Two-Dimensional Analysis of Lower Extremities to Predict Best Initial Condition on Marching Movement

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Abstract. Himpunan Mahasiswa Mesin ITB has a specific type of marching that follows a march song's rhythm called *derap*. In practice, *derap* movement in a group was harder to be maintained and aligned. This difficulty was observed by noting the height differences that occur in the individual's movements during the initial and middle of the march. This study intends to observe and find how the differences vary during this motion. This study utilized five active markers to track the landmarks of the right side of the lower extremities while the motion was captured using a 60 frames per-second (fps) action camera. The duration of the movement in this study was also constrained with three cycles of marching song at 115 bpm. The direct Linear Transformation (DLT) method was used to calibrate the camera and reconstruct the movements using captured marker positions. As the results, the knee angle ROM has decreased from 26.55° to around 15°, which happened during the second song cycle and kept stable for the rest of the movement. This result brought the conclusion that the more extensive *derap* motion would tend to change the form of the body compared to the initial state.

Keywords: *kinematic parameter; lower extremities; marching; motion capture.*

1 Introduction

Marching has the meaning of moving along steadily with a rhythmic stride and in step with others [1]. This movement was primarily associated with basic military training and civilian ceremonial parades. A type of marching that is specific to *Himpunan Mahasiswa Mesin Institut Teknologi Bandung* (HMM ITB) is called *derap*.

Sets of guidelines stated regarding *derap* must be followed by the group, including the position of the body, the alignment to the person on the front and

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the side, and the cadence. The starting position of *derap* follows the head facing forward and at the same height as the person to the side, the trunk remains vertical, and the hands are placed on the lower side of the abdomen. Ideally, this position would be maintained throughout the marching song.

The motion of marching is inconsistent as the marching song is sung, which is supposed to be sung thrice at the tempo of 115 beats per minute (bpm). In practice, the marching cadence mainly was rushing as the song's tempo increased, which causes the group to make more effort to maintain the marching movement just similar to gait [2]. This condition could be observed from the difference between hip height on the starting position and the settling position through marching movement. The behavior of hip position drift would be evaluated and analyzed by obtaining the angular kinematic parameter of knee and ankle angle through the subject's movement. This relative angle was estimated as a kinematic parameter of the marching movement, and this could be acquired by using the motion capture method capturing the lower extremities of the subject [3]. This practice was carried out by placing markers on the desired body landmarks and reconstructing the marker position to the image plane of the camera [4], this coordinate was then processed to obtain the linear and angular kinematic parameters [5].

The purpose of this study is to determine the period where the body position reaches a steady state in this marching case. This data could be utilized to improve the starting position of the *derap* march, allowing the group to exert less effort to maintain the marching cadence over a more extended period.

2 Methodology

To obtain the position of each body segment of lower extremities, this study was conducted using an optical motion capture system that was previously developed by ITB Biomechanics Research Team [6]. This study utilized a motion capture procedure that consists of an action camera with a 1080p resolution with a frame rate of 60 fps. The camera was mounted at a height of 75 cm above the ground and positioned perpendicular to the observation zone at a distance of 160 cm. A 505 mm tile of calibration board was used, while 5×5 tiles with an active marker on each corner were used as a calibration object as presented in Figure 1.

Figure 1 Set-up experiment.

Prior to the data acquisition, five active markers were attached to the right side of the subject's lower extremities, as shown in Figure 2. The markers were placed on the hip, knee, and ankle joints consecutively, the fourth marker is placed on the calcaneus, and the fifth marker was placed on the metatarsal of the subject's right foot. The marker placement in this study followed Helen Hayes' marker set with modification on the thigh and calf marker [7]. Thigh and calf markers were removed because this study only occupied two-dimensional analysis using one camera as the motion capture device. A single camera was more practical method to perform a preliminary analysis study through this marching movement [8].

Figure 2 The placement of the markers on the lateral lower extremity of the subject.

To reduce the noise caused by light reflection, the subject was equipped with black tights. This also ensured that the markers were tacked to the correct position of the subjects' body landmarks. Furthermore, the ground under the observation zone was also covered in black to prevent the reflections of the marker's light captured. The room was maintained dark by isolating every light source apart from the markers. The camera was also set to the lowest ISO so that only desired lights from the markers were captured.

The data was processed under the MATLAB environment that the position of each marker was estimated using the DLT method to reconstruct the movement of the markers on the subject to the two-dimensional image plane [9, 10]. To prevent the lack of marker traceability, the authors chose to use the least square method to predict the marker movement from one to another frame of video as the movement goes on [11, 12], so that the marker index that detected at the same body landmarks remains the same as presented in Figure 3.

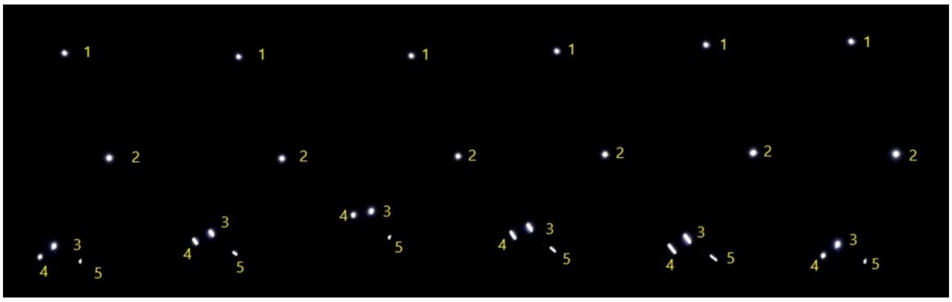


Figure 3 The markers numbering on a cycle of motion.

This study was carried out by recording a male subject that was considered professional in this marching movement. The subject was a trained marching group leader with one year of experience in this movement. The subject's relevant anthropometry for this study is shown in Table 1.

Table 1 Subject Anthropometry.

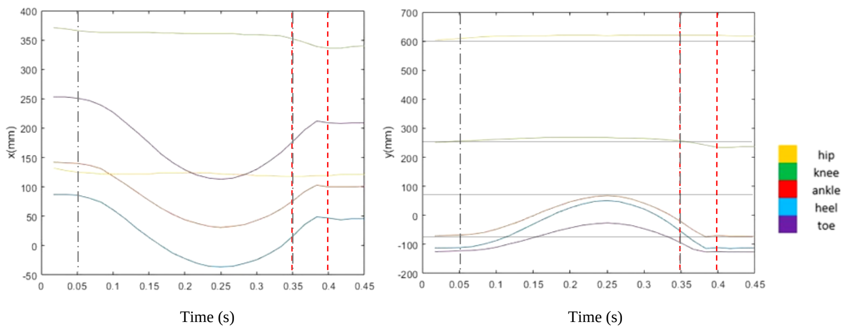
Age (years)	Body Height (cm)	Body Mass (kg)	Thigh Length (cm)	Calf Length (cm)	Foot Length (cm)	Knee Height (cm)
20	172	69	42	42	27	7.5

The subject repeated the marching motion for three cycles of the marching song at 115 beats per minute during the data acquisition. Since the marching movement was considered slow, the subject should maintain the motion in a specific position to ease this study. Thus, the spatiotemporal parameters of this motion were expected to have a stride length of 0m, speed of 0 m/s, and cadence of 115 steps per minute.

The position of the hip, knee, and ankle joints was calculated to obtain the relative knee angle plotted in a time frame. The relative angular position of the knee was then smoothened by using the smoothing spline method. The relative angular velocity and acceleration were obtained from the derivation of its relative angular position which was also smoothened using a smoothing spline method [13].

3 Result and Discussion

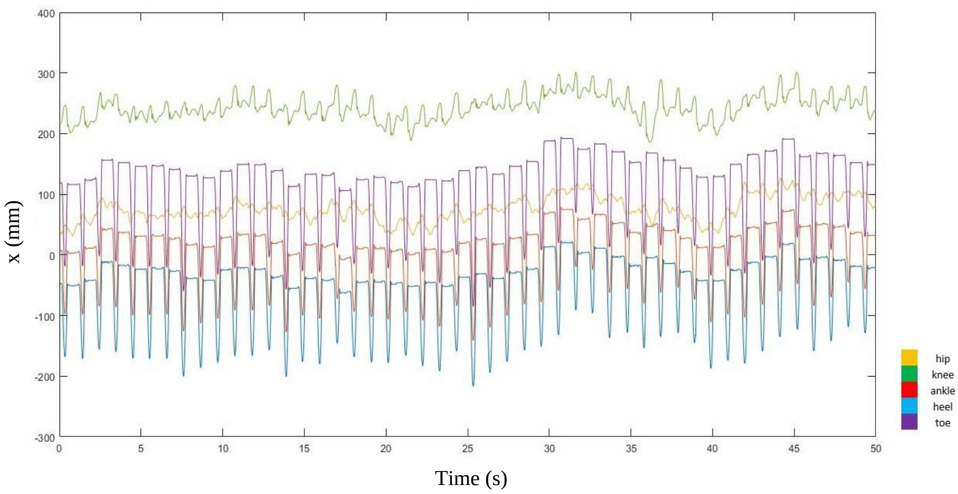
The study results started by carrying out the kinematic parameters at the starting condition of the marching movement. Evaluating the spatiotemporal parameters during the marching movement, the cadence of the subject was equivalent to the tempo of the marching song at 115 steps per minute with a cycle time of around 1.04 seconds for each foot. It was found in Figure 4 that the swing time was approximately 0.31 seconds between the dash-dot gray line, which made up 29.81% of the cycle time. The swing time parameter was much lower than normal gait movements that have a swing time of 38% of the cycle time [14].



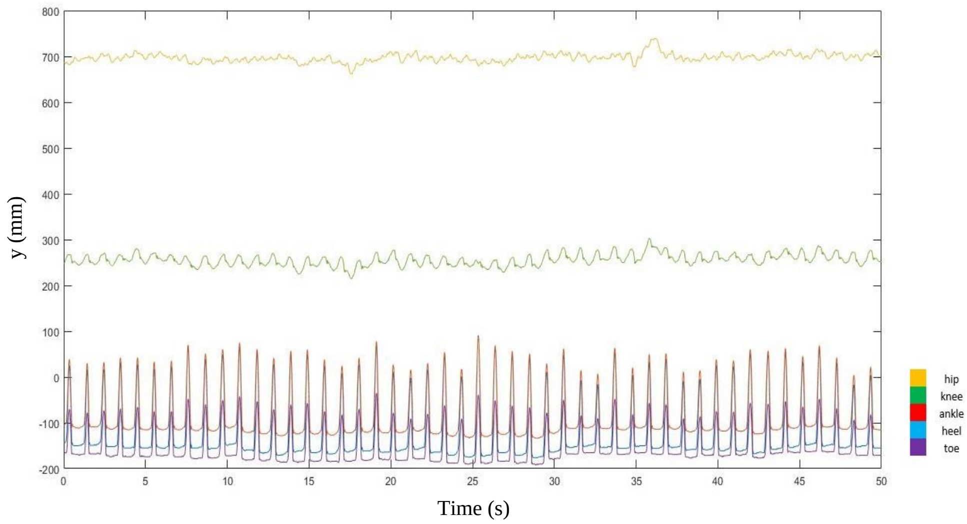
(a) (b)

Figure 4 The trajectories of the markers along the x (a) and y (b) axis overtime during the first cycle.

Neglecting the marker drift along the x-axis, the first cycle of the march affects the position drift of the body landmarks during the movements. The landmarks drift was indicated by vertical marker drift from 600 mm to 622 mm of the hip marker and 253 mm to 248 mm of the knee marker as shown in Figure 4b, it also shows that the vertical ROM of the ankle landmarks was around 150 mm during the initiation of the movement. By plotting the trajectories of the markers on the second cycle of the song, approximately at 60 to 110 seconds during the set of movements, the body position considered becomes steady, this condition was then plotted in Figure 5a at 60 to 110 seconds time frames during the set of marching movements. Figure 5a shows that the variability in the horizontal direction was inevitable since there was no restriction to the subject's movement in the frontal directions. Moreover, in the vertical direction, the variability is considered low by examining Figure 5, where the average of the hip and knee marker's positions remains similar.



(a)



(b)

Figure 5 (a) The trajectories of markers along the x and (b) y-axis during steady condition.

The kinematic parameters of the subject's marching movement were evaluated at two different times. During the first set of the marching (0 to 60 seconds), the average position of the hip is (122.07, 728.95) mm, and during the second cycle of the marching, the average position of the hip drifted to (76.32, 808.86) mm. This shows that the body position changed during the first marching cycle and settled during the second cycle which is considered as the subject body's best form or steady condition. This condition showed the hip joint settles at a higher level (increasing 79.91 mm) than the starting position.

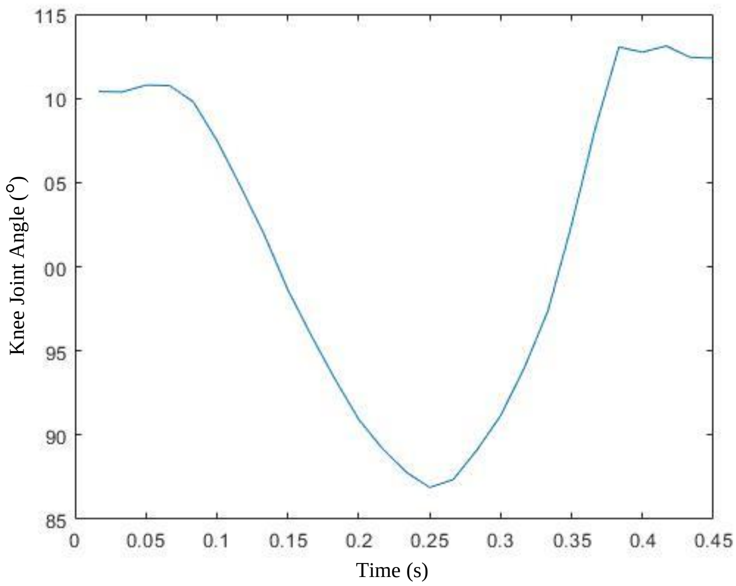


Figure 6 The relative angle of the knee joint during the first cycle of motion.

The relative angle of the knee joint of the subject was also evaluated as shown in Figure 6 for the data during the first sequence of *derap* in the first cycle of the marching song. The relative angle of the knee was around 110.57° with a maximum value of 113.74° and 26.55° range of motion (ROM) at the beginning of the movement.

From Figure 7, it was observed that the relative angle maximum value of the knee joint has increased to around 130° during the second marching cycle. This confirmed that the knee joint angle adjusted from a maximum value of 113.74° with 26.55° of ROM to 130° of maximum value with 15° of ROM while reaching the steady condition as the hip vertical position increases. The ROM of the knee angle parameter of marching movement was smaller compared to normal gait which has 50° of ROM at knee flexion-extension. The difference in the knee angle ROM values will affect the difference in hip position but not the vertical position and acceleration of the ankle landmark as shown in Figure 8.

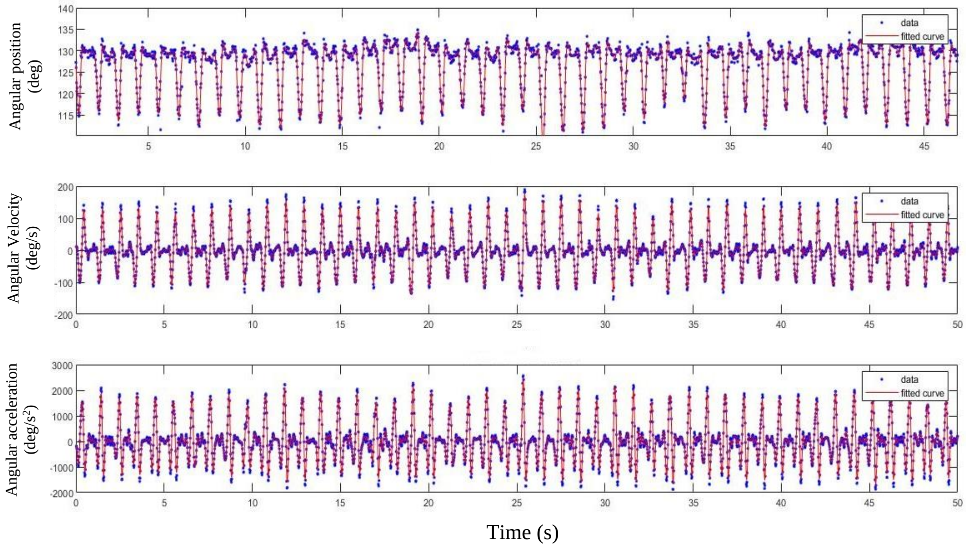


Figure 7 The angular kinematics parameters of knee marker during the steady condition.

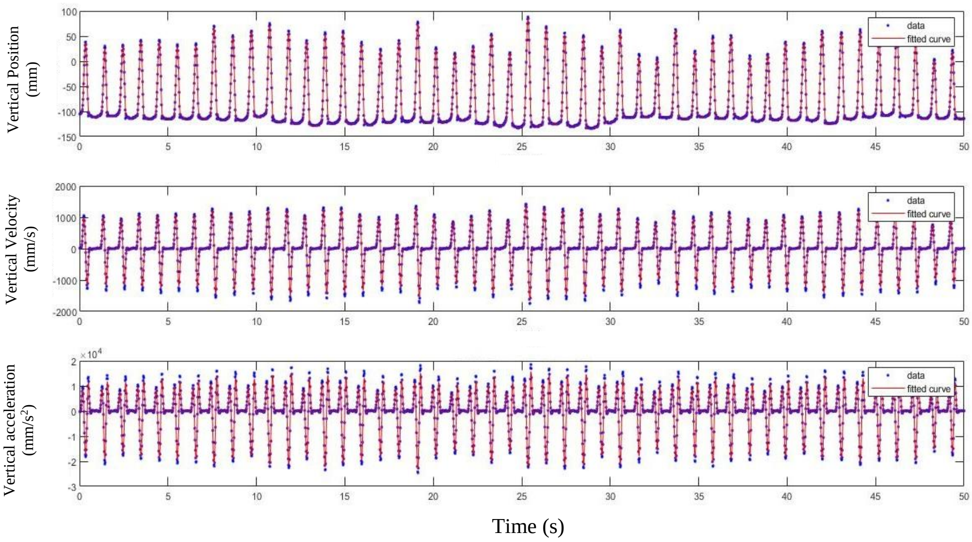


Figure 8 The linear kinematics parameters on the vertical direction of the ankle marker during the steady condition.

The third marker of the subject located on the ankle was analyzed and observed the vertical position, velocity, and acceleration of the marker in Figure 8. It was found that the vertical ROM of the ankle remains the same as the initial position of the movements at around 150 mm. Furthermore, the ankle vertical acceleration data was compared to the recent studies of gait [15], where the control subject has -8 m/s^2 to 7 m/s^2 of vertical acceleration during the walking movement. This gave us evidence that the marching movement conducted in this study exerted higher vertical acceleration in the ankle joint for around -20 m/s^2 to 15 m/s^2 on steady conditions. This acceleration gave higher impulse to the feet when the sole of the feet touches the ground [16]. Since the high impact is inevitable regarding the governing rule of *derap* movement, thus, it is normal that this movement is observed to have a more extreme value of ankle vertical acceleration.

Due to the fact that this movement has a different stance and swing time, knee flexion-extension ROM, and vertical ankle acceleration than the normal gait, this marching movement must be distinguished from the gait classification and analyzed independently. Moreover, by evaluating the whole data of the steady condition, the authors may say that the lower hip position and larger knee angle ROM do not correlate with the amount of acceleration. Otherwise, the attitude of the knee joints is the main factor that would affect the marching effort. A more flexed attitude of the knee joint would need more effort to be done a march cycle and would affect a larger drift of hip position.

4 Conclusion

This study proves that inconsistencies in marching movement did occur, and the body tends to find its comfort form which the authors stated as a steady condition. During the marching movement, the body form change was easily seen from the change of hip position in the vertical direction. Then, it was evaluated that the knee angle ROM of the subject decreased from 26.55° to around 15°. This marching movement requires two times of marching song periods to acquire a steady condition from the beginning of the movement.

This study proved that there would be a variation of height drift during *derap* that is shown by hip position. The body became steady during the second cycle of the marching song. Compared to the previous cycle, the height has increased from the starting position (about 79.1 mm). It is recommended to give more extension to the knee at the starting position of the movement for this specific subject to put the marching movement on lower effort.

During *derap*, the subject has to stomp to generate a loud sound. The force given to the floor would affect the variation of height and relative angle as the authors suspect by evaluating the acceleration that happened on the ankle joint. It was found that there is no corresponding relation between ankle vertical acceleration to the marching effort, otherwise, knee joint attitude may affect marching effort since it was found drifting from the initial state to the steady condition. Further study is needed to obtain the relation between the ground reaction force to the landmarks' vertical kinematic parameters and the angular kinematic parameters variations during *derap* movement. In a further study, various subjects must be conducted to get more data covering classes of gender, body height, and body mass index (BMI).

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