A Machine Learning Approach to a Lateral Continuous Force Estimation for a Walking Biped Robot

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Abstract

In this paper, a regressor for determining a lateral external continuous force applied upon a walking biped robot is investigated and verified by a numerical simulation. A pre-defined walking gait of a biped robot is constructed by the Tchebyshev method. And a continuous force-action classifier is generated. It determines whether the lateral external force is a continuous force or not. A regressor which estimates a lateral external continuous force acted upon a walking biped robot is constructed by SVR (Support Vector Regressor). The regressor is verified by a numerical simulation. We assumed that only lateral force is applied upon the COG (Center of Gravity) of the walking biped robot.

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Keywords: walking, biped robot, SVR, regressor, force estimation..

1. Introduction

The biped robot (humanoid robot) is the robot which resembles human beings. Not only resembles the appearance, but also resembles its functionality. Compared with other function-specific robots, the humanoid robot is versatile in its functionality. In theorem, it can do almost all the works which humans do. That's why many robot researchers are enthusiastic for making and researching a perfect humanoid robot. The most prominent ones of these humanoid robots are Asimo[1], Petman[2] and Hubo[3]. Other state-of-the-art humanoid robots are found in DARPA (Defense Advanced Research Projects Agency) robotics challenge 2013[4]. The humanoid robot may interact with a human being. For example, it may serve a human being by going and taking a cup of coffee to a human being. And it can sweep the house in which the human and humanoid live together. During interacting with a human being, the robot can accidently collide with an object or a human beings. The worse consequence is falling down and gets damage. Many researches are performed to alleviate and avoid this kind of humanoid damages. Fujiwara et.al.[5] made a falling motion control to minimize the falling damage. Morisawa et.al.[6] prevented the collision of a humanoid robot with other objects by incorporating an emergency stop motion planning. Renner and Behnke[7] make use of attitude sensors and reflexes to detect instability and avoid falling down for a humanoid robot. O. Hohn et.al.[8] made a classifier for biped instability. Kim et.al.[9] made a falling detection and avoidance classifier for a biped robot by using SVM(Support Vector Machine). All the above works are about alleviating and avoiding the humanoid damages irrespective of the amount of the external force. If the external force is small, the biped robot can recover from the instability by its inertial. And if the external force is intermediate and large, KNOWLEDGE ABOUT THE AMOUNT OF THE EXTERNAL FORCE will make the biped robot control more specific and efficient. So, the authors made a SVR based regressor for determining a continuous lateral external force in a walking biped robot. This regressor will be used to determine the lateral continuous external force and control the biped robot not to fall down by the external force. The paper is organized as follows. Section 2 explains the pre-defined walking gait of a biped robot. Section 3 set forth the continuous force-action classifier which determines whether the applied external force is continuous or not. The SVR and SVR based continuous lateral force estimator is explained in Section 4 and 5 and the numerical simulation result is in Section 6. And the conclusion is drawn in Section 7.

Contributions are to be in English. Authors are encouraged to have their contribution checked for grammar. American or British spelling should be used. Abbreviations are allowed but should be spelt out in full when first used. Integers ten and below are to be spelt out. Italicize foreign language phrases (e.g., Latin, French).

2. Pre-defined Walking Gait

As pointed out in the abstract, we assumed that the lateral continuous force is applied upon the COG of the walking biped robot. The walking gait of a biped robot is important in making the force-estimating regressor for it changes the lateral dynamics of the biped robot. So, in this section, we explain the pre-defined walking gait of a biped robot. In our previous work [10], an energy-efficient walking gait of a biped robot is constructed by using Tchebyshev method. We adopt the methodology in this paper and made an energy-efficient walking gait. The walking gait is comprised of SSP (Single Support Phase) and DSP (Double Support Phase). However, we only use SSP walking gait for the regressor estimates the lateral continuous force in SSP walking gait. Fig. 1 illustrates the SSP walking gait made by Tchebyshev method. The SSP walking stride is 0.6m and SSP walking time is 1.3sec. The sampling rate of the simulation is 1msec. The walking gaits in Fig. 1 are viewed sagitally.

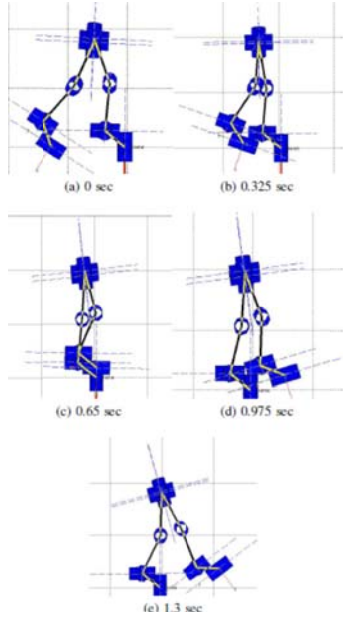


Fig. 1 Walking gait sequence (in sagittal view)

3. Continuous Force-Action Classifier

While the biped robot is walking in a pre-defined walking gait, a sudden lateral external force can be applied to the walking biped robot. The biped controller must determine whether some force is applied or not and furthermore if it is, it must also determine whether the applied force is continuous or impulsive. The continuous force-action classifier determines these. Fig. 2 represents the ZMPy graph during walking in the pre-defined gait. The width of the sole is 0.2m, so ZMPy spans -0.1 ~ 0.1m. The ZMPy graph is a smooth curve within this span, which represents the walking gait is well constructed for the biped robot not to fall down during walking. The sampling rate is 1msec which is previously stated and all the ZMPy points in a SSP walking gait are 1300. The continuous force-action classifier takes 4 points ZMPy(t-3), ZMPy(t-2), ZMPy(t-1) and ZMPy(t) from ZMP sensors and compares this 4 ZMP points with the pre-defined ZMPy at the specified walking time and if all the 4 ZMPy points differ, it returns 1 or returns 0. The returned 1 value means that the continuous lateral force is acted upon a biped robot. Algorithm 1 in Fig. 3 represents these working of the continuous force-action classifier.

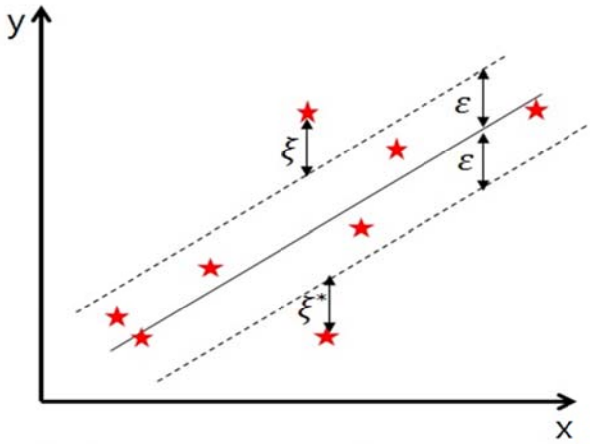
Fig. 2 ZMPy graph (lateral direction ZMP)

```
Data: ZMP_y
Result: 1 or 0
while the biped is walking in SSP do
    read
    ZMP_y(t-3),ZMP_y(t-2),ZMP_y(t-1),ZMP_y(t);
    if The 4 ZMP_y points not-equals the pre-defined 4
    ZMP_y points then
        return 1;
    else
        continue;
    end
end
Algorithm 1: Continuous Force-Action Classifier
```

Fig. 3 Continuous force-action classifier algorithm

4. SVR (Support Vector Regression)

Because the regressor which determines the amount of the lateral continuous force acting upon a walking biped robot makes use of the SVR, we briefly explains what a SVR in this section. SVM (Support Vector Machine)[11] is basically used as a classification problem, however, if it is used as a regressor, it is SVR. The SVR incorporates the same principles as the SVM for classification with only minor differences. In SVM, the constraint is that the distance between the real points and the hyperplane must be larger than ε(the margin). However in SVR, the constraint is that the distance between the real points and the hyperplane must be smaller than ε(the margin). In fact, the SVR solution is solving the optimization problem in Fig. 4.



$$\text{Solution: } y = wx + b$$

$$\text{Minimize: } \frac{1}{2}\|w\|^2 + C\sum_{i=1}^{N}(\xi_i + \xi_i^*)$$

$$\text{Constraints: } y_i - wx_i - b \le \varepsilon + \xi_i$$

$$wx_i + b - y_i \le \varepsilon + \xi_i^*$$

$$\xi_i, \xi_i^* \ge 0$$

Fig. 4 Support vector regression basic framework

5. Lateral Continuous Force Estimator

If the continuous force-action classifier determines that some continuous force is applied, the lateral continuous force estimator is activated to estimate the amount of the continuous force. The whole process of constructing the lateral continuous force estimator is depicted in Fig. 5. In Fig. 5, the SSP gait of a biped robot is depicted. There are 5 consecutive pictures that represent one SSP gait. The walking times are 0, 400, 600, 800 and 1300msec. The biped pictures are viewed sagitally and the inertial coordinate system is represented as X-Y-Z coordinates in right side of the picture. We assumed that the external continuous force is activated laterally in -Y direction to the COG (Center Of Gravity) of the biped robot at any SSP gait sequence.

We divided the SSP walking gait as 5 times (0, 400, 600, 800 and 1300msec) to make it easy to construct a force estimator. At each of this 5 gait times, the lateral continuous force estimator is constructed by utilizing SVR with linear kernel. And if the force is activated at the 4 time intervals (0~400, 400~600, 600~800 and 800~1300msec) the linear interpolation technique is adopted to decide the amount of the applied continuous force. All this procedure is expressed in Fig. 5.

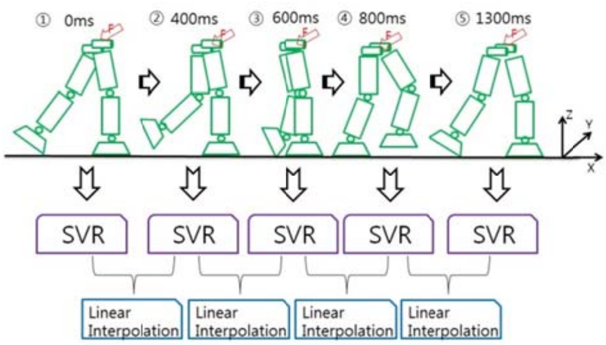


Fig. 5 Lateral continuous force estimator framework

6. Simulation Results

In this section, the simulation results are presented. In Fig. 6 the ZMP vs. the applied force graph at half walking time after training is presented. The points are acquired by the numerical simulation of the biped robot

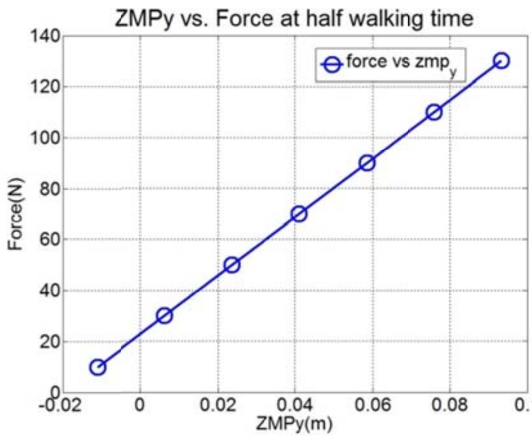


Fig. 6 ZMPy vs. Force at half walking time

and the linear line represents a trained linear SVR. The results show that the ZMP-force graph is almost linear and the resulting trained SVR curve is also almost linear. In Fig. 7 there are two graphs represents the performance of the lateral continuous force estimator. The upper graph is when the force is applied at 500msec in the walking time and the latter graph is when the force is applied at 700msec. The ZMPy points are 2.75, 20.22, 37.69, 55.16, 72.13 and 90.1mm at 500msec and 3.91, 13.46, 30.84, 48.22, 65.60 and 82.98mm at 700msec. the blue rectangular points represents the exact applied force from the numerical simulation and the red triangular points represents the estimated external force. As the two graphs represents, the estimated value is fairly well matches the exact value. The RMS (Root Mean Square) errors at 500msec and 700msec are 0.1838N and 8.3336N. The reason of relatively large RMS error at 700msec compared with

Fig. 6 ZMP-applied force graph at half walking time

that at 500msec is the large estimation error at ZMPy value 0 in 700msec graph. This is the limitation of linear SVR and other kernel-based SVR will cope with this estimation error.

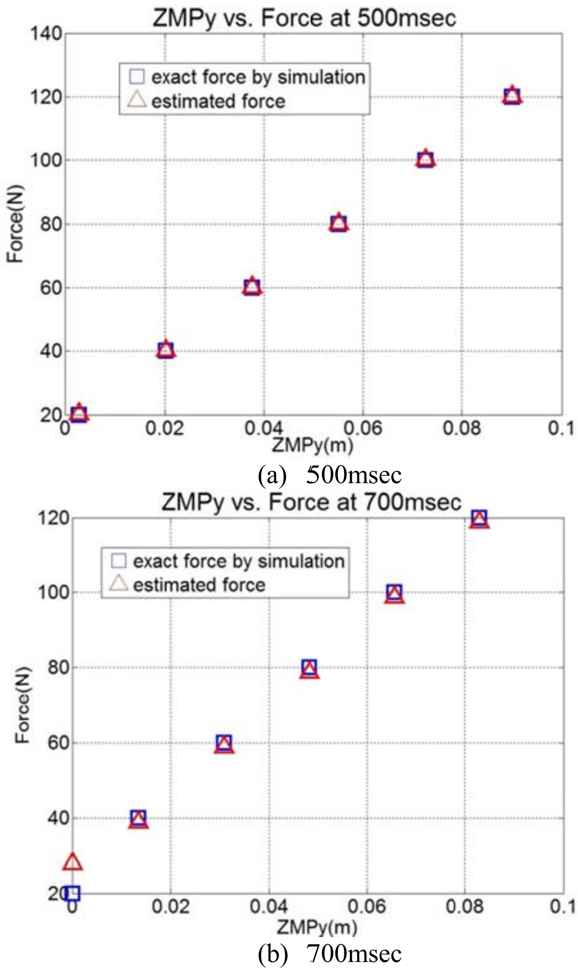


Fig. 7 Lateral continuous force estimator performances

7. Conclusion

In this paper, the lateral continuous force estimator is constructed and verified by numerical simulations. The lateral continuous force estimator estimates the externally applied lateral force when a biped is walking.

We assumed that the external continuous force is applied to the COG of the biped laterally. It makes use of linear SVR and linear interpolation technique. The numerical simulation results show that the estimator well predict the external force. Future works are to train the estimator with different kernel to reduce the RMS error and to perform other regression model except SVR.

8. Acknowledgement

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References

References are to be listed in the order cited in the text. Use the style shown in the following examples. For journal names, use the standard abbreviations. Typeset references in 9 pt Times Roman.

1. K. Hirai, M. Hirose, Y. Haikawa and T. Takenaka, *The development of Honda humanoid robot in Proc. of 1998 IEEE Int. Conf. on Robotics and Automation,* pp.421-439.
2. http://www.bostondynamics.com/.
3. J. H. Oh, D. Hanson, W. S. Kim, Y. Han, J. Y. Kim and I. W. Park*, Design of Android type Humanoid Robot Albert HUBO in Intelligent Robots and Systems, 2006 IEEE/RSJ Int. Conf. on,* pp.1428-1433.
4. E. Ackerman , *DARPA Robotics Challenge Trials: Final Results available at http://spectrum.ieee.org/automaton/robotics/humanoids/darpa-robotics-challenge-trials-results.*
5. K. Fujiwara, F. Kanehiro, F. Kajita, K. Kaneko, K. Yokoi, and H. Hirukawa, *UKEMI: Falling Motion Control to Minimize Damage to Biped Humanoid Robot in Proc. of the 2002 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems,* pp.2521-2526.
6. M. Morisawa, K. Kaneko, F. Kanehiro, S. Kajita, K. Fujiwara, K. Harada, H. Hirukawa, *Motion Planning of Emergency Stop for Humanoid Robot by State Space Approach in Proc. of the 2006 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems,* pp.2986-2992.
7. R. Renner and S. Behnke, *Instability Detection and Fall Avoidance for a Humanoid using Attitude Sensors and Reflexes in Proc. of 2006 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems,* pp.2967-2973.
8. O. Hohn, J. Gacnik and W. Gerth, *Detection and Classification of Posture Instabilities of Bipedal Robots in Climbing and Walking Robots,* pp.409-416.
9. J. J. Kim, Y. J. Kim and J. J. Lee, *A Machine Learning Approach to Falling Detection and Avoidance for Biped Robot in Society of Instrument and Control Engineers Annual conference 2011,* pp.562-567.
10. Y. J. Kim, J. Y. Lee, J. J. Lee*, Bipedal Walking Trajectory Generation Using Tchebychev Method in International Conf. on Mechatronics and Informatics,* pp.265-271.
11. V. Vapnik, S. Golowith and A. Smola*, Support Vector Method for Multivariate Density Estimation in Advances in Neural Information Processing Systems*, vol.12, pp.659-665.