A INTERPOLATION-BASED APPROACH TO MOTION GENERATION FOR HUMANOID ROBOTS

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Abstract: This paper proposes a static posture based motion generation system for humanoid robots. The system generates a sequence of motion from given several postures, and the motion is smooth and stable in the balance. We have produced all the motions of Tai Chi Chuan by the system. Motion generation for humanoids has been studied mainly based on the dynamics. Dynamic based method has, however, some defects: e.g., numerous parameters which can not be always prepared, expensive computational cost and no guarantee that the motions are stable in balance. We have, thus, studied less dependent-on-dynamics approach. A motion is described as a sequence of postures. Our system figure out if we need extra postures to insert for stability. This method enables humanoid robot, HOAP-1 to do Tai Chi Chuan.

1 INTRODUCTION

In recent years, robotics has greatly developed, especially, research for humanoid robots has attracted much attention (e.g,(Nishiwaki et al., 2002), (Sugihara et al., 2002), (Huang et al., 2001), (Yamaguchi et al., 1993), (Li et al., 1993), (Kagami et al., 2001), (Kuffner et al., 2001), (Kuffner et al., 2002), (Kuwayama et al., 2003)). Existing methods of motion generation for humanoid robots are mostly based on the dynamic control theory and the optimization technique. These methods are often specialized in some particular motions, such as walk and standing, which are simple, symmetric or cyclic. This presents an obstacle to general-purpose. These methods may require the mastery of dynamic for use. The methodologies based on the dynamics often require highly expensive computational cost, and the motion control for unconstraint motions is still hard problem. Mechanical characteristic of humanoid robot is an increase in DOFs. There is, however, few studies for motion control such that the DOFs are fully utilized.

In this research, we, thus, take an intelligent software approach to motion control with useful interface and application for various motions. In this paper, we propose a motion generation system for humanoid robots. Our system generates a sequence of motion from given several postures, and the motion is smooth and stable in the balance.

We have produced all the motions of Tai Chi Chuan by the system. All motions have been performed by a humanoid robot.

2 HUMANOID ROBOT AND THE TARGET MOTIONS

2.1 Humanoid Robot

In this paper, we consider the motion control of a humanoid robot, HOAP-1 (Humanoid for Open Architecture Platform) produced by Fujitsu(Murase et al., 2001), shown in Figure 1. The total weight is 6 (kg) and the height is 48 (cm). HOAP-1 has 20 DOFs in total, 6 in each leg and 4 in each arm. The link structure is shown in Figure 2. The sensor architecture of HOAP-1 is consisted of 4 pressure sensors on each sole and angular rate and acceleration sensors mounted in breast. HOAP-1 is controlled with RT-Linux OS on itself or computer connected with USB.

2.2 Tai Chi Chuan

We consider Tai Chi Chuan as the target motion for humanoid robots. Tai chi has several styles. In this paper, we adopted Tai Chi 48. Tai Chi motions have various movement of entire body. Tai Chi motions are

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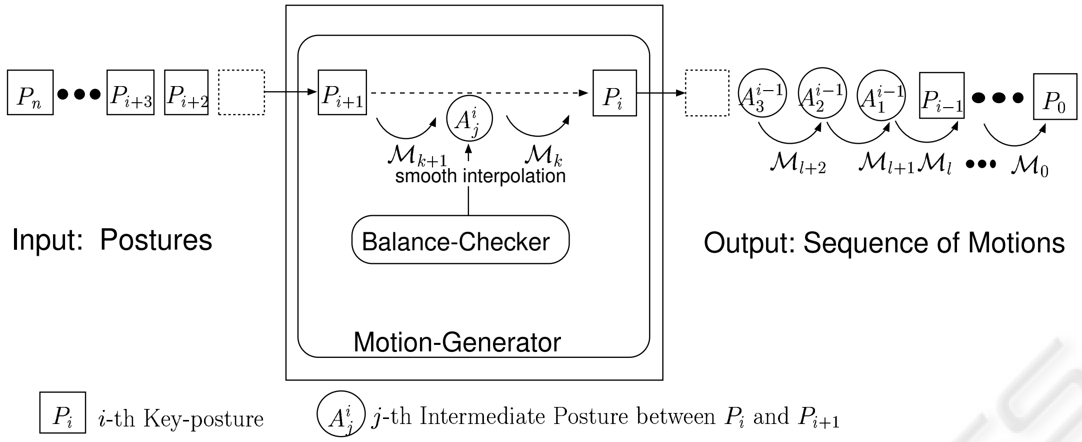

Figure 3: Data flow in our motion generation system.

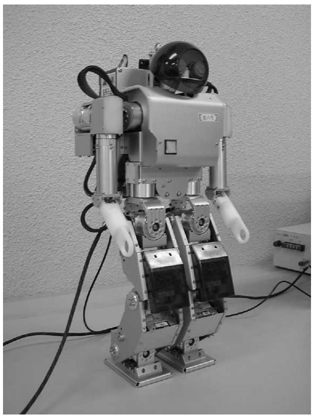

Figure 1: HOAP-1.

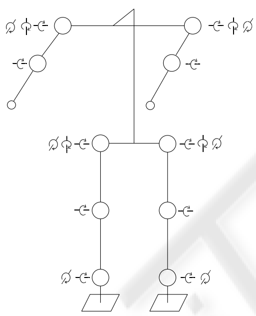

Figure 2: The link structure of HOAP-1.

performed slowly, softly and with smooth and even transitions between them. Tai Chi motions require sophisticated balance control for robots. In addition to stability or energy consumption, Tai Chi Chuan requires concinnous forms. Unlike to walking, Tai Chi motions should not be changed markedly in appearance even for the stability.

3 MOTION GENERATION SYSTEM

3.1 Interpolation-based Motion Generation

The section describes a motion generation system for humanoid robots. Figure 3 shows the outline of the system. Input to the system is a sequence of postures $P = P_0, P_1, \cdots, P_n$, (called *key-postures*). Each key-posture has characteristic form of a motion to generate. In this system, we suppose that each key-posture is statically stable in balance. This supposition is supported by the key-posture adjustment, such that the center of mass (COM) of the upper body is positioned just above the ankle of the supporting leg. Output from the system is a motion sequence $M = \mathcal{M}_0, \mathcal{M}_0, \cdots, \mathcal{M}_m$.

The basic function of motion generation is the smooth interpolation between two postures, P_i and P_{i+1}. The interpolated motions, needless to say, should be stable in balance for humanoid robots. *Balance Checker* evaluates the distance between P_i and P_{i+1} in balance space, and then, inserts a few intermediate postures (corresponding to A_j^i in Figure 3) if the distance is over a threshold. It is, in general, difficult to calculate the distance of postures in balance space. We have, thus, made a rough approximation described in the following section.

3.2 Classification of the Postures in Balance Space

Tai Chi Chuan, our target motion, has wide variation in posture. Interpolation-based motion generation is, however, vulnerable to wide or quick variation in postures. It is, thus, important to consider some relation between two postures to be interpolated. The admissibility of the interpolated motion may be estimated by the relation. In this research, we consider the distance in balance space as the admissibility.

To calculate the distance of postures in balance space is hard problem. In this research, we give this problem an audacious consideration that postures of Tai Chi motion are classified into 13 groups (*posture*

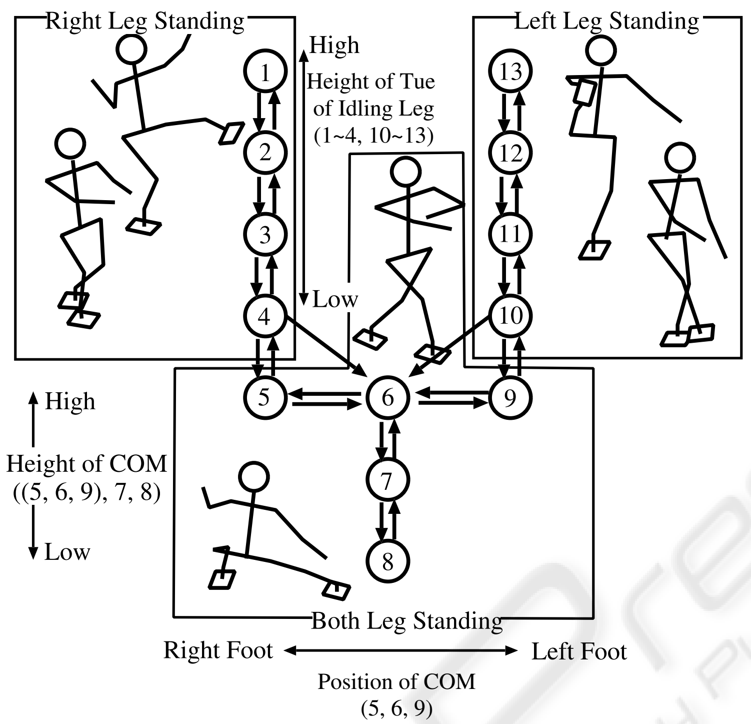

Figure 4: The directed graph of 13 posture classes.

class, or simply *class*) and these groups are connected by 26 arcs in the balance space. The balance space is represented by a directed graph shown in Figure 4. The classification is based on the relative position of COM and the relation of the supporting and idling legs. Firstly, postures are classified into three classes: both leg standing, right leg standing and left leg standing. Single leg standing is classified into four classes according to the height of the idling leg in relation to the supporting leg (see Figure 4):

- lower than the ankle (#4 and #10),
- higher or equal than the ankle and lower than the knee (#3 and #11),
- higher or equal than the knee and lower than the hip (#2 and #12),
- higher or equal than the hip (#1 and #13).

Both leg standing is classified into five classes according to the position of the COM in relation to the COM of the erect posture (see Figure 4):

- the vertical component is less than 80% (#8),
- the vertical component is more or equal than 80% and less than 90% (#7),
- the vertical component is more or equal than 90% and,
  - the horizontal component leans to right more than 20% (#5),
  - the horizontal component leans to left more than 20% (#9),
  - the horizontal component is within 20% from the center of the both feet (#6).

The classification enables our system to approximate the distance of two postures. Let a and b be arbitrary postures to be interpolated, and let g_a to g_b be the classes which a and b belong to, respectively. The distance between a and b is given by the distance between g_a and g_b: the length of the path from g_a to g_b. We, therefore, can estimate the admissibility of the interpolated motion from a to b by the distance between g_a and g_b.

The balance checker in our system utilizes the directed graph in Figure 4 for the decision to insert an intermediate posture or not. The directed graph give a constraint for the stability in balance on the motion generator. The constraint is that two postures to be interpolated should belong to one class or adjoining two classes. For example, interpolation from a posture in class #6 to a posture in class #4 has the risk of tumble. A posture in class #5 should be inserted between them.

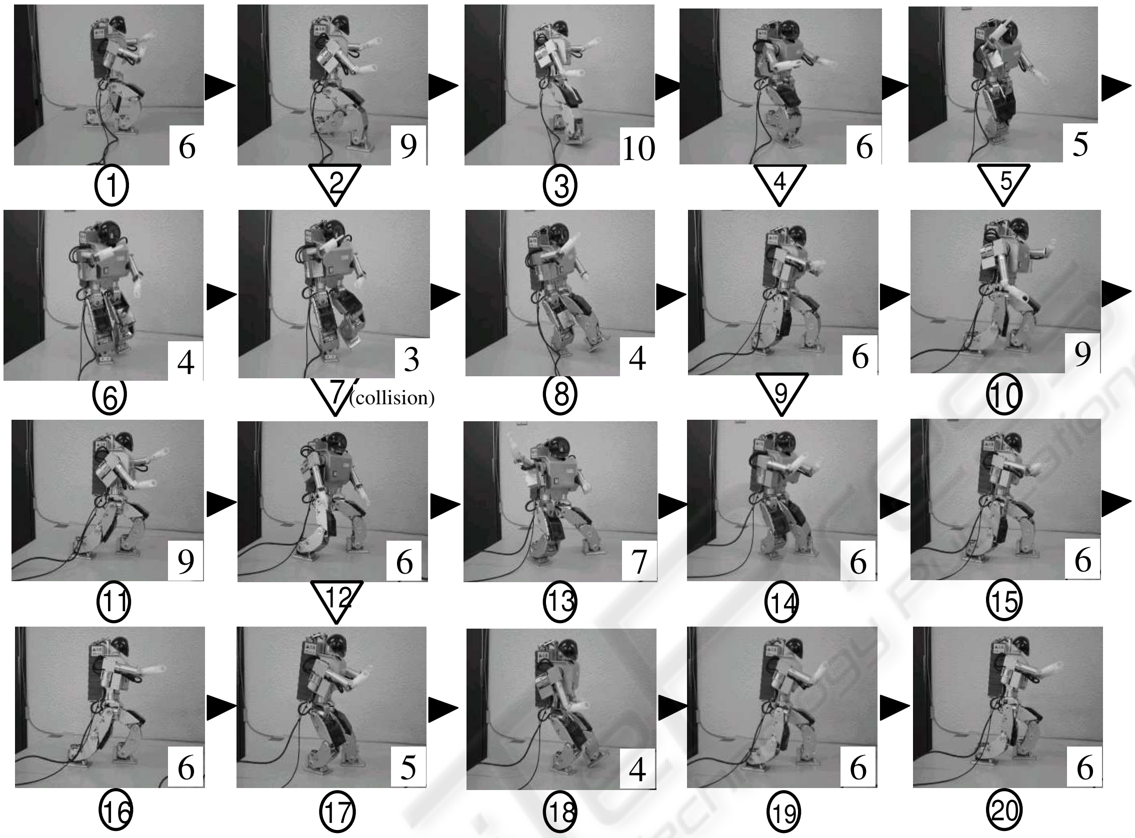

Figure 5: The snapshot of Tai Chi #7 motion by HOAP-1.

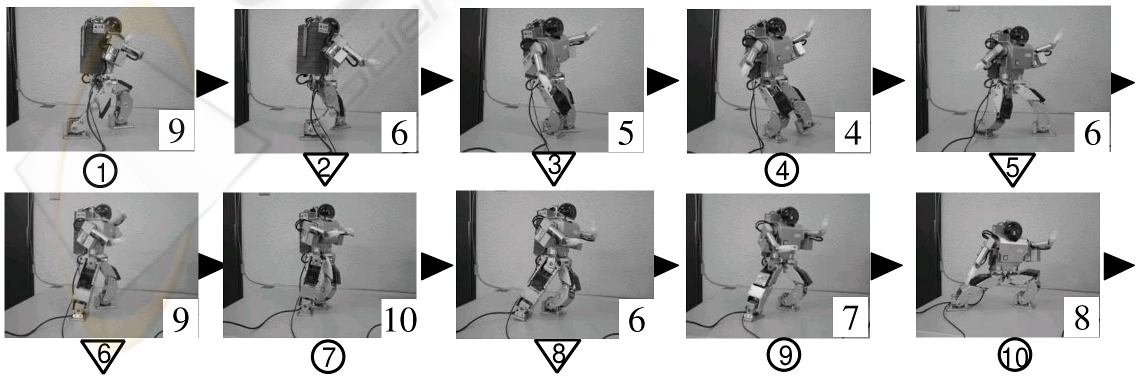

Figure 6: The snapshot of Tai Chi #17 motion by HOAP-1.

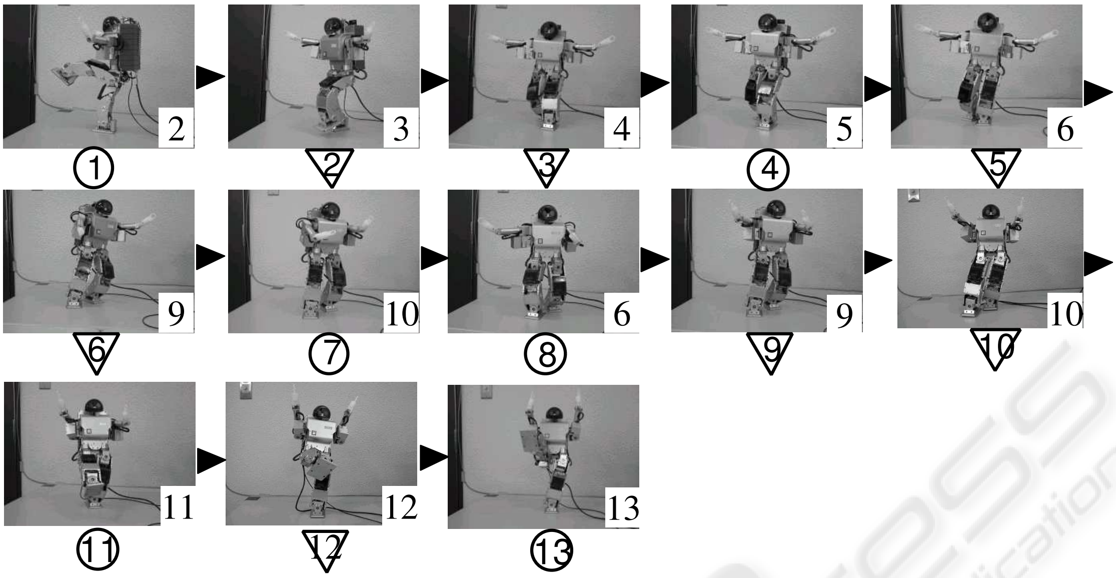

Figure 7: The snapshot of Tai Chi #44 motion by HOAP-1.

4 EXPERIMENT

We have produced all the motions of Tai Chi Chuan without tipping over. Firstly for data input to our motion generation system, we have prepared key-postures for 48 Tai Chi motions, from a tutorial book (Defang, 1999). The system has, secondly, generated the control sequences of servomotors for all the motions. In this particular examples, all motions are well performed by HOAP-1. Table 1 and 2 show the listing of Tai Chi motions and the numerical relation between input and output postures by our system.

4.1 Performance Results

Figure 5, 6 and 7 show the snapshots of Tai Chi #07, #17 and #44 motion by HOAP-1, respectively. Tai Chi #7 composed of the basic walking motion, called *shang bu*. This is easy one in Tai Chi, however, it occurs tipping over without our system. Tai Chi #17 composed of the motion keeping robot's head low, called *pu hu*. This motion HOAP is imbalance in backward and forward movement. Tai Chi #44, which contains high kick called *bai lian*, requires high skill balance control of robot. This is one of the most difficult motions. HOAP-1 can support its weight with one leg skillfully, although the imbalance becomes very high. In these figures, the number in the lower right of the each snapshot means the class which the posture belongs to. The transition of classes satisfies all constraints by the directed graph shown in Figure 4.

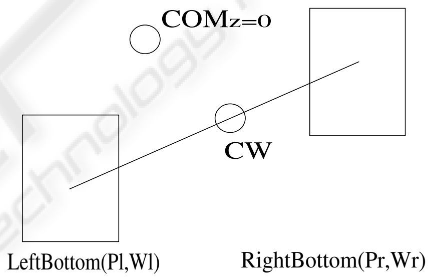

Figure 8: Components for balance quantification.

4.2 Effectiveness of Balance Checker

To verify the effectiveness of our system, we have evaluate the balancing performance for the motions. In this paper, we suppose the quantity of balance as follows. Let COM be the center of mass of whole robot, let COM_z be the vertical component of COM, and let $COM_{z=0}$ be the projection of COM on the floor. Further, let P_l and P_r be the position of the left and right sole, and let W_l and W_r be the weight on the left and right sole, respectively (see Figure 8). The balance is quantified as the following equation:

$$imbalance = |COM_{z=0} - CW| \cdot COM_z, \quad (1)$$

where

$$CW = \frac{Pr \cdot Wr + Pl \cdot Wl}{Wr + Wl}. \quad (2)$$

Figure 9, 10 and 11 show the trajectories $imbalance$ of two Tai Chi by HOAP-1: our method and without *Balance-Checker* for Tai Chi #7, #17 and

Table 1: Key Postures of Tai Chi Generated by Our System

#	name	postures after balance checker	postures by tutorial book
(0)	qi shi	4	4
1	bai he liang chi	5	4
2	zuo lou xi ao bu	4	4
3	zuo dan bian	20	10
4	zuo pi pa shi	4	3
5	lu ji shi	26	15
6	zuo ban lan chui	13	7
7	zuo peng lu ji an	19	11
8	xie shen kao	8	4
9	zhou di chui	11	7
10	dao juan gong	29	12
11	zhuan shen tui zhang	18	13
12	you pi pa shi	4	3
13	lou xi zai chui	9	6
14	bai she tu xin	9	6
15	pai jiao fu hu	31	18
16	zuo pie shen chui	11	5
17	chuan quan xia shi	9	4
18	du li cheng zhang	14	6
19	you dan bian	20	10
20	you yun shou	25	12
21	you zuo fen zong	13	7
22	gao tan ma	5	3
23	you deng jiao	10	6
24	shuang feng guan er	5	3

Table 2: Key Postures of Tai Chi (continued)

#	name	postures after balance checker	postures by tutorial book
25	zuo deng jiao	8	4
26	yan shou liao quan	7	3
27	hai di zhen	6	3
28	shan tong bei	5	2
29	you zuo fen jiao	21	9
30	lou xi ao bu	15	7
31	shang bu qin da	10	4
32	ru feng shi bi	7	4
33	zuo yun shou	25	11
34	you pie hen chui	11	5
35	zuo you chuan suo	33	16
36	tui bu chuan zhang	5	2
37	xu bu ya zhang	6	2
38	du li tuo zhang	2	1
39	ma bu kao	9	3
40	zhuan shen da lu	9	5
41	liao zhang xia shi	11	7
42	shang bu qi xing	4	2
43	du li kua hu	7	4
44	zhuan shen bai lian	12	4
45	wan gong she hu	6	4
46	you ban lan chui	16	7
47	you peng lu ji an	19	11
48	shi zi shou	5	3
(49)	shou shi	3	3

#44 motions, respectively. The result indicates that our system can generate a stable Tai Chi motion for HOAP-1, while the robot loses the balance without our balance checker. In the figures, the numbers over the graph correspond to the frame labeled the same number in snapshots shown in Figure 5, 6 and 7. All motions without balance check tipped over, and after that, the imbalance is not accurate because sensors are not calibrated.

5 CONCLUSION

In this paper, we proposed a motion generation system for humanoid robot. The motion generated by our system is smooth and stable in the balance. Humanoid robot, HOAP-1 with our system has performed whole 48 Tai Chi motions in good balance. Our system performs various and unrestricted motions for humanoid robots without hard problem in dynamics. Our system still has some constraints, that is, platform dependent, interpolation interval, and at least one sole on the floor.

The future work will focus on three phases. Firstly, we will deal with the automatic choreographing the postures to insert. Secondly, we will dedicate to the more generalized control of the motion generation. Especially, it is important to let system free from interpolating interval. Our system often makes motions sprawly in time-axis. This is caused by our policy that stability is more important than speed. There are, however, scenes that speed is important, too. We will respond to this tradeoff. Thirdly, we will dedicate to some interpolation methods specialized to Tai Chi Chuan. The value of the Tai Chi motion is not only stability and speed, but also aesthetic sense and smoothness of the motions. In this phase, we will firstly focus on finding ordinality in the rhythm of Tai Chi Chuan.

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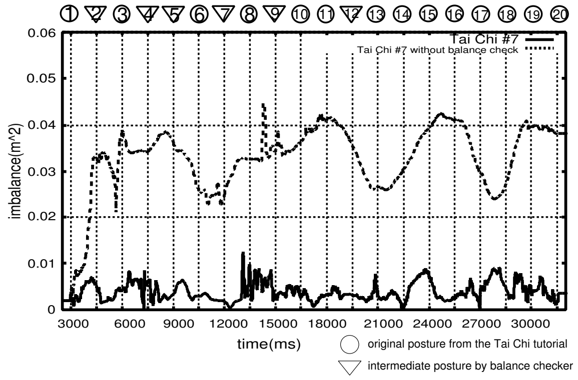

Figure 9: The imbalance of Tai Chi #7.

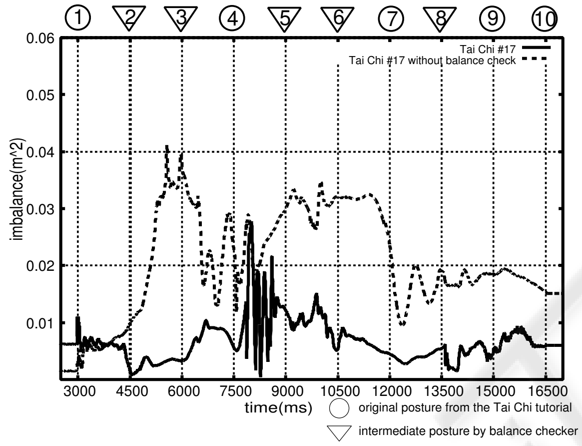

Figure 10: The imbalance of Tai Chi #17.

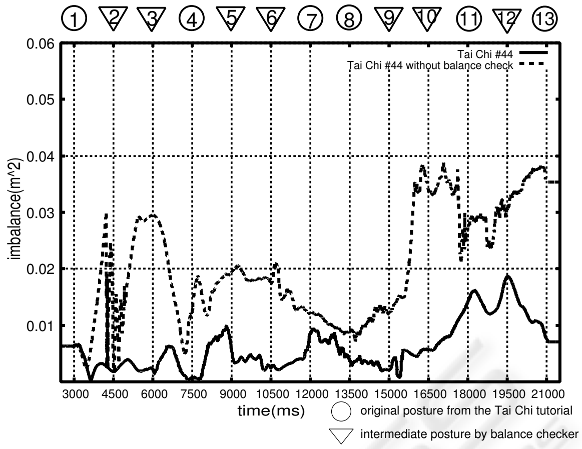

Figure 11: The imbalance of Tai Chi #44.

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