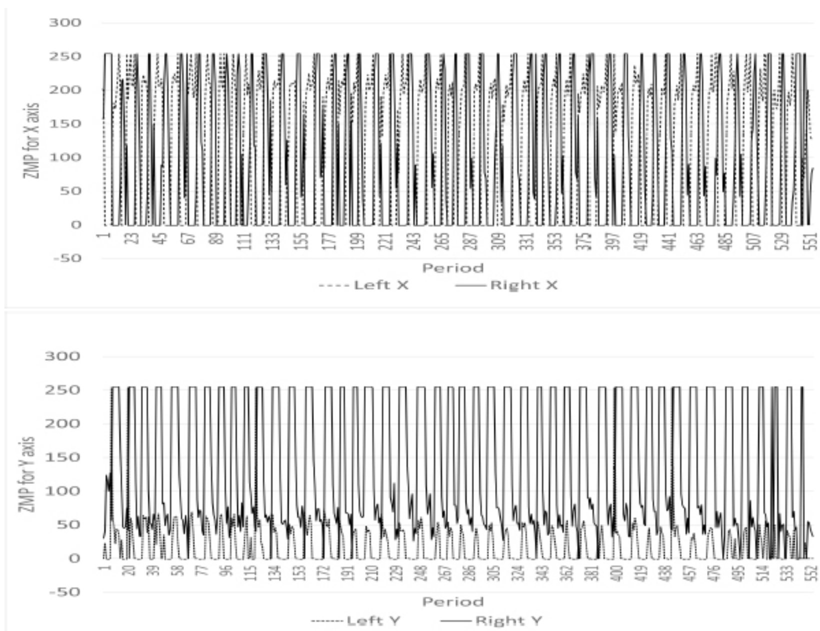


*Figure 6.* ZMP output on even floor. Top: ZMP for *x*-axis on the right and left FSR. Bottom: ZMP for *y*-axis on the right and left FSR

The usage of estimation algorithm shows that Leman is able to modify its walking gait and balance its body based on the accelerometer and gyroscope reading. This enables Leman to continue walking by using the ZMP data provided by the FSRs by integrating estimation value of IMU into Leman's walking controller.

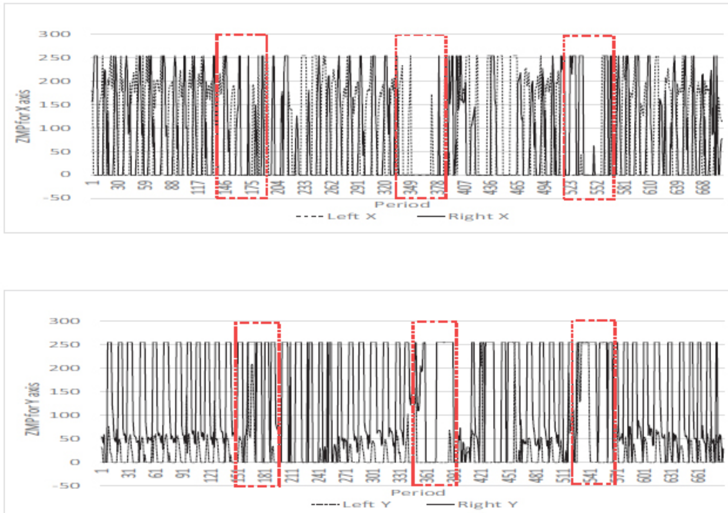


*Figure 7*. ZMP output on uneven floor. Top: ZMP for *x*-axis on the right and left FSR. Bottom: ZMP for *y*-axis on the right and left FSR

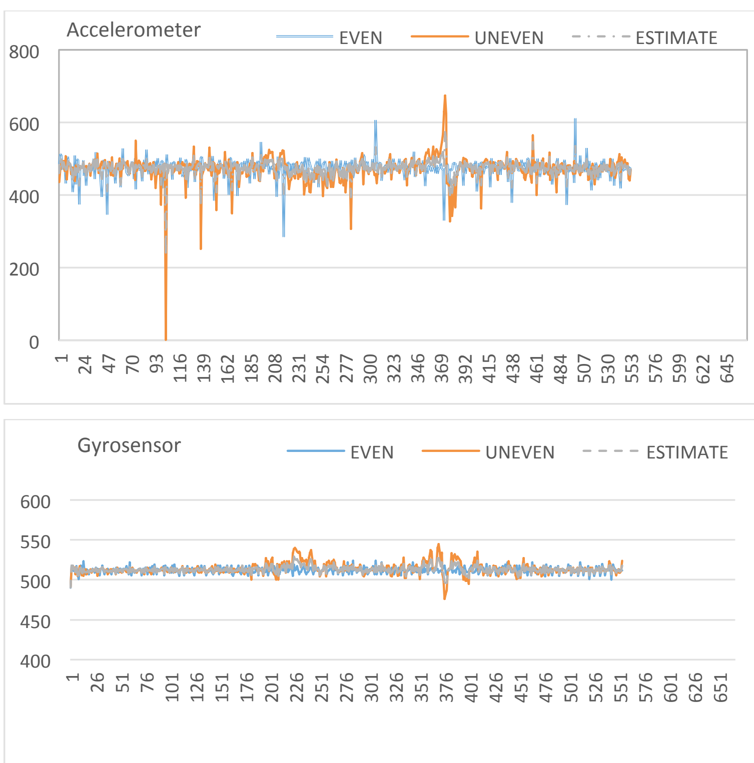


*Figure 8*. Top: The output of Accelerometer and estimation for frontal and back during walking. Bottom: The output of Gyrosensor and estimation for frontal and back during walking

## CONCLUSION

This paper describes experiment conducted to test the feasibility of FSR to detect the unbalanced event and the use of IMU for sensor fusion to maintain robot balance. Based on the experimental results, we proposed a stable walking control model which will utilize the FSR to estimate the ZMP to maintain the balance of Leman in addition to sensor fusion model of IMU. However, there is much work left to be done especially by integrating fuzzy logic and reinforcement learning into the design of the control model for more robust and responsive automatic balancing of Leman.

## ACKNOWLEDGMENTS

This research is funded by Universiti Kebangsaan Malaysia and Zamalah Universiti Penyelidikan.

## REFERENCES

Alias, A. R., Alias, M. S., Shamsuddin, I. Z., Ahmad, R. A. R., & Abdullah, S. N. H. S. (2013, August). Measure the ability and limitation of gyroscope, acceleration and gyro-accelaration for stabilized platform. In *FIRA RoboWorld Congress* (pp. 405-415). Springer, Berlin, Heidelberg.

Allgeuer, P., & Behnke, S. (2014, November). Robust sensor fusion for robot attitude estimation. *IEEE Robotics and Automation Society International Conference in Humanoid Robots (Humanoids)* (pp.218-224). IEEE.

Baltes, J., McGrath, S., & Anderson, J. (2004, December). Active balancing using gyroscopes for a small humanoid robot. In *2nd International Conference on Autonomous Robots and Agents* (pp. 13-15).

Daut, M. N., Azyze, N. L., Sanhoury, I. M., Nafis, M. L., & Amin, S. H. (2013, August). Stable dynamic walking gait humanoid. In *FIRA RoboWorld Congress* (pp. 427-440). Springer, Berlin, Heidelberg.

Gomez, S. O. C. (2014). *Sensing with a 3-toe foot for a mini-biped robot.* Northeastern University.

Ha, I., Tamura, Y., Asama, H., Han, J., & Hong, D. W. (2011, September). Development of open humanoid platform DARwIn-OP. *Proceedings of the Society of Instrument and Control Engineers Annual Conferene* (pp. 2178-2181). IEEE.

Kong, J. S., Lee, E. H., Lee, B. H., & Kim, J. G. (2008). Study on the real-time walking control of a humanoid robot using fuzzy algorithm. *International Journal of Control, Automation, and Systems, 6*(4), 551-558.

Robotis (n.d.). *DARWIN-OP. ROBOTIS e-Manual v1.25.00*. Retrieved from http://support.robotis.com/en/product/darwin-op.html

Shaari, N. L. A., Razali, M. R. B., Miskon, M. F., & Isa, I. S. M. (2013). Parameter study of stable walking gaits for nao humanoid robot. *International Journal of Research in Engineering and Technology (IJRET), 2*(8), 16-23.

Vukobratovic, M., & Juricic, D. (1969). Contribution to the synthesis of biped gait. *IEEE Transactions on Biomedical Engineering,* (1), 1-6.