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State of Art in Real Time Gait Analysis System for Healthy Ambulation

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Abstract- This paper presents state-of-art in gait analysis in the errand on condition that healthy parameters for exercise. There are many such systems available recently and future demand in surrounding but due to cost parameter, due to unawareness of gait trainer it is not much popular worldwide. As a result coming from training is not so effective having too much error in ambulatory consideration. So this paper represents system for healthy ambulatory system in real time. This can be easily wearable by patient during training and can be used for outdoor training. As result of these ambulatory parameter feedbacks must be useful gait analysis provides healthy ambulation with low cost application. The system that represents in this paper is mainly discussing three parameters i.e. sensing parameters; those are time, pressure, and most important thing angular change in walking. With these it again discuss with data storage, and providing feedback in real time.

Keywords □ Gait analysis, Wireless Feedback, FSR(Force sensing Resistor), Accelerometer, IMU, Gyrometer

I. Introduction

Gait analysis is one of the most important parameter in the field of medical (i.e. orthopaedic). Due to abnormalities in lower limb, plenty of persons areunable to walk properly; not only they fail in walking but also they fail to do different things like standing, sitting, running, jumping, etc. Hence this paper proposes gait analysis for getting healthy ambulation. As of now, many such systems areavailable in the market for training and collecting gait parameters. The existing gait analysis system has reached a quite exhaustive level in laboratory. Such as the marker based motion capture system can collect motion data from nearly every part of the body and then calculate the gait parameters for gait situation assessment as shown in figure 1.

Besides, it proposes a Fourteen-Linkage Walking Model for structured describing walking gait, and also carried on normal gait feature extraction.

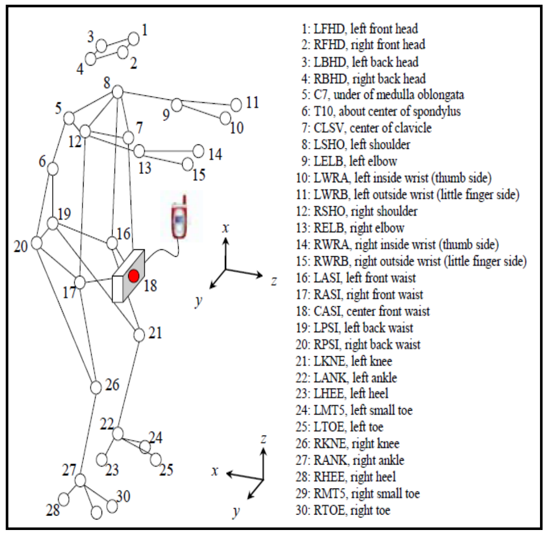

Figure1: Different marker attach to the Body [36].

As to the gait analysis through video images and getting walk characteristics for person identification are not within the scope of this article.

Another kind of gait study was through walking on a ground reaction force plate. It was often in a laboratory environment or in an unnatural walking state. The former usually focuses on the gait kinetic parameters.

Thus from all of these, various gait analysis methods are based on indoor laboratory based very high expensive in cost and having specific experimental environment. Therefore mostly used for sports, rehabilitation of physically disabled people and other specific needs in special case only, not for the general public needs. So it is the need of hour to study more concise, more natural gait data collection methods for gait analysis.

In recent years, inertial sensors have been used in walking analysis as a chipper and convenient used for common application to analysed gait parameters. Because of the inertial sensor exclude indoor laboratory experimental environment. Now-a-days, research is going on to construct ambulatory and wearable system with real time application. With the usage of wearable devices such as accelerometer, gyrometer, etc. various things get affectedwhich assist gait parameter. It has made significant change to get healthy ambulatory parameter.

With inertial sensors the other main attraction is awake on force sensors to analyse walking, since it is directly concerned with both ground as well as feet contact. As the force sensor are more costly than inertial sensor still popular in field of gait analysis, because of its accuracy and ability to provide convenient result for gait analysis in exchange of few bucks. Also there are a few problems in front of designer for collaboration of the data and representing it; in real time, in easy way to understand forlayman.

Common use of wireless inertial sensor or force system is designed to be cheap, easy gait analysis, and escape from the need for expensive laboratory equipment and cumbersome pre-calibration process. However, the use of multi-sensors still needs proper calibration. As each experiment has the different sensor placement, the researchers neither have standard hardware configuration, nor have standard software to be used. So, many researchers which use force or inertial sensors systems must develop algorithms by themselves to detect gait. The main categories of algorithms are about deciding gait phase.

II. Gait analysis method

1. Aim for walking gait analysis

In early days, walking gait analysis was used to clinical estimation for disabled person. Doctor through their naked eye's observation concludes gait parameter; whether patient's walking parameter is good or need assistance. As sense is changing rapidly, plenty of devices have been introduced by the medical science. But this is only in case of well developed countries. Since, plenty of countries fail to provide such devices for gait analysis.

First, is to study the walking pattern, then to do some gait feature extraction for special gait population. By the determination of the gait cycle and gait phases, and by the validation of gait events, it can obtain a series of parameters related gait.

Second isto provide worldwide solution for detection of abnormal walking parameter, since plenty of countries use older methods for gait analysis, which are based on only doctor's or physician's assumptions.

Third is early diagnosis for some diseases which may affect the gait and doing some prediction of fall risk. Gait analysis is not only important for the diagnosis of many neurological diseases such as Parkinson'sdisease; also it can diagnose some of osteoarthritis which may affect the walking gait.

Besides, gait analysis can be as a tool for evaluation of walking function, and to assess the recovery degree of walking ability in patients after treatment. Sometimes gait analysis also can be applied to assist in physical rehabilitation guidance. That will help clinical doctors very more if we can use gait analysis conveniently not in a laboratory. But, the real time using gait analysis for clinical disease diagnosis is very fewer. Therefore, the assistance for disease diagnosis and rehabilitation may be the main aim or application of gait analysis in future.

2. General sensors used to analyse walking parameters

There are various types of sensors being used for gait analysis. These can been shown in table I. Here they can be used separately or in combinational manner. In these the FSR (force sensor unit) is most popular sensor, which is used in every now and then. Moreover, researchers mention the use of FSR for finding gait parameter in their paper. With these accelerometer is quite popular; also there are various researchers who mention multiple sensory elements. There are different specification and type in both FSR's and accelerometer. There are low gains or high gains with variation in tolerable force applied by normal walking. There are biaxial or tri-axial accelerometers with low gravity or high gravity, and so on.

Table I: Most popular sensors discuss

Sensor Category	Discuss by Paper	Mention Rate (%)
Accelerometer	[1-8, 21, 22, 35,36]	31.42
BSN	[8-12]	14.28
FSR	[13-26]	40
Gyrometer	[1, 13-14, 27, 35]	14.28
Image	[28-31]	11.42
IMU	[18, 32-35]	14.28
Magnetometer	[8]	2.85

The most systems, which are used in these days is indoor laboratory system; hence considering image processing is the best option but only for the indoor system. Since this paper deals with wearable sensory system it is tough to analyse gait analysis using image processing, and having major in cost factor. Hence other system gets advantage.

Table II: Location of body to place sensor[36]

Body Location	Attached Methods
Heel/shoe lateral	Velcro
Instep	Straps
Shank	Belts
Thigh	Belts, Velcro
Knee	Elastic Belt
Pelvis	Velcro
Lumber/waist	Band, belt
Upper Trunk	Velcro
Arm	Belts
Head	Helmet, cap
Ear	e-ar

3. The locations of sensors placement

In order to capture gait parameters, researchers usually used one or more inertial sensors, and then placed in different parts of the body [1]. Although normal human walking is to be implemented by the feet, but the stability of gait is decided by a variety of factors. These include walking speed, gait rhythm, ground conditions, nervous system, and so on. The human body is an organism, whether there is a physical injury or a problem of central nervous, it can affect the walking gait. Table II, shows some examples of inertial sensor placement of body. You can see, the inertial sensor placement is not limited to the lower limbs, such as heels, ankles, instep of feet, tibias and thighs. Also, the inertial sensors can be placed in upper body, such as waist, abdomen, spine of back, etc. The higher locations are the head and ears. The acceleration of these parts of the body can better describe the gait balance and gait stability when human is walking.

But it was clear that even if we put the sensor on the instep, where different locations of the instep will still affect the adjustment of sensor coordinates and the accuracy of the test parameters. Wearable inertial sensor systems can be used continuously and unobtrusively to assess gait during every day by particularly with regard to gait analysis techniques become more mature and improved.

III. Key Problems

1. The consideration of sensors

On the whole, it is necessary to consider various features of the sensors, such as area or size, preciseness, portability, wearability, etc. For different purposes or uses of sensors, the consideration of some features may be emphasized.

The gait parameters can be measured by wearable sensors such as FSR's, accelerometers, gyroscopes, magnetometers and goniometers. The sensors attached to the foot provide better results for normal walking and require only little signal conditioning. In case of accelerometer by adding gyrometer reduce errors caused by accelerometer vibration. The accuracy problems when using the inertial sensors or FSR separately to measure the gait parameters have been better solved through data redundancy, data complementary and data fusion.

Although the use of more sensors will improve the accuracy of gait parameters, but too much of sensors will affect the system's portability. Especially if you want to do some clinical diagnosis, auxiliary rehabilitation and so on, the portability may be more important. It should be considered the balance between accuracy and portability.

When using wearable sensor system to do a more sophisticated gait analysis, it will be used the sensor information from other parts of body besides on the foot. It also needs to consider the interoperability between multiple devices and multiple systems. A subtle gait analysis system can find out some special gait characteristics, it can be used for long term gait data analysis to acquire the little changes or little differences compared with some before.

Again realising walking gait parameter in real time is very crucial task. If we consider multi sensory system analysing data in real time and represent it is massive job to do. Again with whatever information we collect it can store for long time and sending data for long distance is again makes headache.

2. Gait events detection

There are many papers researched on gait event detection. The gait events refer to the phases of gait cycle. In early time, the gait events detection was by heel switch to start the cycle of gait. In literature, the procedure of segmentation divided the gait cycle into four phases: stance, heel-off, swing, heel strike, and the different gait events were heel-off, toe-off, heel strike and foot-flat. That is, human gait was broken down into three states, namely Stance, Push off and Swing phase. The instances that indicate transition between these states were Heel off, Toe off and Heel strike. But the classical gait cycle was to be divided into seven phases beginning at Initial contact or Heel strike, including Loading response, Mid-stance, Terminal stance, Pre-swing, Initial swing, Mid-swing and Terminal swing. In practical application, this gait phasing may not be conducive to inertial sensors to identify them. So in recent years there are still various gait models visible in the study reports.

Normally, the gait events detection was achieved by a motion analysis system with some algorithms, but if the leg segments' orientations cannot be accurately obtained and combined with the signals of the sensor units, it is almost impossible that all the gait phases are effectively detected. The gait events or phases detection is a necessary process of the gait analysis using sensors.

IV. Promising Paper Direction

1. Evaluate the effectiveness of measurement methods

It has been found many different sensor configurations for gait detection in ambulatory systems. Force and Inertial sensors were often set up to consider the use of single or multiple, easier to put on, less influence with people's daily lives, and the test reliability. There should be some evaluation criteria to assess the effectiveness and the accuracy of the measurement. But this is almost impossible task due to the current situation. Almost every study had its self-designed sensor systems for gait analysis. Various sensors or sensor combinations were used and were capable of providing relevant physical signals of gait.

FSR seeking most used sensor, that seemed with the combination of wireless feedback system creates more interest in it. As it is some tedious to interface and demands special kind of arrangement for sensing force it disappoint in making fine set up. To finding main pressure points and put it below provides information about heel struck and toe off of both legs. There are various ambulatory systems, but due to their experimental application it limits ambulatory used.

Accelerometers seemed to be another significantly used sensor, and often used in combination with gyroscopes. In addition, the sensor positioning less critical as placing the sensor at nearly any location that includes heel, ankle, instep, shank, thigh, trunk, and their combination. Both legs were possible with appropriate signal processing. Although many experiments called as ambulatory systems, but only a few which are suitable for daily ambulatory use. Most methods have been developed for use under laboratory conditions causing design constraints which limit their clinical usability.

In previous decades, diseases diagnostic accuracy used with gait analysis has not yet been proven reliably, so that there is no applicable clinical tool so far. This requires more detailed experimental work, as well as clinical patient assistance. So in the future, it should proceed from the clinical application to set evaluation criteria or guidelines. The first is ambulatory, the inertial sensors system should be easy to put on and take off. It should also use less cables or wires and then make more use of wireless devices. Followed by practicability, the sensors system will encounter the ordinary populace of patients. Furthermore the durability, the hardware of sensors system itself must to be more stable, not easily damaged, as well as energy-saving considerations.

2. Long-term assessment under normal daily activities

In order to compute the temporal parameters such as the duration of swing, single and double stances during a gait cycle, it is necessary and sufficient to determine for each leg the precise moments of heel strike and toe-off during that cycle. This is one of the purposes of long-term assessment under normal daily activities. Another aim is to construct a promising monitoring tool for several purposes. For example, it can do in regularly survey of normal gait with the long-term assessment system. It allows measurements of gait features during a long period of walking and thus supplies the stride-to-stride variability of gait. So the system must be portability, it can be used in other settings not in a gait laboratory and therefore provides information that is more likely to reflect the actual performance of the subjects. It can be used in many clinical applications for elderly subjects, such as a diagnostic tool for abnormal gait analysis, a predictor tool for fall risk estimation, or a monitoring tool to assess progress through rehabilitation. The system may have a high acceptability by elderly subjects.

3. Sensors with applications

As we discuss on the various types of sensors, we can examine different kinds of applications. Some of them listed in table III. Hence from these we may pay more attention on those applications for helping in gait analysis.

As we see from these table mostly FSR are calibrated for fair gait analysis. The references mentioned above are belonging in year 2011-2012. Hence from it we shall tell that future systems belong on FSR; as others have their own erroneous conditions. To surplus these things; many of times multi sensory system is best option. But it has its disadvantage too. But this is not the sense in FSR; it can able to generate fine result.

4. Feedback system

In modern way the most suitable way to realising the feedback from sensors is using Mobile Phone system. This is quite interesting question that; why Mobile Phones? But as we all know the most developing area now our days belongs to mobile phones and tablets. These are most user friendly devices present in surrounding. Different kinds of application makes better for making user more familiar with technology. De-novo for feedback system towards mobile computing was debatable [8, 13] as shown in figure 2. Researcher can also take care of mobile computing. Hence system gets more complicated.

Table III: Sensors and its Applications

Category of Sensor	Discuss in Reference	Application
Accelerometer	[1-8, 21, 22, 35]	Human motion track, Gait analysis, activity analysis, Gait feature extraction-parkinson's and alzheimer's disease, step detection in mobile computing, evaluation of arm motion, analysis of walking parameter
BSN	[8-12]	analysis of walking parameter, Gait analysis Ubiquitous Healthcare, Biofeedback network for Medical E-health care, Implementation of Virtual sensor, Walker recognition
Gyrometer	[1, 13-14, 27, 35]	Gait analysis, Human motion track, sit-to-stand motion analysis, Humanoid robot
FSR	[13-26]	Walking gait analysis, Treadmill walking analysis, Collecting six day data running through desert, Haptic feedback, bipedal and quadrupedal robot
Image	[28-31]	Gait analysis, Gesture interaction
IMU	[18, 32-35]	Gait analysis, Collecting six day data running through desert, Joint motion analysis
Magnetometer	[8]	analysis of walking parameter, Gait analysis

Few years ago, the system present is using laboratory instruments that make helpful to researcher. In laboratory environment, using wired system for generating feedback is the best option as shown in figure 3. The disadvantage of this kind of system is its cost. Due heavy traditional instruments cost get affected and patient restricted only in closed rooms where gait analysis is not that much effective due to less hurdles for facing.

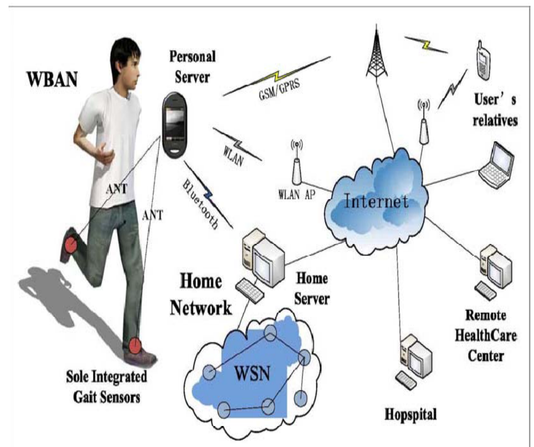

Figure 2: Mobile Based BSN system [10]

Taking control action on traditional instrumental problems, new research held toward wireless feedback system. Generic view towards wireless system feels better for outdoor training. Provide new wild scope for walking gait analysis.

Figure 3: Traditional Laboratory Environmental for gait analysis.

Table IV: Wireless Feedback system

Type of System	Discuss in paper	Application
Mobile	[2,4,8,17, 19]	Gait analysis, Walking in place, Gait monitoring,
Wi-Fi	[9]	Body area network
Xbee	[21,22,25 ,32]	Gait analysis, wireless smart network for walking analysis, system for Rehabilitation

Not only mobile was the most useful tool but different kinds of tools such as Wi-fi, Bluetooth, GPRS, GSM, etc. which can able to send data as per our requirement, as Bluetooth, Xbee. Table IV shows, some Feedback systems which are very helpful for gait analysis.

5. State of arts

As previously discussed in table III, plenty of application comes in-front of us for gait analysis in ambulatory system. These can be categorised as per their primary function into various sub system like; monitoring system, rehabilitation assistance devices and long term medical aids. Basically the main attention going towards, providing dedicated monitoring of specific medical conditions.

Applications are shortlisted as

- Clinical disease diagnosis
- Healthcare and disease prevention
- Functional assessments
- Physical activity pattern assessment
- Artificial leg
- Judging medical fitness
- Sports

These are few but main domain where this kind of system provides little more advantageous. The wearable sensors system can provide valuable information for assessment of volumes, intensity and pattern of physical activity across the daily and weekly patterns of all peoples. This will helpful to physical activities that are specifically tailored for the needs for all age patients.

V. Conclusion

Discussion on above parameters, more over concentrated in the wearable system. Since it does not need more complicated instruments and not willing any restriction on training surface. As per the above observation mostly paper take interest in FSR followed by Accelerometer [13-28, 1-8]. As there are unwanted signals generate due to vibrations on walking. To minimize these erroneous effect normally considering gyrometer that's create IMU system [1, 35]. The main algorithm used in this field is mainly concern with SVM modelling where all axial parameters summed in singular parameter. This technique is helpful but it again has disadvantage, which mostly deals with the angular change in locomotion. It does not give direct relation between surface and foot. These problems are overcome by the sensor FSR.

Recently most popular trend in gait analysis comes over the FSR due to direct interaction between ground and feet [13-26]. Since plenty of application discus in recent days; to used FSR as the Gait analysis is their main application. Not only that making artificial electronic Knee with self intelligence is upcoming area in the field of FSR. Combination of FSR sensors with Gyro sensor makes system much better for others applications [13-14].

At the present time, there are many potential applications of gait analysis in ambulatory systems. Wearable devices can be broadly categorized according to their primary function into monitoring systems, rehabilitation assistance devices and long-term medical aids. The primary function of monitoring devices is to provide dedicated monitoring of specific medical conditions. Rehabilitation devices are those that can actively assist in the rehabilitation process while retaining a monitoring element. Long-term medical aids are the devices used to improve the user's quality of life, and have been described as assistive technology devices.

Firstly, it is used in clinical disease diagnosis. Some diseases that mainly cause abnormal gait, such as the central nervous system disease, the Cerebro-vascular disease, the early Parkinson disease, osteoarthritis, and so on, may be found through long-term gait analysis.

Secondly, the healthcare and disease prevention like Parkinson's and Alzheimer's. This is done mainly by the real-time gait analysis, when the unexpected abnormal signals output, that shows some aspect of the body in poor condition. This exception alert can remind the user or guardian timely to pay attention. Because of the earliest symptoms of the disease could be found, you could get treatment in time to prevent the disease progression or down to danger. Also healthcare includes prevention falls in elderly persons with a high fall risk.

Thirdly, the ambulatory gait analysis system will serve as professional reference for screening disability rehabilitation planning. This could be demonstrated by identifying early symptoms of some diseases like osteoarthritis and providing proper individualized functional training plans for the patients, in order to prevent grievous injury to joints. It will help for gait corrections based on the study of historical gait characteristics.

Fourthly, physical activity patterns assessment. One study provided evidence that wearable sensors offered a feasible tool for the assessment of several aspects of physical activity in older people. The results show that older adults emerge as significantly less active than young adults. The wearable sensor system can provide valuable data for the assessment of volumes, intensity and patterns of physical activity across the daily and weekly patterns of all people. This will help inform physical activity promotion strategies and guidelines for health-related physical activity that are specifically tailored for the needs not only of the elderly but also of all age populations.

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