Optical Pedometer: A new method for distance measuring using camera phones

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Abstract—Present day pedometer applications lack the ability to identify and measure each step for individual data with high precision. The rapid growth and evolution in the capacity of today’s smartphones now present the opportunity to investigate new methods that gives the possibility to measure each individual step, providing data such as length, width and time by using an out of shelf smartphone. This paper introduces the Optical Pedometer (OP for short) that differs from traditional smartphone pedometer applications in the way that it is based on computer vision, providing new possibilities as to actually identify and measure steps with help of the phone’s camera. Our proposed method was evaluated and compared to the existing methods within this field; accelerometer based pedometers and GPS applications. The results showed that the OP method presented more accurate measurements, thus proving it applicable for shorter measurements requiring a higher degree of accuracy.

Keywords: android, pedometer, computer vision, distance measuring

1. Introduction

Measuring traveled distances with your smartphone is a popular concept used in contemporary applications predominantly within areas concerning health, exercise and recreation.

To measure covered distances the system rely on either one or two of the phone’s sensors: the Global Positioning System (GPS) sensor and the accelerometer. The GPS sensor in the phone sends information about the current position in form of coordinates. The length between the coordinates can then be calculated to give an account for the total distance traveled. The accelerometer, on the other hand, is often used to create a step counter or pedometer which identifies changes in the signal provided by the accelerometer to detect when a step has been taken [12]. The total number of steps is then multiplied with the users estimated average step length resulting in an assessment of the total distance walked.

However, none of these methods works well for measuring shorter distances to any high degree of accuracy. For example the GPS approach is used for most exercise applications and works well for longer distances as its accuracy improves the further the distance you travel. However, according to the American Department of Defense [2] the public civilian GPS type called Standard Positioning Service (SPS) hold a horizontal accuracy of 7.8 meter (95 percentage Confidence interval) which makes it inapplicable for measurements of shorter distances with a high degree of accuracy. Another problem with the GPS method for measuring distances is the signal which easily gets obstructed by nearby buildings and trees which subsequently inhibits its indoor use.

With the pedometer method on the other hand distances are measured based on an average step length approach. The accuracy of the measurement will, in similarity to the GPS approach, increase as the distance covered increases. The reason behind this comes from simple statistics; as a sample size increases the measurement becomes more reliable. Besides missing the actual length of the steps it also has problems with false positives meaning that other movements of the phone could be identified as steps leading to incorrect results.

Thanks to the rapid growth and continued improvement of capacity in today’s smartphones, according to Moore’s law [8], new possibilities have arrived allowing more accurate ways of measuring distances, even as short as 10 centimeters. To overcome the inaccuracy of earlier methods for short distance measuring we propose a new competitive method based on augmented reality through computer vision and basic math to develop an Optical Pedometer (OP).

The introduction of computer vision as the foundation in a pedometer application gives an advantage to the aforementioned methods by actually identifying the person’s feet and track their movement in comparison to each other and the distance between them. Algorithms and basic mathematics can then be applied to get data such as: number of steps taken, the average step length, the step median, and the total distance traveled. To the best of our knowledge the deployment of a smartphone computer vision based method for counting and measuring steps has not been investigated in previous research. The technique is interesting compared to traditional techniques because it provides accurate measurements even in distances below 10 meters and is nowadays available in out of shelf mobile phones.

To evaluate the OP we conduct a comparative study based on the following main aspects: the number of steps identified and the total distance traveled. These features will be compared to current pedometer and GPS methods for measuring distances. New data is also presented attained with the OP such as average step length, width and time.
2. Theoretical background

2.1 GPS tracking applications

Applications that rely on the GPS to measure traveled distance, do this by using the GPS sensor in the phone. The sensor can receive signals from the GPS network containing 24 satellites, the estimated location is then derived from a technique called trilateration, using three or more satellites which gives the estimate position of the receiver (our phones GPS sensor) in latitude and longitude coordinates [1]. The application then stores the user’s different coordinates and can calculate the difference between them or plotting them to a map to show the traveled distance.

Limitations to this approach involve its short distance uses, since its accuracy improves with increased distances. This is because of the horizontal accuracy of the Standard Positioning System (SPS) used for smartphones which is, 7.8 meter with a 95 percentage confidence interval according to the American Department of Defense [2]. This means that if you travel a distance of 10 meters, chances are that the results will have a high degree of error percentage to the actual distance traveled, while if you travel 1 kilometer the error percentage will be lower and therefore yield more accurate results. Another problem with the GPS method for measuring distances is the signal which easily gets obstructed by nearby buildings and trees which subsequently inhibits its indoor use [2].

2.2 Accelerometer based applications

The accelerometer sensor in smartphones is used to identify differences in acceleration. The signal is then analyzed in order to identify the Gait cycle, example of how this is done can be found in [7]. So in simple terms it works in similar manners to traditional independent pedometer devices in the meaning that it senses the users movements and through this identifies when steps are taken.

The average step length of the user is then assessed by the user or through a calibration process, and used for the estimate assessment of the total distance walked. As Hoang et al [7] concludes, the method has limitations in terms of actually identifying steps mainly because the fact that each individuals walking pattern is not constant but varies throughout the session and also day by day and for person to person. It also has limitations in not being able to measure the actual length of the steps and thus any measurements are based on average step length or step time, leading to variations in accuracy from time to time. However, in similarity to the GPS tracking approach; accelerometer applications has a higher degree of accuracy with increased distance traveled simply because of the increased sample size which makes the average step more accurate and consequently the total distance traveled.

3. Our new proposed method, the Opti
cal Pedometer

3.1 Project background

In this section the background information regarding the techniques and theories behind OP are presented and their relation to different key aspects and functions are explained.

The prototype is developed for the Android platform using Nvidia Tegra Android Development Pack 2.0 for Linux with the minor modification of an updated version of the included OpenCV library to version 2.4.8.

3.2 Android pixel coordinate system

To be able to position items on the screen, a coordinate system of x and y is used to map every pixel. It is also possible to retrieve the coordinates from objects shown on the screen. As Figure 1 shows, the android system has both x and y as 0 in the top left corner and the maximum values in the bottom right corner. This means that if we analyzed a frame from our camera with two equal objects e.g. our feet, we could safely assume that the object with the lowest x value on the picture also is furthest to the left and the one with lowest y value would be the one positioned in front of the other.

3.3 Computer vision

Computer vision is the field where software is used to calculate and extract the information from a picture or frame provided by a camera. Algorithms are then used to process the images after the desired objects or patterns. For instance in advanced robotics computer vision is well applied to navigate. The robot uses a camera as its eyes and software as its brain, trying to figure out what it sees and how to react to it [6].

OP is based on computer vision, meaning that it’s the method through which it identifies feet and therefore also recognize steps.
3.4 Object identification

To make our prototype able to detect and measure steps, we first need it to be able to identify the user’s feet. There are several techniques to identify objects through computer vision: you can analyze and search the retrieved images after a key item, a specific color or shape. We have chosen to identify the user’s footwear through simple color detection which is based on the provided color blob example in the OpenCV android library.

To accomplish this we first need to determine what color the object, in our case the user’s footwear is. This is accomplished by letting the user identify its feet on the phones display and then tapping on one of them. This will start our tracking color identification which calculates the average color from the surrounding pixels at the users tap position on the screen. From this the user’s footwear is deduced to be equivalent to the two largest areas of linked pixels with the target color range. To identify which foot is which, we let the pixel area with the lowest x value coordinate be identified as our left foot and the second as our right foot.

There are many aspects of this method that bring limitations, e.g. the feet need to be of a unique color in respect to the surrounding in order to minimize the amount of false positives. However, the method is general and can be used for every kind of footwear, shape or size. This makes it an adequate choice to fulfill the evaluation of the OP method.

3.5 Object tracking

Object tracking can be described as looking at the position of the identified object on one frame and estimate the difference relative to its position on the previous frame. In our case we look at the relative position of each foot on each frame and the distance between them, to see how it compares to the same values on the previous frame.

It’s through this process we are able to determine when a step is taken and the length of each individual step. To do this we need some rules to define when a step is taken (what is the start and the end of one step) and what value to assign for its length.

a) Step identification: To identify when a step is taken we first need to set a rule defining what constitutes a step. For this instance we choose to classify a step as the action in which one foot is in front of the other. When the left foot is in front of the right foot we call it a left step and the opposite condition for a right step. This gives us the possibility to separate between a left step and right step.

We can then use the relative position of each foot to identify when a step has occurred. E.g. our left step starts on the first frame where the left foot is in front of the right foot and it ends on the first frame where the right foot is in front of the left foot, hence initiating the right step. This could be described with the simple pseudo code as shown in Algorithm 1.

b) Step data: Once step identification is achieved the next process is to determine the length of each step. On each frame, for every step, we calculate the length in pixels between the foremost part of the left foot to the foremost part of the right foot. We then let a variable keep track of our step length, if the number of pixels between the feet are greater than the variable, the variable will adopt the value of the current frame. This way we ensure that the step length is the maximum distance measured in pixels between both feet on all frames during the cycle of a step. This could be described with the simple pseudo code as shown in Algorithm 1.

The same method is also used to measure the step width, which is the longest distance measured between the feet along the x-axis during the cycle of one step.

To measure the step time, we store a Unix time stamp at the start of each step cycle. We then subtract the time stamp from a newly made one at the end of the step cycle, leaving us with the total time in millisecond of each step.

Algorithm 1 Identify step

```
while measuring do
    if left foot is in front of right foot then
        if leftStep then
            saveStep
            leftStep = true
        else
            if steplength < newlength then
                steplength ← newlength
            end if
            end if
        else
            if leftStep then
                saveStep
                leftStep = false
            else
                if steplength < newlength then
                    steplength ← newlength
                end if
                end if
            end if
        end if
    end if
end while
```

3.6 Reference size

We use basic proportionality in order to convert step length in pixels to a size on the metric scale in cm. Since the main object of our attention is the footwear attached to our feet, we have the possibility to get the actual length of the shoe by simply converting the shoe size into the metric scale. For instance the European shoe size is based on Paris points which are convertible to cm by using formula 1 [3].

\[
(\text{Paris points}) = \frac{3}{2} \times \text{foot length (cm)} + 1.5 \text{ cm} \quad (1)
\]

This way we can prompt the user for his or hers shoe size and get a relatively precise measurement that can be used
as a reference size for our conversion from pixels to cm. This is possible since we now know both the actual length in cm of the shoe and its length represented in pixels on our screen. If we take the pixel size of the shoe and divide it by its actual length in cm we get how many pixels per cm proportion. So when we then want to convert our step length and total distance from pixels to cm we now have a constant value which we can use for the conversion.

If the user wants even more precise measurement or is wearing socks or other types of footwear the size can also be entered directly in centimeters.

3.7 Calibration

There are several factors that can affect the outcome of one measurement to another for example the person’s height or shoe size. Also, the height at which the phone is held over the floor will make the image representation of the feet larger or smaller depending on the distance and this will affect the reference size. Another factor we need to take into account is perspective distortion, which means that at wide angles and short distances the objects representation may look distorted or stretched which could affect the distance in pixels. Also the lenses between different cameras may have different specifications resulting in different object representation.

To make a general solution that applies to phones with different camera types, people with different height and feet size calibration is needed. The calibration is done by putting one foot forward reaching the middle of the screen and the other one back at the end of the screen. When the button is pushed the feet’s total pixel size are added up by taking its lowest pixel coordinate’s y value minus its biggest and divided by two to identify the average pixel representation of one foot (M) with equation 2 where f1 and f2 denote the pixel representation of the feet.

\[
M = \frac{f_1 + f_2}{2} \tag{2}
\]

This will minimize the distortion error from the distance equation. Because the foot which is left behind will be distorted and therefore showing a bigger size compared to the one positioned at the screen’s middle. It will also adjust the reference size to match the persons height and shoe size.

Even if the calibration helps minimizing and eliminating some error factors it will not have any effect on the error happening during the actual measurement. For instance the movement of the phone along the vertical plane while measuring.

4. Data selection and validation

In this section we will evaluate the OP capabilities to measure steps but also the individual methods within the OP will be evaluated. In section 4.4, 4.5 and 4.6 equation 3 for standard deviation is used and all the tests are done from our largest dataset from the 100 meters distance test in section 4.3.

\[
s_N = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2} \tag{3}
\]

4.1 Calibration

To evaluate if our calibration method is working, we let two persons measure one step of 40 cm against a folding ruler as a reference to the actual length. The two test subjects will be equipped with different phones and be of different length and feet size as shown in the list below. As there is a low error margin shown for both test persons we conclude that our calibration method is working satisfactorily for the purpose intended.

[Test 1]
Person 1: length 180 centimeter, feet size 26.5 centimeter
Phone: LG G2, 13Mega pixel camera, camera lens F2.4, screen resolution 1080x1920
Reference size: 15.76
Result: 39.46 cm
Error margin: 1.35 %

[Test 2]
Person 2: length 165 centimeter, feet size 24.5 centimeter
Phone: Samsung S3, 8Mega pixel camera, camera lens F2.6, screen resolution 1280x720
Reference size: 11.59
Result: 40.28 cm
Error margin: 0.7 %

4.2 Pedometer

To evaluate our OP’s capability to identify steps we compare it to the accelerometer based pedometer application according to the 20 steps test [9]. Also, we will perform a 50 steps and 100 steps test on the same test credentials as the 20 steps test with a maximum of 5 % error rate as acceptance limit. As shown in Table 1, the accelerometer based pedometer failed two out of three tests. OP on the other hand has a 0.0% error percentage in all three tests.

Table 1: Step identification test.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Optical Pedometer result</th>
<th>Pedometer result</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>57</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>102</td>
</tr>
</tbody>
</table>

4.3 Total distance traveled

To evaluate the distance measuring capabilities of OP we performed a series of test with OP, GPS and the Pedometer application on a range from one centimeter to 100
meters. The error percentages from the true values were then calculated for each of the three methods. For tests done with the GPS method Runkeeper was used [5] and for the accelerometer based pedometer Runtastic pedometer was used [4].

For measurements below 10 meters a measuring tape is used and for all other a running track is used as a reference size.

As illustrated in Table 2 below, our findings showed that neither the Pedometer nor the GPS based applications were able to measure distances below 10 meters making OP the only application with this capability. However OP error percentages on distances below 10 centimeters are too high to be trust worthy. We also see that OP remains below a 6% error rate in the range 10 centimeters to 80 meters. Where the other methods has a lot of variety in their results. This is mainly because they are only able to give estimates in the 10 meters range results, mainly because they are only able to give estimates in the 10 meters range.

The possibility to use a similar rounded values approach for the OP method is of course possible. However, not enough tests have been done to be able to validate an approach of this sort and therefore we chose to present the result as they are.

<table>
<thead>
<tr>
<th>(m)</th>
<th>OP result</th>
<th>error (%)</th>
<th>GPS result</th>
<th>error (%)</th>
<th>Pedometer result</th>
<th>error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.02</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.05</td>
<td>0.06</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.1</td>
<td>0.101</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.2</td>
<td>0.208</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.5</td>
<td>0.57</td>
<td>1.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>1.02</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>5.02</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>10.06</td>
<td>0.06</td>
<td>20</td>
<td>100</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>60</td>
<td>63.47</td>
<td>5.7</td>
<td>60</td>
<td>0.0</td>
<td>50</td>
<td>16.6</td>
</tr>
<tr>
<td>80</td>
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<td>5.5</td>
<td>80</td>
<td>0.0</td>
<td>80</td>
<td>0.0</td>
</tr>
<tr>
<td>100</td>
<td>109.1</td>
<td>9.1</td>
<td>90</td>
<td>10</td>
<td>90</td>
<td>10</td>
</tr>
</tbody>
</table>

### 4.4 Average step length

To be able to evaluate the OP’s capability to measure step length, standard deviation was calculated. Then both left and right steps were individually analyzed through the same method and test sample. No data was excluded from the population during this calculation and it was calculated as uncorrected sample standard deviation. The results are visualized in Gauss curves as shown in Figure 2 and 3 for all steps respectively left vs. right steps.

Our analysis shows that our median step has a length of 74.68 centimeters, and as shown in Figure 2 the mean step is 73.2 centimeters which compared to findings of previous research is indicated to be around 79 cm for males [11]. Which we take as a sign that the OP is well equipped for measuring average steps.

However we should remember that the dataset used for this analysis has a total distance error of 9.1%. Since our dataset contained 149 steps and the actual distance traveled was 100 meters our average step should be around 67 centimeters. We have no way to determine if the error is equally spread among the steps or if there are few steps which contains all the error. However if we deduct 9.1% of our mean step we get a new mean value of 66.55 centimeters which is closer to the previously mentioned value. Despite this we find the OP method qualified for estimate a person’s average value with a relatively low error percentage which we estimate to be below 10%.

Figure 3 shows that the mean length for all steps are 73.2 centimeter, the diagram also illustrates that the left steps are slightly shorter, at 73.1 cm, compared to the slightly longer right steps, at 73.3 cm. Meaning that the person has a slightly longer right step than left step. However, if we look at the peak of the curves we see that the deviation is also slightly higher for the left steps with 6 centimeter respectively 4.7 centimeter for the right steps. After analyzing the results and dataset we can conclude that the OP is fully capable of analyzing an average step. Nonetheless the method requires active measuring from the test person, meaning it is not applicable for jogging or walking in high pace as it demands the person’s attention.
4.5 Average step time

To evaluate our step time we use the same approach as with our step length evaluation and furthermore base them on the same dataset. However the first step is removed from the population resulting in one sample less. This is because the first step is a part of the calibration process and therefore its duration is longer than the average step which will affect the outcome of our calculations.

As seen in Figure 4 our mean step time is calculated to 703 ms, which if combined with our average step length could give us an average speed. The length 73.2 cm in 1.43 sec gives us an average speed of 3.75 km/h. This could be considered a slow speed for walking, which could be compared to that of a pedestrian walking which is found to be around 5.42 km/h for people below 65 years of age [10]. This is related to the current state of OP’s development which demands a slower pace for more accurate measurements.

4.6 Step width

When analyzing our 100 meter dataset in regards to step width, we found that the mean step width was that of eight centimeter, and with a standard deviation of three centimeters. This gives us a variance of nine centimeter, and as shown in Figure 6 92.6 percentage of our steps where within two standard deviations.

5. Discussion and open problems

The Computer vision approach for developing a pedometer application has proven to be functional and possible to use with out of shelf smartphones. The method does provide unique possibilities to see and measure distances between feet, both in terms of length and width.

However in order to create a solution that is usable for the wider public, another method for identifying feet is necessary. The color identification approach is too sensitive to be practical in everyday situations because of the implication of the surroundings. For instance the color of the ground, shoe or pants and to some degree the lightning will affect the stability to correctly identify the feet.

Another downside for the computer vision approach is that it requires a lot from the phones resources, making the phone run a little slower than real-time pace. Therefore, the actual walking speed during the measuring process will have to be that of a slower pace. This allows the tracking process to view as many frames as possible during each step.

The basic proportionality of our reference size has been proven to be a valid method for conversion between pixels to the metric scale. However this approach works only because of the parallel and constant positioning of the camera over the feet. Any movement along the vertical plane or tilt of the phone would make the reference size misleading. A possible solution would be to perform an automatic calibration for each step or calculate an average reference size for each step based on its containing frames. Perhaps, also apply math with readings from the phones gyroscope to reduce some errors caused by tilting during measuring, this however is out of scope for this paper.

Our algorithm for step identification has proven to be very efficient and with a low to none error percentage. Regarding to step identification capabilities of pedometers the OP could
be considered as the one to beat with a 0 error percentage in our tests.

To summarize, the method works but is sensitive and puts restraints on the user, in terms that it requires an active measuring. Hence, to achieve accurate results the user must have the phone moving as little as possible in the vertical and horizontal plane while walking in a pace that allows the software in the phone to measure the steps accurately. However, this could be a sacrifice worth making if the user wants to measure short distances or get detailed information about left vs. right steps or step width not available by any other method.

References