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# Evaluation of the Performance of Digital Video Analysis of Human Motion: Dartfish Tracking System

Moataz Eltoukhy, Shihab Asfour, Craig Thompson, Loren Latta

**Abstract**—Motion capture has been used to analyze various aspects of human motion. There are two basic approaches to analyze motion, two dimensional and three dimensional. These approaches are often supplemented with the use of computer packages in order to handle complex calculations. The research performed attempted to determine whether a modest, portable motion analysis tool can provide results comparable to those obtained using 3D motion capturing system (Vicon) during a simple motion. The 2D software under investigation is called Dartfish which uses digital video as input and is able to generate values for the location of markers in two dimensions. It was found that the magnitudes of the differences in the markers' trajectories between Dartfish and Vicon were about ± 5 mm. Based on the statistical analysis, it was concluded that this 2D method has serious potential for future studies that involves more complex movements.

**Index Terms**— Digital video, human motion, Dartfish, Tracking. .

## 1 Introduction

MOTION capture has been used to analyze various aspects of human motion. The focus of the measurement depends on the context of the motion capture. For instance, a surgeon may want to compare the pre-surgical motion of a joint or a limb to the post-surgical motion

There are two basic approaches to analyze motion, two dimensional (2D) analyses and three dimensional (3D) analyses. The 3D system uses multiple cameras to track reflective markers attached to the body. 3D systems are considered to be accurate for motion analysis, but tend to be expensive and difficult to use for the average person. Some applications of 2D video based systems can capture the video with an inexpensive off the shelf camera. This video can be streamed instantly or loaded on a computer at a later time for analysis.

If a 2D video can be analyzed, and if the data are validated by an accepted laboratory model, this model can be widely used and adopted for many innovative purposes. The data can be used to make informed decisions that can improve the treatment of a patient. Athletic performance can be analyzed, refined and potentially mastered. Proper form and technique can be taught by coaches through use of tools that are readily available, a computer and a video camera.

Attempts have been made to provide an affordable and intelligent sports training system that will require only a single stationary camera to record the motion of a subject. Wang et al. (2008) set out to examine the performance of such a system compared to a 3D motion based analysis tool.

The research performed attempted to determine whether a modest, portable 2D motion analysis tool can provide results comparable to those obtained using state of the art 3D motion capturing system during a simple motion.

The 2D software under investigation is called Dartfish Pro-Suite 5.5 (Dartfish) which uses digital video as input and is able to generate values for the location of markers in two dimensions.

In this work Dartfish generated data were compared to Vicon generated data and the differences were discussed. In addition to marker positions, knee joint angle, knee joint moment, ankle joint angle and ankle joint moment were also compared as generated separately by the two systems.

Although Dartfish is in widespread use, no studies quantifying software performance when compared to a gold standard have been conducted.

There is no intervention to the subject unless markers are placed on them. The makers used in Dartfish do not have to be specialized; they simply must be of a different color than the background.

## 2 Methodology

The goal is to prove that Dartfish can provide, with reasonable accuracy and precision, the location of markers in a controlled laboratory setting. If it is established as a reasonable tool to examine simple planar motion, it paves the way for expansion and uses in other applications.

During simultaneous capture of digital video and infrared three dimensional data from Vicon a comparison will be made for the simple squat motion. In other words data will be generated by Vicon and also independently of Vicon using Dartfish to process digital video acquired during the motion capture. This will reveal how the two systems differ with regard


- *Moataz Eltoukhy is a postdoctoral associate in industrial engineering in University of Miami, USA. E-mail: meltoukhy@gmail.com*
- *Shihab Asfour is a professor and the associate dean of the college of engineering in University of Miami, USA. E-mail: sasfour @miami.edu*
- *Craig Thompson earned his M.S. degree in industrial engineering in University of Miami, USA. E-mail: craigthompson305@gmail.com*
- *Loren Latta is a professor in the department of orthopaedics, Miller School of Medicine, University of Miami, USA. E-mail: LLatta@med.miami.edu*

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to data generation when measuring the same subject performing the same motion at the same time.

The squat is relatively simple planar activity where the major motion occurs in two dimensions. The software is used to generate X and Y components of marker location in the sagittal plane. Anatomical measurements can provide the depth component or marker depth in the coronal plane if an estimate is necessary.

The marker's position is measured in reference to the origin set. The magnitude of the distance traveled in the X or Y direction is calculated based on a reference distance set by the user. This reference distance is specified in the video using a segment attributed to a known length of an object in the video that is in the plane of motion (Fig.1).

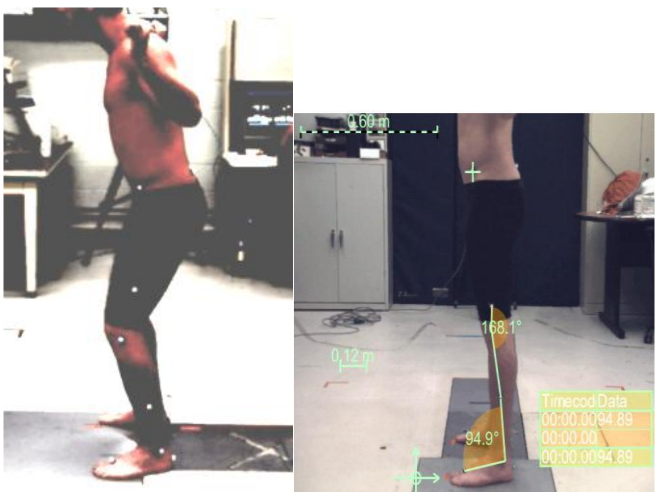


Fig. 1. Snapshot of Dartfish ProSuite 5.5 video Analyzer

### 3.1 Set Up

The University of Miami Biomechanics Research Laboratory contains Vicon Motion Technology equipment.The hardware for the system includes:
(1) 10 Vicon MXF40 infrared cameras (MX cameras)
(2) 4 Basler A602fc digital video cameras (DV cameras)
(3) Vicon MX Ultranet HD to synchroniz the MX and DV cameras.

The subject is dressed in compression shorts that fit tightly to the body. The reflective markers are placed on the body according to the lower body plug-in-gait model. The model consists of 16 markers: LASI, RASI, LPSI, RPSI, RTHI, LTHI, RKNE, LKNE, RTIB, LTIB, RANK, LANK, RHEE, LHEE, RTOE and LTOE. The entire Plug-in-Gait marker set can be found in Figure 2.

The lower extrimety model that utilizes sixteen markers placed in various locations from the hip bones down to the feet can be found in Figure 3. Anthropometric measurements of the subject are taken such as height, mass, etc.

### 3.4 Data Collection

The frame rate of the Vicon system cameras was set at 60 frames per second to coincide with the Dartfish rate of 60 frames per second. All cameras were synchronized to the system via the same sync signal that is sent out by the Ultranet HD device. This ensures that when the trial is initiated the digital video and the infrared video are operating simultaneously and have the same time stamp associated with the same frame. This allows one frame of Vicon data to also have, at the same instant in time, a Dartfish associated paired measurement.

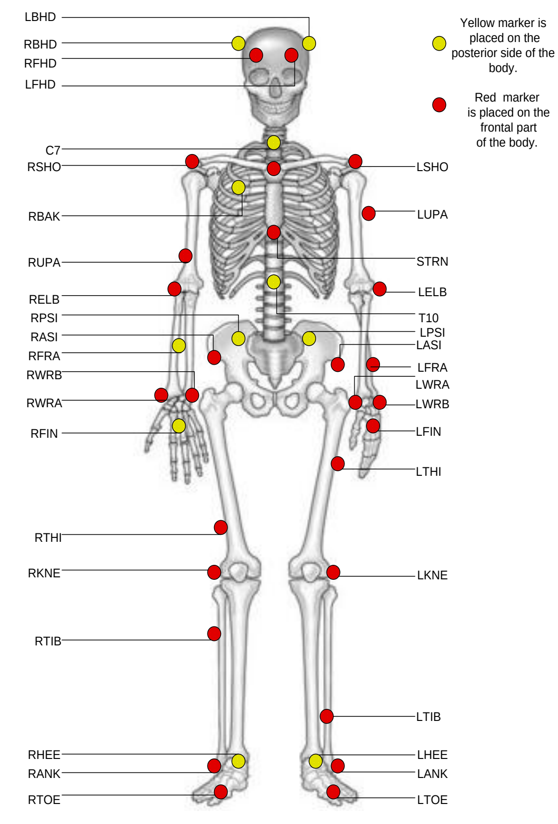


Fig. 2. Full Plug-in-Gait marker set

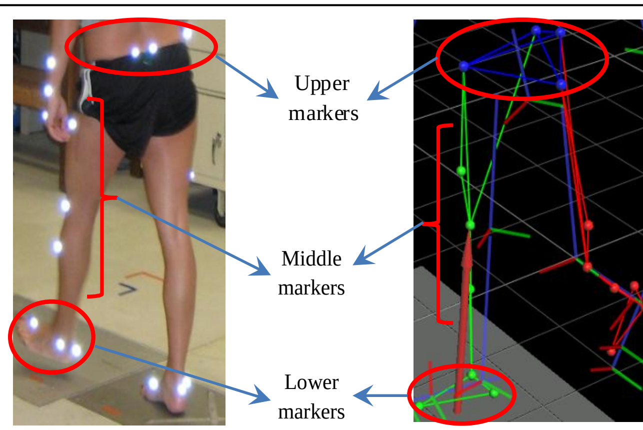


Fig. 3. Markers subsets.

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The Vicon data was processes in the NEXUS software package to reconstruct the motion in three dimensions. This is a widely accepted method for performing motion analysis as stated in many papers including Barker et al (Barker et al. 2006). Dartfish ProSuite 5.5 was used to extract data for each marker, and recorded these values via tables. After the position data were collected of each marker in the horizontal and vertical directions, the knee joint and ankle joint angles were determined using the marker tracking capability on three markers. One marker was tracked as the apex of the angle and one marker was tracked for each of the two legs of the angle. A developed macro was used to create equations for the knee and joint angles with time.

The next step in processing the marker data was to code a program to calculate knee and ankle joint moments in MATLAB R2010b (Matlab). The equations for marker position and joint angles were input to Matlab, and the appropriate derivations to get velocity and acceleration equations were performed. The equations for moments were taken from (Winter, 1990).

## 4 Statistical Analysis

The presented work yielded two sets of data with the same number of points, one from the three dimensional Vicon system and one from the two dimensional analysis tool Dartfish ProSuite 5.5.

The null hypothesis was that the rudimentary calculations made with Dartfish positional data will be statistically different from the Vicon three dimensional reconstructions for a simple squatting motion with an alpha of 0.05. Paired t-tests on the data were conducted. In the study pertaining to comparing data generated by the two motion capture systems, Vicon and Dartfish, the sample size was, N=187.

The null hypothesis was rejected in 38 out of 40 tests, and the tests failed to reject the hypothesis in the other two cases. The parameters in which the test failed to reject the null hypothesis were the right knee horizontal component and the left heel vertical component (Tables 1 and 2).

## 5 Results and Discussion

The magnitudes of the differences in marker positions between the two systems were between -10 and 20 mm overall. The magnitude of the relative difference between the markers tends to remain closer to a certain value and fluctuate above and below that value.

In other words if at time 0 a marker is offset by 15 mm, the difference between the two systems will be between 15 plus or minus 5 mm. It was much higher for some markers such as the LPSI marker which was approximately offset at time 0 by 5mm and the difference was plus or minus 10 mm.

The magnitude of the differences in marker positions of the two systems was smaller in the horizontal direction in general. The magnitudes of the differences are roughly plus or minus 5 mm. There could be multiple reasons for this.

### 5.1 Upper Markers Trajectories Horizontal Component Differences

Figure 4 shows the horizontal component of the upper marker subset. In general, the hip markers travel at higher speed and over larger distances than the other markers. The lines on this graph seem to reflect the same magnitude of difference on both sides. The values obtained from the camera view and video of the right side are centered on the zero line, whereas the values obtained from the left camera view are shifted below the zero line. With the origin at the edge of the force plate, the hip markers are far from it throughout the squat in the vertical but are close to crossing it in the horizontal component.

TABLE 1
Paired t-test P-values generated for marker positions with Minitab

| Mraker | P-Value | Mraker | P-Value |
|---|---|---|---|
| LASI Y | 0.000 | LHEE Y | 0.000 |
| LASI Z | 0.000 | LHEE Z | 0.175 |
| RASI Y | 0.000 | LTOE Y | 0.000 |
| RASI Z | 0.000 | LTOE Z | 0.000 |
| LPSI Y | 0.000 | RTHI Y | 0.000 |
| LPSI Z | 0.000 | RTHI Z | 0.000 |
| RPSI Y | 0.000 | RKNE Y | 0.340 |
| RPSI Z | 0.000 | RKNE Z | 0.000 |
| LTHI Y | 0.000 | RTIB Y | 0.000 |
| LTHI Z | 0.000 | RTIB Z | 0.005 |
| LKNE Y | 0.000 | RANK Y | 0.000 |
| LKNE Z | 0.000 | RANK Z | 0.000 |
| LTIB Y | 0.000 | RHEE Y | 0.000 |
| LTIB Z | 0.000 | RHEE Z | 0.000 |
| LANK Y | 0.000 | RTOE Y | 0.000 |
| LANK Z | 0.000 | RTOE Z | 0.000 |

TABLE 2
Paired t-test P-values and confidence intervals generated for joint angles and moments with Minitab

| Joint Angle or Moment | P-Value |
|---|---|
| Left Knee Angle | 0.000 |
| Right Knee Angle | 0.000 |
| Left Knee Moment | 0.000 |
| Right Knee Moment | 0.000 |

### 5.2 Middle Markers Trajectories Horizontal Component Differences

Figure 5 shows the horizontal component differences in mm of the middle markers. The middle markers are the thigh, knee and tibia markers. The left side markers are almost entirely shifted below the zero line, and the right side markers are almost entirely shifted above the zero line.

In most of the examinations of the differences it appears that the reference distance and origin play a huge role in the generation of data. There seems to be a distinct difference in the left and right data as generated by the different videos, and they seem to be grouped with each other somewhat.

### 5.3 Lower Markers Trajectories Horizontal Component Differences

The lower markers include the ankle, heel and toe markers. These markers remained essentially motionless throughout the squat motion (Fig.6). During the Dartfish tracking it was noticed that the software would attempt to follow a moving marker even if the marker was not moving. In other words the Dartfish tracking would float around the tracked region possibly to test for changes in the contrast.

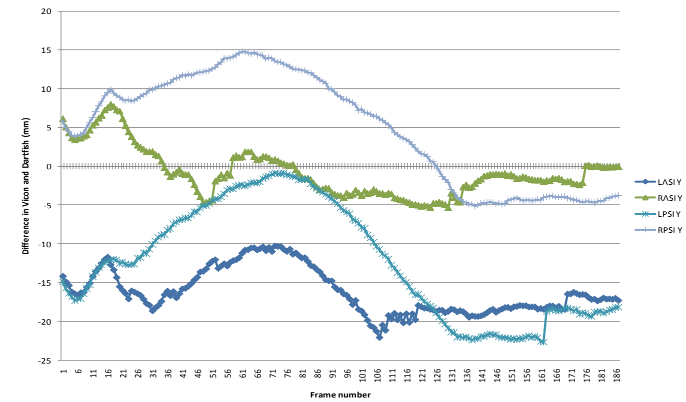


Fig. 4. Difference in mm between measurements made by Dartfish and Vicon motion systems.

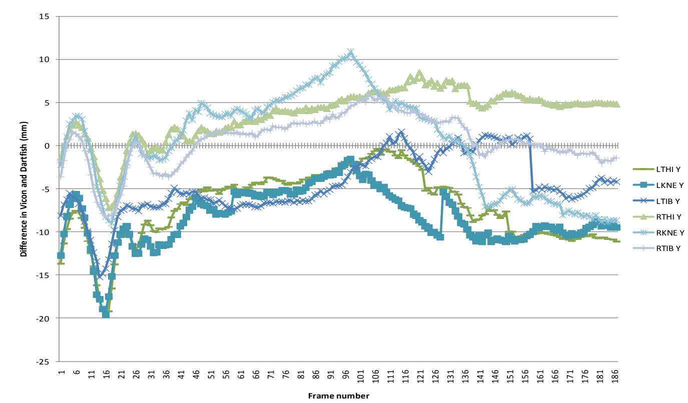


Fig. 5. Difference in mm between measurements made by Dartfish and Vicon motion systems.

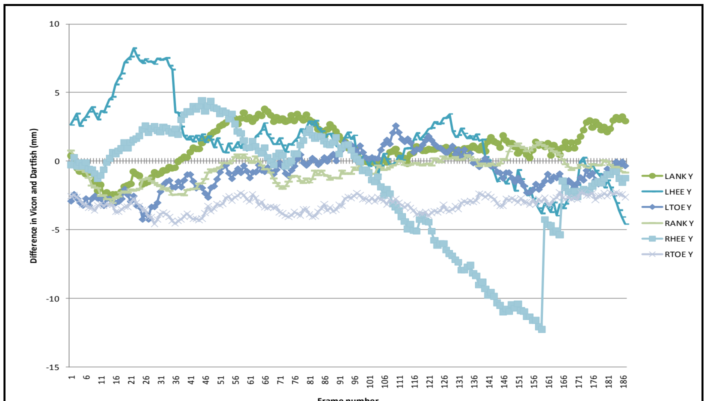


Fig. 6. Difference in mm between measurements made by Dartfish and Vicon motion systems.

## 5.4 Knee Joint Angles

The right knee angle averages 4.7% difference between the Dartfish and Vicon systems. The left knee angle has an average value of 6.9% for the percentage difference between the angle measurement techniques (Figure 7). Differences in the way that the two systems measure joint angles will be discussed later. The differences are minor in the case of the knee angles but are drastic in the case of the ankle angles (Figure 8).

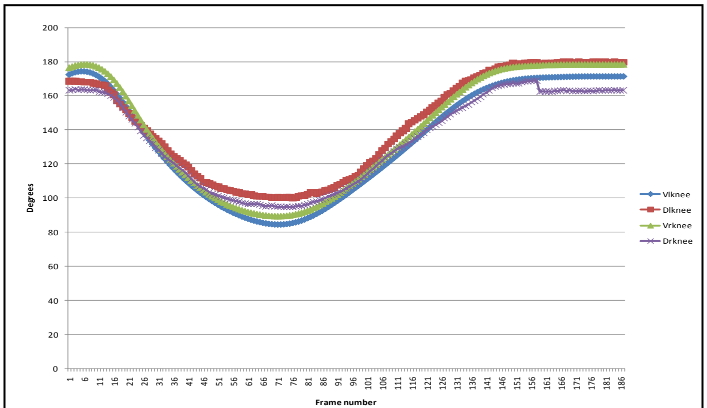


Fig. 7. Values for left and right knee joint angles measured by the two systems.

## 5.5 Ankle Joint Angles

At first glance on Fig. 8, one would assume that the values for ankle angle are way off. This comes down again to the way in which the two systems measure the angle. The left ankle angle differed between the two systems by an average of 13.1%. The right ankle angle differed as measured by the two systems by a rather large 19.1%. It appears that both ankle angles are offset by approximately 12 degrees, with the Vicon angle being about 12 degrees more narrow. In measuring the angles with Dartfish, the user must track 3 markers simultaneously; the error involved in tracking one marker will be multiplied across 3 markers.

When examining the angles for knee and ankle it appears that the values are typically within plus or minus 10 degrees.

Comparing the joint angles between the two systems was not a straightforward task. In Vicon Nexus will take all of the marker data and process it with an internal model.

Basically the internal model will generate positions of limb segments and then find the angle between these segments, which are reported as joint angles.

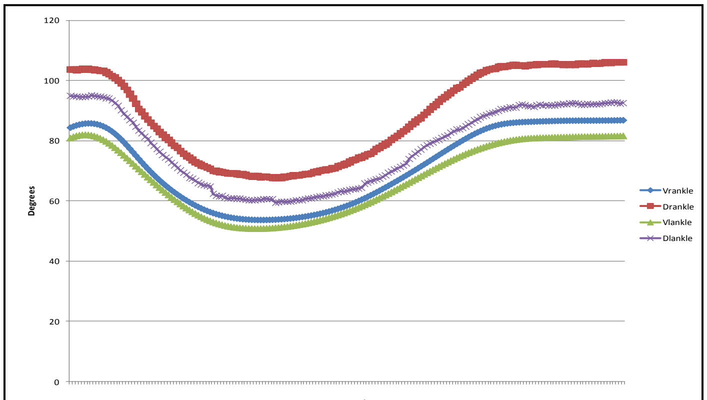


Fig. 8. Values for left and right ankle joint angles measured by the two systems

For instance using the toe, ankle and heel markers a segment location is found for the foot (Fig.9). The tibia, knee and thigh markers are used to create a segment location for the shank and thigh. The ankle angle is then calculated as the angle between the foot segment and the shank segment. On the other hand, in Dartfish the angle is measured from the toe marker, ankle marker and tibia marker, not through the segments.

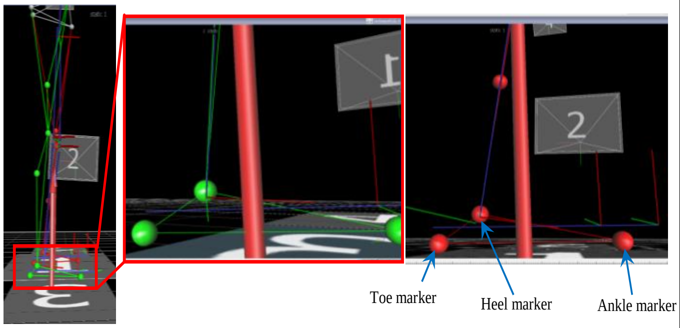


Fig. 9. Right and left ankle angle viewed in Nexus with Vicon marker positions and Vicon limb segments

### 5.6 Ankle and Knee Moments

Figures 10 and 11 deoicts ankle and knee moments respectivley, comparing the two motion capturing systems studied.

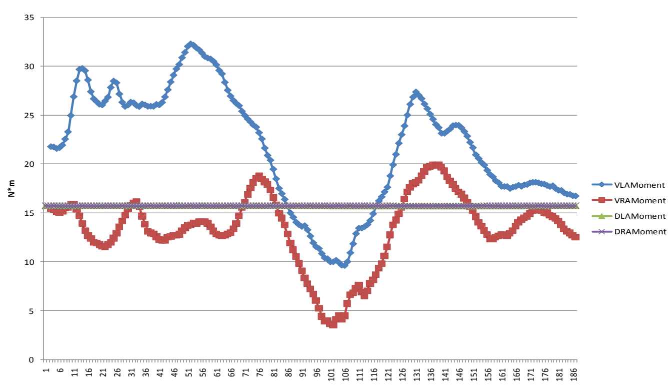


Fig. 10. Ankle moments measured with Vicon and calculated with Matlab

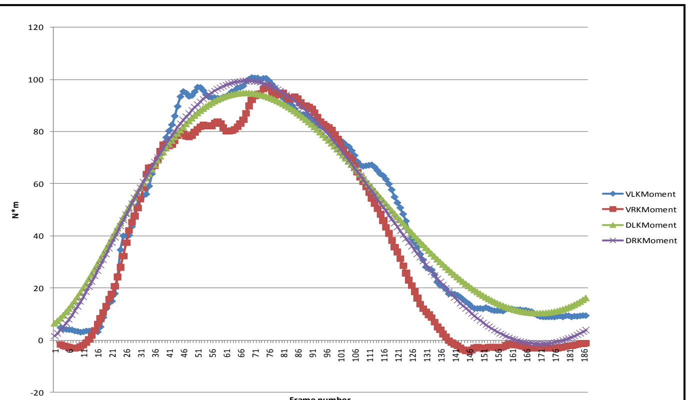


Fig. 11. Knee moments measured with Vicon and calculated with Matlab

### 5.7 Moment Comparisons

This is one of the most interesting aspects of this study. Vicon generates values for joint moments using force plate data when the force plates are active. When the force plates are not active it is claimed that the system uses mathematical equations from Winter (1990). Some interesting points will be explored as it relates to Vicon and its moment values.

In order to calculate moments from Dartfish data a few assumptions were made. The first assumption is that the ground reaction force was applied 4 cm anterior to the ankle joint and did not move. In reality the joint reaction force will move based on the center of gravity of the subject during the motion. The second assumption made was that the reaction force was distributed evenly between the two legs.

In reality this was not the case and weight can shift from side to side to a certain degree which will have change the moments on each leg. Even though the reaction force was split between the two legs evenly, the moments were not equal. They were calculated based on the marker location, acceleration, angular acceleration and other data generated with Dartfish.

In order to calculate the moments about the ends of the segments, the center of mass of the segments must be used. Based on anthropometric tables the center of mass of the shank for example, is 0.433 from the proximal end (Winter 1990).

Using the Dartfish marker data, equations for the position of the center of masses of the needed segments were developed. Using these equations in conjunction with the angle equations, the subsequent derivations of the position equations, values were obtained for ankle and knee moments.

From Figure 12, it can be noted that the moments differ by as much as 27 N*m in the worst case as exhibited by the left knee moment. The value for the right ankle moment never differed from the Vicon generated value using force plates by more than 12 N*m.

It looks as though the equations used from (Winter, 1990) yielded rather good results for ankle moment. The source of variation between these measurements is not in the angle value (i.e. angular acceleration of the foot) which has a small effect on the joint moment. The source of variation is from the movement of the ground reaction force.

As the ground reaction force moves toward the ankle joint,

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as shown in Figure 13 during the squat the moment arm is reduced, and therefore the ankle moment is reduced. This could be remedied with the use of a floating ground reaction force model based on tracking of the subject center of mass.

In order to examine the assumption that the ground reaction force is stationary, change in the ground reaction force with time according to Vicon was examined.

This was done by first looking at the standing subject and the location of the ground reaction force (Fig.13.a). It looks as if the assumption of the ground reaction force at 4 cm anterior to the ankle joint was spot on. However during the midpoint of the squat, the ground reaction force is in a different location (Fig.13.b). From the figure one can see that the ground reaction force is located much closer, about 1 cm in front of the ankle joint.

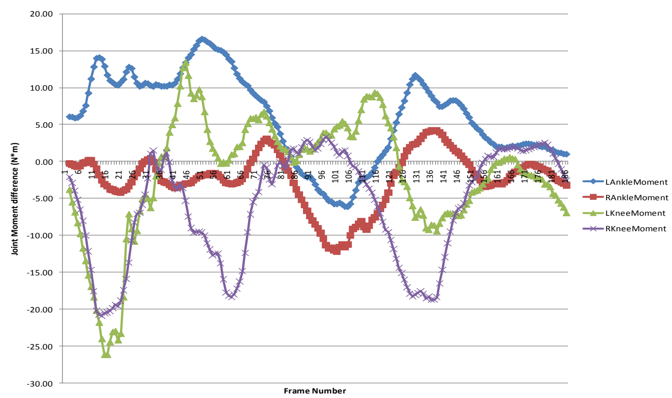


Fig. 12. Difference in N*m between moment values generated by Dartfish and Vicon motion systems.

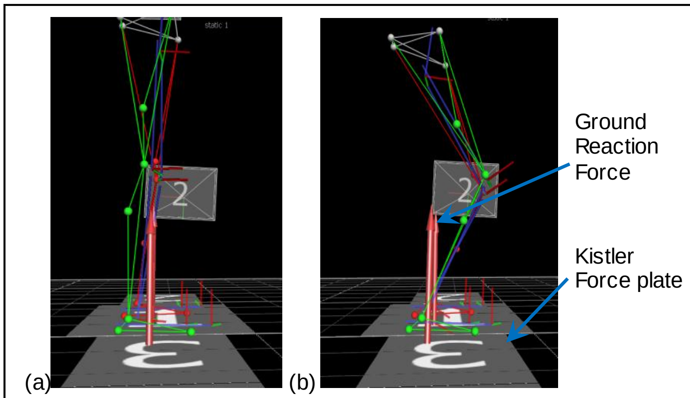


Fig. 13. (a) Location of ground reaction force as measured by Vicon standing.(b) Location of the ground reaction force during the squat motion, it is closer to the ankle joint.

## 6 Conclusions

It was concluded that this method has serious potential. The moment calculations were rather close to the 3D motion capturing system (Vicon) measured values.

There are a lot of estimations involved with the current method for moment calculation, and in future work some of these estimations should be directly measured. This would be the case with the center of mass.

It is likely that Dartfish could generate higher quality values if the amount of markers tracked is minimized. Only markers that will be used to describe motion should be tracked. Markers could be directly placed on the center of mass locations for the limb segments. This would give direct measurements for center of mass location instead of relying on mathematical methods applied using the difference of two points. Using two tracked points will increase the amount of error associated with marker tracking.

Finally, the overall center of mass of the subject should be tracked. This can be done by tracking the center of mass of the limbs and the head and torso. Anthropometric measurements can be used and programmed so that calculation for estimation of the overall center of mass is possible. This way an equation for a floating reaction force could be developed that would be less of an approximation than the currently coded moment equations. This technique may be developed and possibly explored examining more complex movemens.

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