Cost Efficient Gait Analysis Using Lasers

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Abstract

Gait analysis is the methodic measurement, description and evaluation of factors that affect human locomotion. It can be used for rehabilitation purposes, for optimizing sport results and lower risks of injury and as a diagnostic tool for neurological diseases, example given Parkinson. Hitherto, there are many precise methods of doing gait analysis. However, expensive equipment is often required, otherwise the only option is visual analysis, which is less reliable. This study will construct an inexpensive method to analyze gait, that is both reliable and portable. One laser was attached to each shoulder and two on a helmet put on the subjects' heads. The lasers formed a formation of laser dots on the ceiling. The test subjects walked on a treadmill, which caused the laser dots to move. These were recorded with a camera. The video sequences were then analyzed with a program written in MATLAB. The results showed the laser movement, as intended. By analysing the laser movement in different walking conditions, for example with different shoes, it was shown in this study that they differed and the method could be useful to compare gait. However, further research needs to be undertaken in order to confirm these findings.

Introduction

Biomechanics is an increasingly well-known field of research, which takes a mechanical approach to the human body. As a combination between mechanics and biology, it can help increase our knowledge in orthopaedics and ergonomics, but also in other areas such as rehabilitation and sports [4, 5, 7].

An important sub-field of biomechanics is gait analysis which is the methodical measurement, description and evaluation of factors that affect human locomotion [1, 6]. The invention of the camera made it possible to investigate human bipedal locomotion more accurately. However, this early technique required the pictures to be analyzed frame by frame, which was ineffecient and time-consuming. As technology developed and computers enabled faster analysis, gait analysis became more efficient [2, 6].

Using clinical gait analysis, joint disabilities and some neurological diseases like Parkinson can be discovered and evaluated in an early stage [2, 4, 6]. Gait analysis can also be used to identify individuals, for example, in recorded security footage after a crime scene. This identifying type of gait analysis is called biometric gait analysis [4, 9].

A common method in motion analysis is tracking. There are many forms of tracking, where the common denominator is video analysis. Tracking is often divided into three steps when analysing videos. First, the moving objects of interest are detected, then these are tracked one frame at a time, and at last these tracks get analyzed to identify their behaviour or inconsistent movements [8]. Tracking is a useful tool when analysing gait, since gait is a complex motion needed to be investigated, divided into as small parts as possible.

Hitherto, there are many precise methods of gait analysis. The problem with these are that they are either too expensive and need special laboratories for analysis, which results in both economical and practical disadvantages, or inexpensive, but based on only visual analysis and therefore are more unreliable [3, 5, 6]. In this study, a new, less expensive and portable method, based on tracking the motion patterns of laser diodes attached to the body, is tested and evaluated to find differences of the gait of the individual.

Method

In this study the gait is analyzed by filming the movement of lasers, attached to a walking person. The gait is subsequently analyzed with MATLAB to see whether there are differences between locomotion that can be examined with lasers as help.

Four lasers were mounted on the test subject – two on the head and one on each shoulder. The lasers on the head were mounted on a helmet, one at the front above the forehead and one at the back above the neck. The lasers formed a formation of four laser dots in the ceiling. The ceiling used had to be as flat as possible to minimize errors. It was also important that the test subject kept his head as straight forward as possible when walking on the treadmill, so that the central dots did not twist. The camera used was a GoPro HDhero. The experiment was performed in a dark room for optimizing the contrast between the laser dots and the surroundings. The test subject walked on a treadmill with closed eyes because it made the gait more natural. Some different walking conditions were tested, so data from different circumstances could be analyzed. The different walking conditions were:

- Walking barefoot
- Walking with running shoes (Adidas Supernova)
- Walking with toe-shoe (FILA skele-toes 2.0)
- Walking with a fixed right or left knee
- Walking with a fixed back
- With right shoe on and left shoe off vice versa

The fixed knee, the fixed back and the walking with one shoe aimed to simulate different injuries: the fixed knee simulated knee pain, the fixed back simulated back problems and the walking with one shoe simulated one kind of limping. The pace was set on the treadmill to 3 km/h.

The recorded video sequences were analyzed with MATLAB. A program was written that first finds colour differences in the video. That was the reason for having a high contrast difference between the dots and the surroundings. By finding the colour differences, the red laser dots were found. The dots then got coordinates in each frame. Their movement were found by finding the nearest coordinate in the next video frame, etcetera. This formed the movement of the laser dots in a graph. This method was then repeated.

Results

The laser dots should, on a healthy person, move in a cyclic pattern since gait is a cyclic movement. The graphs plotted show the coordinate movement of the laser dots. If the dot moved in a circle, for example, the graph shows a circle. Figure 1-6 show the lasers movement in the tested walking conditions. The upper left curve in each graph represents the motion of the laser attached to the left shoulder. The upper right curve represents the motion of the laser attached to the right shoulder. The upper central curve represents the motion of the laser attached to the front of the helmet and the lower central curve represents the motion of the laser attached to the back of the helmet.

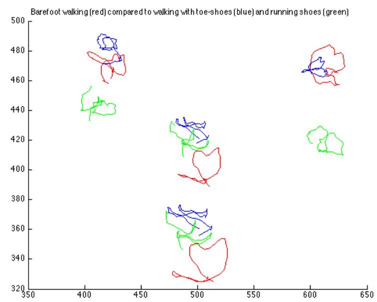

Figure 1: Walking barefoot compared to walking with different shoes on

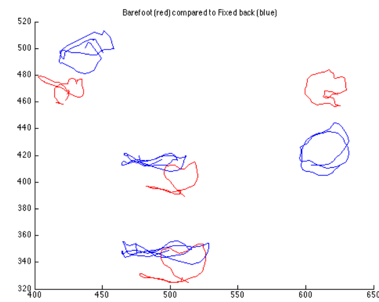

Figure 2: Walking barefoot compared to walking with a fixed back

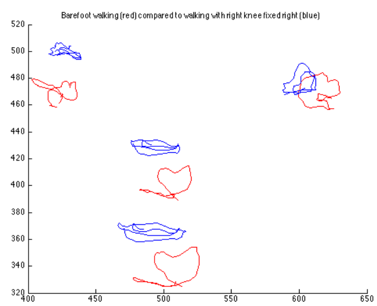

Figure 3: Walking barefoot compared to walking with a fixed right knee

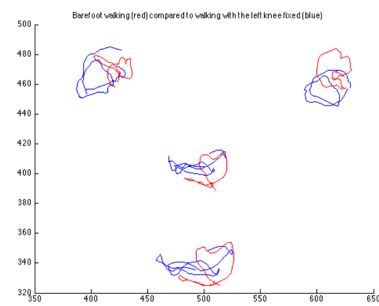

Figure 4: Walking barefoot compared to walking with a fixed left knee

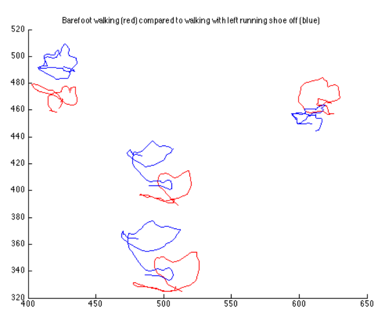

Figure 5: Walking barefoot compared to walking with left shoe off

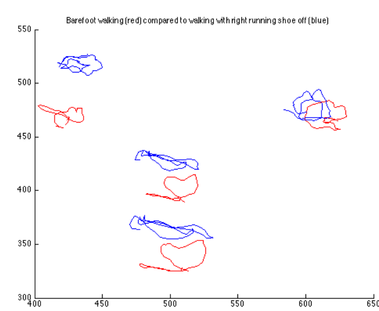

Figure 6: Walking barefoot compared to walking with right shoe off

Discussion

Motion is very difficult to analyze since there are many stages where information can be lost. For example, information gets lost because of the complexity of the human gait and changes in the surroundings. In this study, this occurs as the tested subjects have different proportions between shoulders and heads, different heights, different lengths of steps, etcetera. [8].

It can be seen in figure 1-6 that differences exist between the different walking conditions. It is although difficult to make reliable conclusions of what these differences mean since this is a novel method and no standard data to compare with exists. Too few test subjects have been tested and analyzed.

Some pattern can be seen however. Figure 3 respective 4, show that the area of the movement of the lasers is bigger above the fixed knee than above the other knee. This could indicate that the body weight is not balanced when a knee is fixed and that the torso tilts, which changes the slope gradient of the laser and therefore the movement area on the ceiling. This pattern is an indication of that this method could work. Even though a pattern can be seen, it is not certain if it is correct since not enough data has been collected.

This method could be used in clinical studies if more standard data was collected. Differences in different gait conditions can be seen, and if more data is collected from different persons with different irregularities would this method be very usable to analyze and compare gait with, even if it would not be as precise as the expensive analysis made with expensive equipment.

Our method would be a low-cost alternative for gait analysis that could be used in clinics with a restricted budget and in clinics that have no motion analysis laboratory. It is therefore incredibly important to improve it, and make it more reliable. To make this method reliable, more data has to be collected. Some major sources of errors have to be eliminated.

One error is that it is difficult to stay in the exact same position when walking on a treadmill. It is therefore highly likely that the subject has moved either forwards or backwards on the treadmill, which changes the movement of the lasers. This is a major problem with this method, that can be solved with a treadmill that senses the walking velocity of the subjects and adjust its speed by that. This would increase the probability for the subject to stay in the same position during the experiment.

Another source of error is that the lasers attached to the shoulders could slide and slightly change position. This would also change the movement of the lasers and therefore make it more difficult to compare data. To avoid this, a special t-shirt where the lasers are fixed to the shoulders could be designed. This would make the distance between the lasers constant and give more reliable results.

Since this research was done with limited time, there was no time to make an automatic analysis. Therefore, visual analysis had to be made. In future research, automatic analysis should be made.

The conclusion is that differences can be seen between different gait conditions using this method. If this is just coincidences or if this is the case for every situation can only be seen when more subjects has been tested with an improved version of this method. This method is at this point not very reliable. More research has to be done to improve it, before using it in clinics. If improvements were made and the method would work, would the method have two major advantages: it is inexpensive and it is portable. These are the reasons why the method should be used in clinics. But first, the major sources of error must be eliminated and more data gathered to be able to compare and analyze different gait conditions, gait irregularities and gait patterns.

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A Matlab Gait Analysis Program

```
clear

obj = mmreader('name_of_file.avi');
lastFrame = read(obj, inf);
endFrame = get(obj, 'NumberOfFrames')

x_koordinater = zeros(endFrame, 4);
y_koordinater = zeros(endFrame, 4);

for n = 1:endFrame
one_frame = read(obj, [n n]);
red=one_frame(:,:,1);
red = red(1:540,:);
BW = red > 10;
se = strel('disk',10);
BW=imclose(BW, se);

if 1
%if (n >= 13) && (n<=15)
if (n == 13)
%if rem(n,25) == 0
  %figure(1)
  %imagesc(BW), title(num2str(n));
  %colormap(gray)
```

```
  %pause(1)
end
end

L = logical(BW);
s = regionprops(L, 'Area', 'Centroid');
areor = zeros(1,size(s,1));
centra = zeros(1,size(s,1));
%Uncomment to show the BW image
%imshow(BW);
%title('Binary Image');
%xlabel('x-coordinate')
%ylabel('y-coordinate')

%if size(s,1)<4, break, end

for kk = 1:size(s,1)
  areor(kk) = s(kk).Area;
  Xcentra(kk) = s(kk).Centroid(1);
  Ycentra(kk) = s(kk).Centroid(2);
end

[areor indx]=sort(areor, 2, 'descend');
Xcentra = Xcentra(indx);
Ycentra = Ycentra(indx);
```

```
x_koordinater(n, :) = [Xcentra(1) Xcentra(2) Xcentra(3) Xcentra(4)];
y_koordinater(n, :) = [Ycentra(1) Ycentra(2) Ycentra(3) Ycentra(4)];

end



%%%%%%%%%%%%%%%%%%%%%%
%x-coordinates
%%%%%%%%%%%%%%%%%%%%%%

xindx = zeros(endFrame, 4);
trackade_x = zeros(endFrame, 4);

xindx(1,:)= [1 2 3 4];
trackade_x(1,:)= x_koordinater(1,:);

for n = 2:endFrame
    for xnr = 1:4
     dx = abs(x_koordinater(n, xnr) - x_koordinater(n-1, :));
     dy = abs(y_koordinater(n, xnr) - y_koordinater(n-1, :));

     dx = sqrt(dx.^2 + dy.^2);

     [dx indx] = sort(dx);
     iinnddxx = find(xindx(n-1,:) == indx(1));
```

```
     %if isempty(iinnddxx), dx, indx, xindx(n-1,:), end

     xindx(n, iinnddxx(1)) = xnr;
     trackade_x(n, iinnddxx) = x_koordinater(n, xnr);
     trackade_y(n, iinnddxx) = y_koordinater(n, xnr);
    end
end


%%%%%%%%%%%%%%%%%%%%%%
%y-coordinates
%%%%%%%%%%%%%%%%%%%%%%


if 0

yindx = zeros(endFrame, 4);
trackade_y = zeros(endFrame, 4);

yindx(1,:)= [1 2 3 4];
trackade_y(1,:)= y_koordinater(1,:);

for n = 2:endFrame
    for ynr = 1:4
   dy = abs(y_koordinater(n, ynr) - y_koordinater(n-1, :));
   [dy indx]=sort(dy);
```

```
   yiinnddxx = find(yindx(n-1,:) == indx(1));
   yindx(n, yiinnddxx) = ynr;
   trackade_y(n, yiinnddxx) = y_koordinater(n, ynr);

    end
end

end

figure, plot(trackade_x(2:end,1), trackade_y(2:end,1),'b')
figure, plot(trackade_x(2:end,2), trackade_y(2:end,2),'g')
figure, plot(trackade_x(2:end,3), trackade_y(2:end,3),'r')
figure, plot(trackade_x(2:end,4), trackade_y(2:end,4),'c')

figure
hold on
plot(trackade_x(2:end,1), trackade_y(2:end,1),'b')
plot(trackade_x(2:end,2), trackade_y(2:end,2),'g')
plot(trackade_x(2:end,3), trackade_y(2:end,3),'r')
plot(trackade_x(2:end,4), trackade_y(2:end,4),'c')
hold off
```