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MOBILE PHONE AS PERVASIVE ELECTRONIC MEDIA TO RECORD AND EVALUATE HUMAN GAIT BEHAVIOR

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Gait recognition has been of great importance for disease diagnosis, rehabilitation assessment, as well as personal identification. Conventional gait analysis generally has to rely heavily on complex, expensive data acquisition and computing apparatus. To significantly simplify the evaluation process the mobile phone, which is one of the most indispensable electronic media in human daily life, was adopted as a pervasive tool for gait study, by using its digital imaging recording and analysis function. The basic procedure to record and quantify the video of human gait was illustrated and demonstrated through conceptual experiments. Potential applications were discussed. Some fundamental and practical issues raised in such flexible technology were pointed out. This method is expected to be widely used in future human analysis.

Keywords: Gait analysis; telemedicine; pervasive medicine; low cost medicine.

1. Introduction

Gait, reflecting individual physiological function, pathological conditions and mental state, has been known as one of the most universal and yet most complex forms of all human activities. For this reason, analysis on human gait was found to have a wide range of applications. An accurate gait analysis can assist doctors in conducting diagnosis and rehabilitation assessment in clinics. Human gait also has relationship with ergonomics, sports science, bionic body and bionic manufacturing.[1] Therefore, studies on human gait have significant, fundamental and practical value.

The most basic parameters for human motion include all joints angle and limbs movement measurements.[2] A typical human gait analysis generally includes angle detection of hip, knee, ankle and other joints when walking. Such information provides the criteria to evaluate the movement trajectory of special link when human movements are recorded and then processed through software analysis. However, conventional measurements on

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human gait are not only time consuming, but also may bring pain to the test subjects. The use of reflection sheets and protractors promoted the development of human parameters measurement.[3,4] Early gait analysis system also utilized movie technology to uptake various real-time parts for analysis. With the development of modern technology, many research institutions established human gait motion tracking systems based on image processing.[5–7] Most of them paste reflection sheets or shiners with contrast color to the background on the major joints of the subjects, with two or more cameras shooting from different angles, then collect characteristic parameters of landmarks to study the movement of subjects through image processing techniques. Overall, the apparatus ever involved usually are too complex or expensive for operation which limited its wide application.

Here, aiming to develop a low cost analysis method on human gait, we proposed to use the mobile phone, which is so far the most popular electronic media in daily life, to record and analyze the human gait. It is expected to serve as a pervasive way to study human activity.

2. Gait Recognition Based on Low Pixel Camera of Mobile Phone

People may have a suspicion about the possibility of using mobile phone for gait investigation, because of its low pixel. Such a puzzle however can be well resolved through appropriate calculation. The following study is dedicated to demonstrate the capability of using mobile phone image for gait study. Presently, such device is mainly suitable for analyzing low speed movements due to its low pixels.

2.1. *Image acquisition*

In the experiment, treadmill is used as movements of the human upper limb are slight while activities of human lower limb appear more evident. The test subject is a 22-year-old healthy boy with 179 cm height and 60 kg weight. In order to facilitate the analysis of human gait, we paste three marks with contrast color with the background at the hip joint, knee and ankle joints of the subject, respectively. The subject is dressed in black pants, and the marks look like white rotundity. The phone used in the experiment is Acer F900 with 240*320 resolutions when shooting video (Fig. 1).

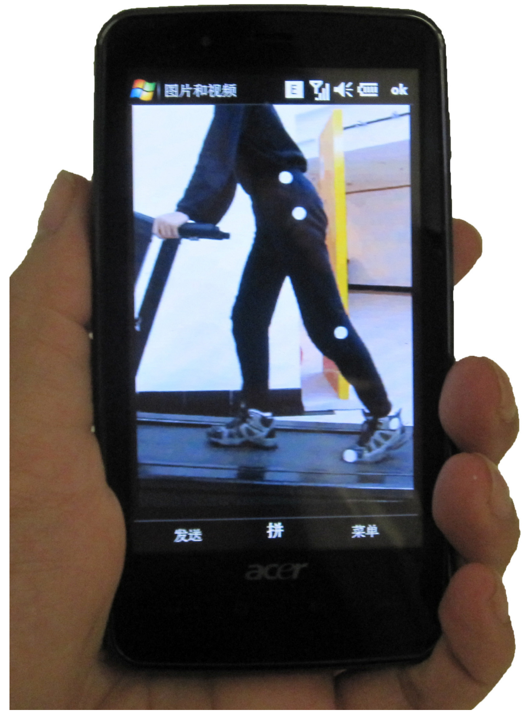


Fig. 1. The phone used in the experiment.

2.2. *Measuring principle*

Depicted in Fig. 2 is a simplified human model for lower limb motion. The dots from top to bottom represent waist, hip joint, knee joint, ankle joint and toe, respectively. Their coordinates in the plane are (x_w, y_w), (x_h, y_h), (x_k, y_k), (x_a, y_a) and (x_t, y_t), respectively. Then, one can compute the angles by

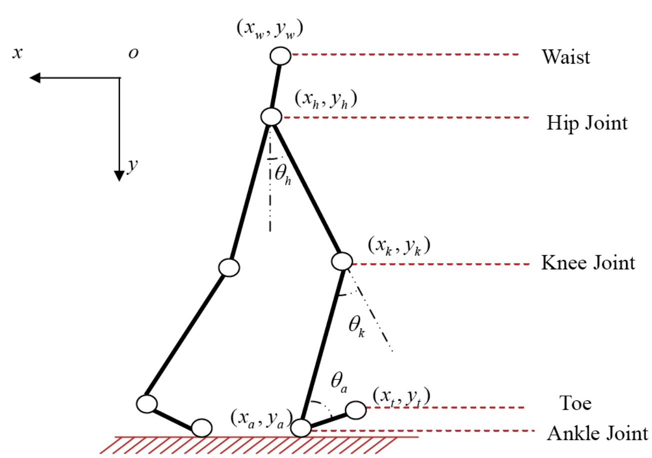


Fig. 2. The human model of lower limb motion.

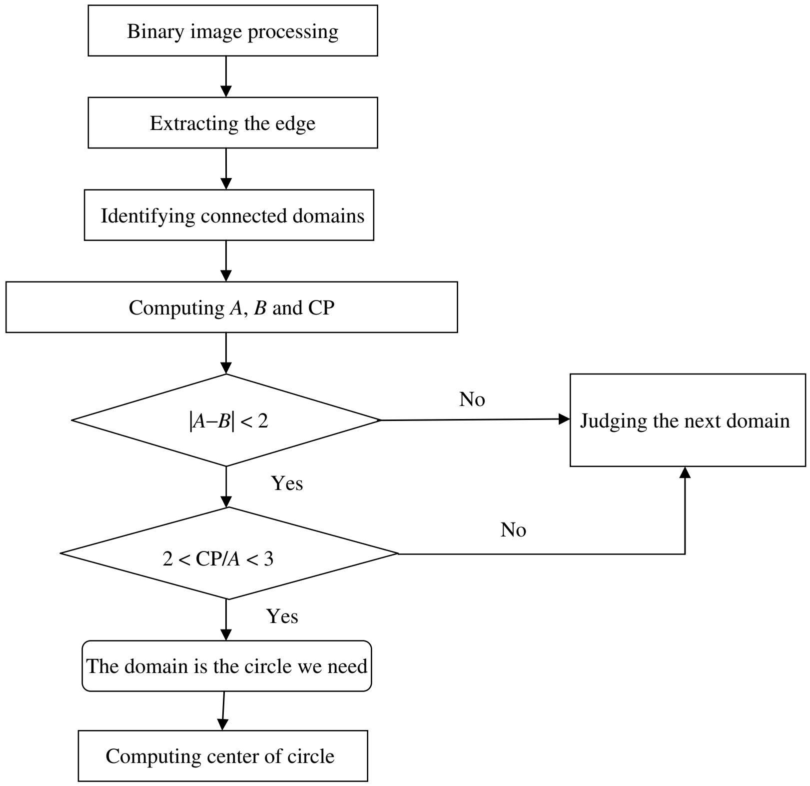


Fig. 3. Arithmetic for marks identification.

the following equations:

$$\theta_h = \arctan[(x_k - x_h)/(y_k - y_h)], \quad (1)$$

$$\theta_k = \arctan[(x_k - x_a)/(y_k - y_a)] + \theta_h, \quad (2)$$

$$\theta_a = \arctan[(y_k - y_a)/(x_k - x_a)] + \arctan[(y_t - y_a)/(x_t - x_a)]. \quad (3)$$

2.3. *Image processing*

Mark recognition is the key for image processing.

First, we took threshold as 0.2 to convert the existing image into binary image. The binary image can also remove interference of the gray shadow. Then, we use a log operator to extract the edge of the image. The edge pixels are 1 and the others are 0. Afterwards, we can identify the entire connected domain, and recognize which domains are circular ones that we want.

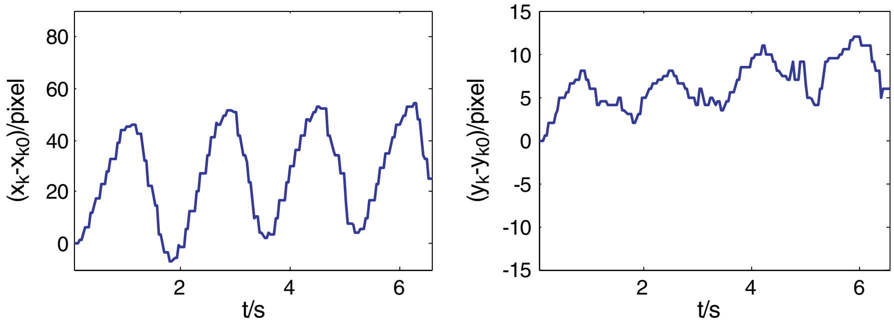
There are two main judgments on whether it is circular domain or not. We note the number of pixels around the edge of each domain as CP. For each domain, we compute the maximum horizontal pixel number as A, while the maximum vertical pixel number as B. If (1) $|A - B| < 2$; and (2) $2 < \mathrm{CP}/A < 3$, then we treat it as a circular one. The center of the domain is the center of the circle. Figure 3 shows the whole arithmetic of marks identification.

There may be some interference marks in the background, which will be identified through the above process. How to eliminate this impact? We can identify marks in the two images with different motion states, and then discard the identical marks. Therefore, the remaining marks will need to be calculated. However, the premise of the method is that the background does not change during the entire course.

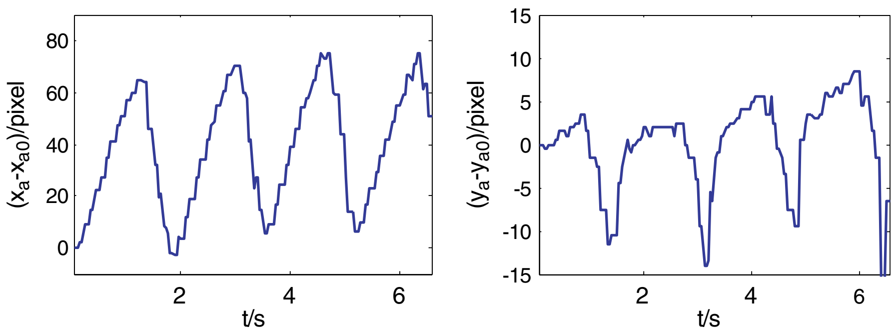
After finding right marks in the first frame image, we use local search to find marks in other images with the same algorithm.

3. Results

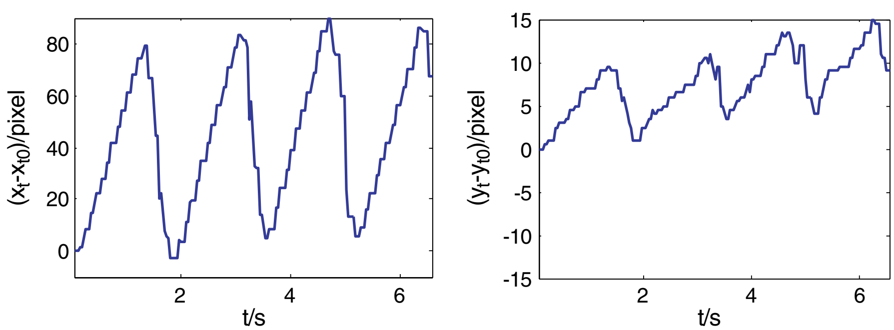
The following results (Fig. 4) depict the movement trajectory of knee, ankle and toe in horizontal and vertical directions, respectively. We consider the first frame image as the reference image, and the ordinate shows the movement pixel difference compared to the reference image.



(a)



(b)



(c)

Fig. 4. The trajectory of joints in horizontal (left) and vertical direction (right). (a) The trajectory of knee joint, (b) the trajectory of ankle joint and (c) the trajectory of toe joint.

There are several factors affecting the results. Although the subject walked as stable as possible on a treadmill, there are still some irregular rocks on the ground which may inevitably cause trouble for the walking in reality. Besides, the marks will become out of shape during walking, which also influences the final results.

The results of horizontal movement have an upward drift baseline which indicates that the subject has a backward movement trend. Additionally, the results confirm that the fluctuation amplitudes in horizontal are bigger than that in vertical for every joint, and the movements of all joints are obviously regular and cyclical. For example, the movement of knee joint in horizontal direction is nearly 30 pixels more than that in vertical direction. During walking on a treadmill, the feet have maximum movement amplitude.

The relative angle for hip, knee and ankle joints are shown in Fig. 5. Clearly, the results are within the reasonable range.

In addition, we can plot the stick figure of one leg when walking in treadmill (Fig. 6). This depicts intuitively the trajectories for every joint and the

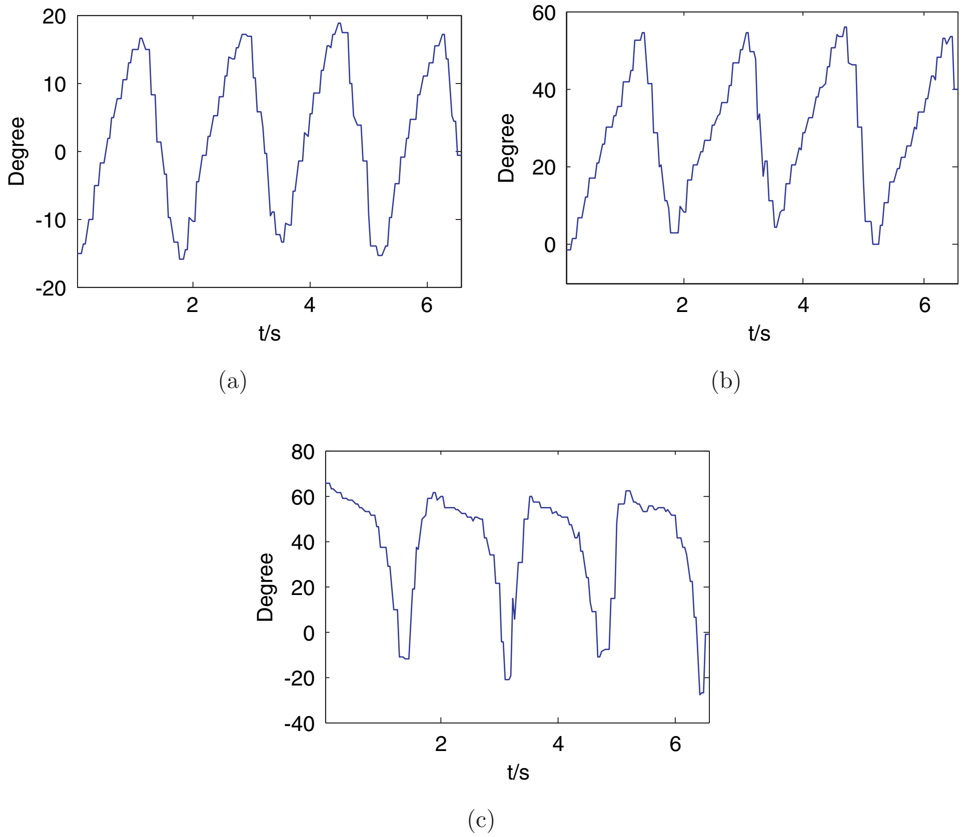


Fig. 5. The relative angle of different joints. (a) The movement angle of hip joint θ_h, (b) the movement angle of knee joint θ_k and (c) the movement angle of hip joint θ_a.

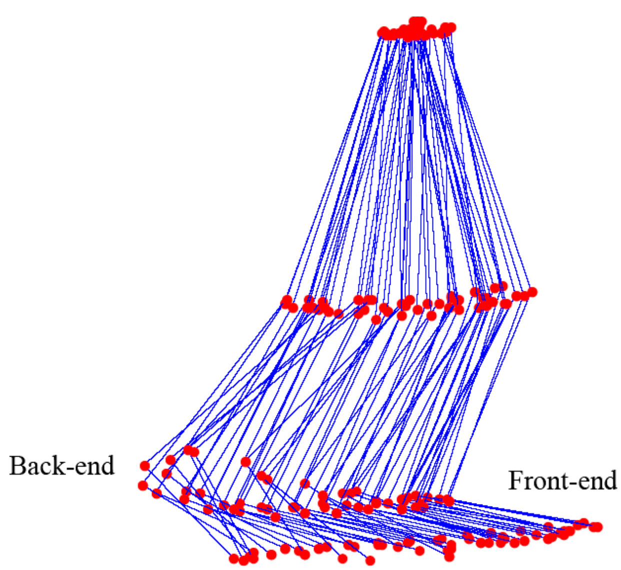


Fig. 6. Stick figure of one leg when walking in treadmill.

whole lower limb. The hip joint has minimum movement amplitude. In the stick figure, the back-end is more sparse than the front-end, and then it can be found that the subject resides less time at the back-end because of faster movement at this time.

As long as the marks can be recognized, we can analyze many features, such as subjects' walking stick, the trajectory of the major joints in one gait cycle and so on. Then, these features not only help to diagnose certain human diseases about motor function, but also guide and evaluate rehabilitation training using effects of prostheses and artificial joints. What is more, it can help identify the person's identity through walking.

4. Discussion

The mobile phone imaging methods can in fact be used more flexibly. Through combination with many other data recorded via various sensors embedded in the phone, the image is able to provide more information on human gait. One can find a series of coupling technologies for such purposes.

4.1. *Gait information from accelerometer sensor*

Some mobiles (e.g., iPhone) already install accelerometer sensor, which are used to measure the orientation or vertical and horizontal positioning of the phone, then alternate the view of the screen depending on how you are holding it. Another application is about the use of acceleration sensor to detect user's posture and activity.[8] Together with the Swiss Federal Office for Sports and the company ActiSmile, CSEM has designed and developed a portable biofeedback device to continuously monitor the physical activity of its user. The key technology resides in sophisticated signal processing methods for multi-axis accelerometer sensor systems, including modern feature extraction, classification algorithms and low-power implementation on real-time platforms. A set of classification features has been defined for the following human activities: Standing/sitting, lying, walking and running. This is a novel healthcare tool to motivate its user to be physically active and to lead a modern and healthy life.

Besides, this technology can be considered as a way to identify different humans. For example, if one lost his phone, the accelerometer sensor installed in the phone can make them harder to be stolen by detecting changes in their owner's walking style and then freeze to prevent unauthorized use. Such devices in fact have already partially been realized. Compared with passwords and other traditional bio-identification, such a gait recognition method based on accelerometer sensor is relatively simple: Confirmation of identity takes place as a background process without any need to intervene user's activity.

However, there are still some drawbacks in this method. On the one side, the accelerometer sensor will be disturbed by the users' speed, shoes or something else. On the other hand, the accelerometer sensors used for recording gait are not yet common. Nevertheless, gait study on mobile phone based on accelerometer sensors is a trend in the future, with the development of the technology and improvement of mobile phone functionality.

4.2. *Gait information from pressure sensor and Bluetooth*

Gait analysis involves dynamic analysis, which studies mainly the interaction between feet and support surface when people walk. Plantar pressure analysis exposes the characteristics of plantar pressure under different conditions, and has turned into an important biomechanics method diagnosing feet pathology and evaluating feet rehabilitation.

Our lab has developed a human plantar pressure sensing system based on mobile Bluetooth communication.[9] The pressure sensor is put under the feet which would transport the real-time pressure into the mobile through the Bluetooth.

4.3. *Combinations with telemedicine*

Another advantage of mobile phones is their communication function, which can connect them with telemedicine. The stored activity features can be sent via a wireless link to a PC or a mobile phone for a more detailed analysis, so the equipments for complex calculation and processing are not necessary for every user.

Figure 7 shows the whole system for gait study using mobile phone where the phone can use video camera and accelerometer sensor or something like that to grasp the human gait information. Maybe the latter pays more attention to the spatial displacement while accelerometer sensor pays more attention to the acceleration when human move. At the same time, the phone can carry out simpler data processing, and then transmit the data to a PC which has powerful computing and processing capability or to the doctor's mobile so that he can monitor the patients' state conveniently at any

Fig. 7. The system for gait study on the mobile phone.

time. The processing results or the advices from the doctor can be fedback through the system as soon as possible.

4.4. *Personal identification*

Early medical researchers found that human gait has 24 different components. If these 24 elements are all taken into account, gait provides a unique index to the individual behavior. Gait recognition is a relatively new biometric technology which is gaining rapid importance in recent years. For instance, the U.S. Department of Defense Research Projects Agency (DARPA) set up a major project-HID (human identification at a distance) program, aiming to develop multi-modal visual surveillance technology to detect, classify and identify humans at a long distance. Clearly, mobile phone, as a pervasive tool in daily life, will contribute significantly to the application in this field.

4.5. *Challenging issues*

When the test subject moves faster, the marks may become fuzzy. This will affect the image processing. Therefore, it may not work well for fast movement compared with high speed camera because of limitation of current low pixel mobile phone. However, there exist two solutions to tackle such issue. One is to improve the pixel of the mobile phone. With development of the technology, many mobiles possess higher and higher pixel, for example, the highest pixel has already reached 1200M. Another way is to use external camera. The ideal design is to use cameras to obtain images, and then transport them into the mobile via Bluetooth or mobile internet, which can also guarantee the feasibility of using several cameras to spatially shoot at different angles, which may lead to 3D analysis on human gait.

Furthermore, incorporating many complicated programs in a mobile phone may cause heavy burden for the device. Actually, the communication functions of a mobile provide a potential solution. This can be done via transmission of the acquired data to the workstation in charge of data processing. The workstation can then support complicated calculation and provides comprehensive database for human gait analysis. What the mobile phone needs to do is only to receive the processing result. Given its easy availability, the mobile phone is expected to play an important role in studying human behavior.

5. Conclusion

From the results as discussed above, the mobile phone was demonstrated to have the ability to perform human gait analysis. Not only the step length, speed and frequency can be obtained, but also displacement and speed of every joint, angle and stick figure can be drawn. The movement speed has more influence on the results. And one can overlay the recognized marks on the original image, so that user can check the correctness of the marks and modify error. Overall, the gait studies are of great importance. However, to reduce costs and expand the application range is a question worth of serious consideration. Mobile phone provides a pervasive way to solve this problem owing to its widespread existence, convenience and powerful functions. Clearly, in future such a device is not only for communication or entertainment, but can also serve as a rather convenient medical assistant.

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