ESTIMATING LEAN ANGLE THROUGH APPLICATION OF THE GRAVITY LINE PROJECTION ALGORITHM

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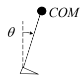
INTRODUCTION



- In the study of the human postural control system, the single link inverted pendulum model is frequently used. In the model, the lean angle of the pendulum is often used as output, and compared with the desired lean angle.
- Lean angle (θ) is defined as the angle between vertical and a line connecting the ankle and body center of mass (COM). Among numerous methods for estimation of the COM (e.g. [2]), we chose the zero-point to zero-point double integration of ground reaction force and center of pressure (COP) data, i.e., the gravity line projection, (GLP) method [4] .
- In this study, we modified the GLP method using an interpolation method and verified its application to the estimation of the body lean angle.

METHODS

Original GLP Algorithm (summarized)

- Step1 : Determine the COP at the instant when the horizontal ground reaction force is zero.
- Step2 : Calculate the second integral of F_x/m. Use initial value of $\dot{x}_0$ and x as zero and x_{COP}.
- Step3 : Estimate initial value, $\dot{x}_0$.
- Step4 : Repeat Step2 with new initial value.
- Step5 : Repeat Step1-4 for the entire data set.

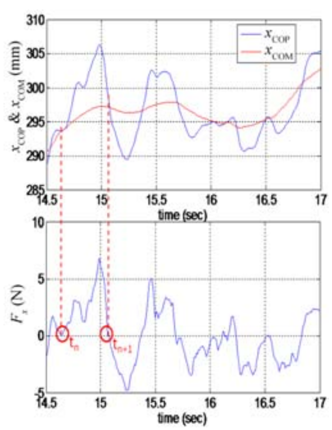


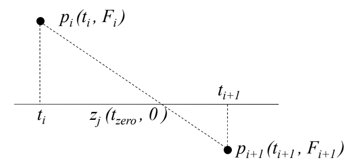
Figure 1. *COP, COM and force plots in AP direction*

Modification of GLP algorithm with interpolation method

Idea: Pre-process force data in AP direction, F_x, and then apply original GLP algorithm. Finally, post-process newly-generated x_{COM}.

Procedure:

Step A (Pre-process) : Find exact zero-crossing points by finding index i where $F_i * F_{i+1}$ is negative, and by applying interpolation method.



By simple geometry, t_{zero} can be found as follows.

$$t_{zero} = \frac{|F_{i+1}|t_i + |F_i|t_{i+1}}{|F_i| + |F_{i+1}|}$$

Step B (Pre-process) : Insert newly-found zero-crossing points into F with ascending order of t.

F_{old}	...	p_{i-1}	p_i	p_{i+1}	...	
F_{new}	...	p_{i-1}	p_i	z_j	p_{i+1}	...

Therefore, F_{new} has $n+m$ elements.
$1 \le i \le n,\ 1 \le j \le m$
n : number of original samples of F
m : number of zero-crossing points

Step C (GLP) : Apply original GLP algorithm to F_{new} (Steps 1-5).

Step D (Post-process) : x_{COM}, the output of Step C ,has $n+m$ elements. By decimating elements of x_{COM} whose indices are same as z_j's in step B, x_{COM} with n elements can be finally found.

Experimental Validation:

- Eight young adult subjects
- 3 quiet standing (QS), 3 voluntary sway (VS) trials in AP, for 30s.
- Ground reaction force and COP data were recorded with a force plate (AMTI, BP600900), and kinematic data were collected using a motion capture system (Vicon 460). All data were sampled at 120 Hz

Data Processing

- Location of the COM was estimated by kinematic algorithm [3]. Length between the ankle and COM was estimated by anthropometric data (58.71% of body height for males and 57.48% for females) [1].
  Lean angle was then calculated by simple trigonometry from single link inverted pendulum model.

Data analysis

- We used the root mean square error (RMSE) and cross-correlation between the two calculation methods
- We also checked variability to the uncertainty generated due to estimating the ankle to COM distance by varying body height up to ± 20%.

Result

Table 1. *RMSE (SD), cross-correlation, and w/ and w/o height uncertainty*

	Regular body height		Regular body height ± 20%	
	QS	VS	QS	VS
RMSE (deg)	0.036 (0.008)	0.287 (0.094)	0.057 (0.01)	0.276 (0.11)
XCorr	0.985 (0.014)	0.992 (0.006)	0.985 (0.014)	0.992 (0.006)

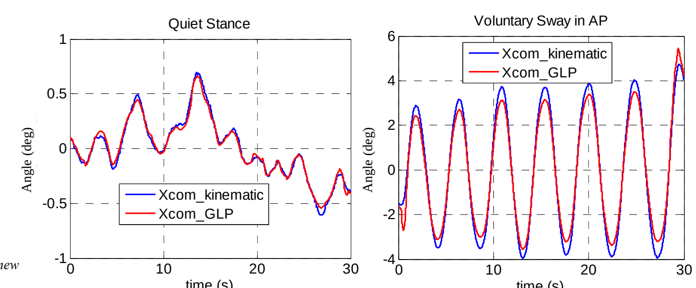


Figure 2. *Body lean angles (quiet standing, voluntary sway)*

SUMMARY

- Modified GLP algorithm is very robust and convenient with no need to estimate threshold value by trial and error method.
- By applying the modified GLP algorithm to estimate the horizontal displacement of the body COM, we calculated lean angle successfully.
- This method is a viable approach especially when kinematic motion capture data are not available.

References:

[1] King and Zatsiorsky, *Gait Posture* 6, 27-38, 1997.
[2] Lafond et al., *J Biomech* 37, 1421-1426, 2004.
[3] Vaughan et al., *Dynamics of Human Gait,* 1999.
[4] Zatsiorsky and Duarte, *Motor Control* 4, 185-200, 2000.