Human activity tracking using wearable sensors in loose-fitting clothes: survey

Maryam Adnan Fadhil, Waleed F. Shareef
Department of Control and System Engineering, Faculty of Engineering, University of Technology, Baghdad, Iraq

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ABSTRACT

Human activity tracking using wearable technology is an important research field of study and is employed in many applications such as healthcare, aged care, fitness, and tracking activity. Although this field has been well addressed by researchers in the last decade that most of the research is done with tightly fixed sensors (either to the body or to the tight garment), while in contrast, the majority of our daily clothes are loosely fitting so we must be interested in this fields but the main challenge in tracking/recognizing activities in loose clothing is the higher level of noise generated by the movement of clothing compared fixed sensor. This paper reviews recent research on human activity tracking techniques that use sensors that are attached or embedded in loose-fitted clothes. It is predicted from recent studies that many low-cost, reliable, and socially acceptable wearable devices will be available to aid activity tracking. Survey also predicts an increase in the interest for wearables in loose-fitting clothes due to their wide real-time applications. Most of the reviewed work based heavily on off-shelf microcontroller board and sensor, which are characterized by their moderate performance. Hence most of the reviewed work used machine learning to enhance results classification.

Corresponding Author:

Maryam Adnan Fadhil
Department of Control and System Engineering, Faculty of Engineering, University of Technology
Baghdad, Iraq
Email: cse.20.07@grad.uotechnology.edu.iq

1. INTRODUCTION

Everybody deserves to live independently, emerged technology communications and sensors give easy life attention to the people to make them control their life as much as possible, it lets users know what is around them, detects objects, and provides continuous monitoring by collecting various measurements by wireless sensor networks (WSN) [1], including in the huge collection of applications mainly in medical health systems [2], such as glycemia regulation [3], blood glucose regulation [4], hypoglycemia prediction and avoidance [5], fingerprint recognition [6], remote electrocardiography (ECG) signal monitoring [7], control systems for the handicapped [8], wheelchair movement control system [9], another field that benefited from these technologies include detecting and classifying moving vehicles [10], vehicle control [11], a mobile robot for surveillance applications [12], sensors technologies are proven extremely useful even in applications that predominantly require human intervention such as farm management [13], or detect crime locations [14]. With the development of wearable sensor technology, it has become the focal point of interest for lots of recent research in activity monitoring in many areas because it is easy to wear as external accessories embedded in clothing, or implanted into the body especially in human activity. People's daily lives now depend heavily on wearable technology and inexpensive sensors to monitor activity. Using inertial sensors, activity recognition will be simple due to the advantages of inertial sensors in wearable technology for motion monitoring and recognition [15], as well as the fact that they can operating without the need for external ambient-based sensors like radar, cameras, or infrared sensors or any limitations on operating conditions [16]. Activity tracking is a field of study related to the spontaneous detection of daily routine activities performed to identify the specific movement or action of a person based on time series recordings using sensor data [17], to benefit from it in identifying the type of activities that an individual does, technology movements are often typical activities performed indoors [18], such as walking, talking, standing, sitting, running, and jogging [19].

These sensors may be on the hand, leg, finger, wrist, or some sensors embedded in clothes that mean smart clothes. Which are two categories of clothing tight clothes and loose-fitting clothes. We will be interested in the sensors that are embedded in loose-fitting clothes, while a lot of recent study in the field of wireless sensing has concentrated on touch-sensitive or tight-clothed wearable devices like wristbands, phones, and glasses. Smart loose apparel, or the integration of wearables into loose clothes, has received very little attention loose garments, on the other hand, have been gradually growing and are expected to have one of the fastest growth rates among wearable in the next period. Smart sensing garments can enhance the functionality of clothing beyond aesthetic and protective purposes.

In contrast to sensors that are attached to the skin, with the emergence of technology and device sensors mixed with fabrics. The fast improvement in fabric generation and the small length of the electronics used caused the combination of various kinds of sensors in fabrics, which caused the emergence smart loose clothes, confirming fabrics can be used continuously and are an essential substrate for wearable devices. ensing clothing must suit the wearer comfortably and properly by covering significant portions of the body surface. It became the crucial foundation for widespread physiological signal and movement monitoring in daily living you may find out an extensive variety of body postures and sports that create new possibilities in tracking fitness and health to recognize the activity it will be using machine learning algorithms to know the activity from the data in the sensor at loose-fitting clothes. They're utilized in extensive packages within the subject of current sports and rehabilitation solutions, medical, entertainment, security, and industrial fields.

The content of this paper is organized as: section 2 summarizes the recent related work that presented a survey on wearable technology in general. Section 3 presents a brief explanation of the wireless sensor data mining (WISDM) database, a potential online dataset for wearable technology. Section 4 defines what loose-fitting clothes and loose-fitting wearables within the scope of this paper mean. Section 5 reviews the very few related works (to the best of our knowledge) that addressed this specific issue of loose-fitting wearable, and summarize these works main setup feature and sample sizes. Finally concludes the work in section 6.

2. RELATED WORK

Many recent types of research are focused on providing a more thorough introduction to be given to newcomers and researchers to wearable and track human activity with wearable sensors. One of the most helpful technologies for many areas is sensor-based human activity tracking. These wearable sensors have become an important part of increasing efficiency, improving applications, improving quality of life, and providing safety. Several recent authors present an evaluation of wearable sensors for activity tracking focusing on healthcare programs [20], in monitoring vital signs including heart, breathing, and body acceleration sensors [21], coronavirus disease of 2019 (COVID-19), heart rate, temperature [22], rehabilitation [23], stroke patients [24], recognize hand gestures [25], sports activities [26], analyze the behavior of human arm movements [27], and monitor for prosthetic limbs [28]. With the development internet of things (IoT), which will be one of the latest technologies in the current era of wearable technology, the advances in sensor technologies will evolve these sensors, and hence the revolution of Internet of Things programs will increase very quickly [29]. It is a attracted interest and became a controversial topic in this field [30]. The concept of the Internet of Things involves a collection of devices like sensors and electrical devices that are connected to the Internet through computer or portable devices [31]. It also has been used in many applications with wearable sensor such as in healthcare [32], smart city [33], fire detection [34], environmental protection [35], surveillance systems [36], and robotic monitoring [37]. All of these applications use sensors to collect data, which is then sent to cloud servers for analysis and review. These data can then be analyzed by various algorithms to determine the type of activity [38].

The surveys were tailored toward many areas of greatest use of creating new medical and monitoring systems, such as those found in [39], the most promising solutions to improve the everyday lives of older people. Another study about the development of wearable sensor-based systems for health monitoring by providing low-cost solutions, and predicted to allow both disease prevention and early detection of different medical conditions [40], this approach survey about provides detailed of wearable sensor systems for monitoring infants' movements [41]. Kumari *et al.* [42] reviewed survey about activity tracking technologies for the care of elderly persons by wearable sensors have been developed to monitoring electrooculogram (EOG) and electroencephalogram (EEG), it can provide for the disease diagnosis and treatment. Another study reviewed sensors for fall protection for the elderly and human gait analysis are studied concerning the state of the art in wearable sensor technologies [43], reviewed a survey about a systematic of wearable sensors and techniques used in real-time gait analysis [44], detecting the type of activity get to monitor the player's activity during his sporting activities [45], and state-of-the-art human activity tracking based on wearable sensors according to their response time and learning scheme, flexibility, and recognition accuracy [46]. Finally, a reviewed survey about the state-of-the-art fall detection and prevention systems [47], and more many.

There are several authors interested in wearable technology in several fields. From the aforementioned surveys, it is clear that the vast majority of the research done in the field of human activity tracking using wearable focused on sensors that are attached firmly to users such as watches, glasses, and skin fixtures. In contrast, it goes without explanation that most of our clothing is loose-fitted garments. This leaves much research area to be covered in the field of wearable sensors.

However, there is an emerging tendency to tackle the problem of loose-fitted sensors in various applications. Unlike other surveys, this paper reviews very few researches that addressed the loose-fitting wearable. Several authors have talked about how sensors are incorporated into loose clothing and identify human activity and ways to detect and categorize activities using wearable sensors that are not firmly attached or fixed to the users.

3. WISDM PROJECT

Recently, there have been many online-available data base regarding the human activity tracking, WISDM is one of the widely referenced data base. Although the work of WISDM, project does not include loose-fitting clothes examples, it is worth mentioning here due its importance in the field of wearable technology. The data base [48], have been cited in more than 2000 papers, which make the data set a reliable reference point for comparisons with new cases such as loose-fitting wearable.

The WISDM laboratory is directed by Dr. Gary Weiss, a professor in Fordham University's School of Computer and Information Sciences. The lab is focused on collecting sensor data from smartphones and other recent mobile devices (such as tablet computers and music players) and mining this sensor data for useful knowledge. WISDM dataset is used constantly expanding to include new segments in mobile application development and development of original scope to include areas such as healthcare, architectural studies, and analytics. The datasets contain data collected through controlled, laboratory conditions. The dataset from the WISDM to human activity tracking include walking, jogging, upstairs, downstairs, sitting, standing, the raw data refer to the original data collected from the sensors, while transform data refer to the same data sets but after applying fast Fourier transform (FFT) algorithm. Table 1 and Table 2 summarize the database sample sizes and classes.

Table 1. WISDM dataset

Description	Raw time series data	Transformed data
Number of examples	1,098,207	5,424
Number of attributes	6	46
Missing attribute values	None	None

Table 2. WISDM class distribution

Type	Number	Percentage of total data (%)	Type	Number	Percentage of total data (%)
Downstairs	122,869	11.2	Downstairs	529	9.8
Sitting	59,939	5.5	Sitting	307	5.7
Standing	48,395	4.4	Standing	247	4.6
Walking	424,400	38.6	Walking	2,082	38.4
Jogging	342,177	31.2	Jogging	1,626	30.0
Upstairs	122,869	11.2	Upstairs	633	11.7

4. LOOSE-FITTING CLOTHES TERMINOLOGY

Loose-fitting clothing is generally worn to allow better body movement and flexibility. As our arms and legs are not tied up in narrow sleeves, we can bend and roll without worrying about sitting. It is very important in our daily life if we have many tasks in the day, we should wear comfortable clothes so as not to be disturbed in our work. It's also important to think about ventilation, support, and comfort when it comes to clothing. In the fashion business, other names may be used to indicate similar meanings e.g., baggy, wide, comfortable clothes to mention a few. However, as mentioned before that most of our clothes fall in the loosely fitted category. The loose-fitting cloth category is so versatile it also includes workers' and laborers' overalls and jackets, traditional clothes as well as parties' dresses and attires as shown in Figures 1(a) to (d).

With sensors adaptation in clothes, and emerged technology knowing smart clothes that have embedded sensors in these clothes, in contrast, most sensors and applications benefit from the close proximity to the fabric body and ease of suitability of a garment-embedded acceleration sensor to recognize body postures. Previous studies have confirmed that people frequently perceive tight-fitting clothing as uncomfortable. On the other hand, new study prototypes based on loose-fitting sensing clothing showed that postures and activities may still be recognized using sensors with less accuracy and difficulty selecting the correct sensor positions.

(a) (b) (c) (d)

Figure 1. Examples of loose-fitting clothes: (a) firefighter suit (left), (b) Indian traditional sari (middle left), (c) middle eastern traditional thawb (middle right), and (d) lab-coat (right)

5. RECENT WORK ON LOOSE-FITTING CLOTHES

This section reviews previous works related to activity tracking using wearable sensors in loose-fitting clothes. Although the works in this area are very scarce, this section reviews them and groups them by their applications into three categories, the first is related to health and medical applications. The second category is related to posture and gesture detection in general purpose wearable applications. The last category is about automatic human pose annotation to detect several human postures, activity and/or gait rate.

5.1. Health applications

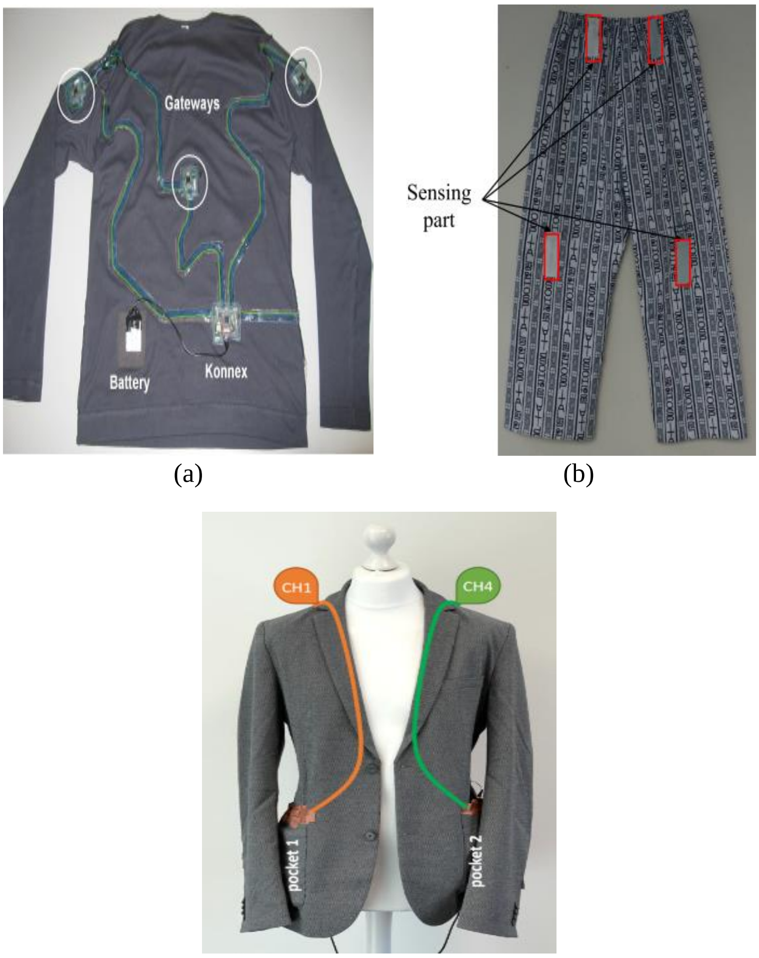
One of the most important uses for wearable technology is to detect and measure human movement in loose-fitting clothes, it can detect the movement of all parts of the human body depending on the type of motion sensor data using activity classifying algorithms [49]. Classification is an essential basis for determining activity in various health-related applications, including assistance for motor rehabilitation to restore the flexibility of movement to maintain upper body postures during daily activities, sensors must be lightweight and unobtrusive to be suited to the patient's body [50]. In the medical field, researchers are typically interested in patient activity tracking when the patient wears loose-fitting clothing. In Harms *et al*. [51] suggested a shirt with a loose-fitting long sleeve equipped with acceleration sensors as shown in Figure 2(a) to determine the postural resolution for applications in movement rehabilitation with loose-fitting clothes, they conducted several trials with 12 posture types and relevant for shoulder and elbow joint rehabilitation for 8 users, their results reached the classification ratio of 89% on average. In a previous study [52] show the study used a loose shirt worn by 7 participants, with classification accuracy using sensor data on average of 75%, to examine the effects of a loose-fitting garment on the automatic recognition of 21 postures pertinent to shoulder and elbow rehabilitation. Another system for patient motion and posture monitoring was presented in [53] proposed system uses flexible piezoelectric sensors attached to the knee and hip parts on loose pants shown in Figure 2(b), to perform gait recognition it employs 10 subjects and 5 movements each movement include walking, standing, supine, sitting, and sitting knee extension, the proposed system achieve 93% classification accuracy.

A similar system for patient position monitoring based on flexible sensors is presented in [54], the sensors are placed in parts of the loose patient clothing near to the knee and hip, the detectable postures are based on 6 human motions for 3 patients. Their results show classification rate of over 88%. Finally, in [55] proposed comprehensive modeling and simulation to predict recognition performance in casual loose-fitting garments, they use acceleration sensors that are attached to the forearm and upper arm to defind the action. Table 3 highlights the main specifications of the aforementioned researches.

5.2. Posture and gesture detection applications

Motion recognition is a topic created by dialects to interpret human signals through a mathematical algorithm [56], which are represented by hands with assistance from facial expression and body posture [57]. Many researchers have been interested in designing a wearable system for detecting body postures and gestures that do not require sensors attached tightly to the body, using sensor system embedded in loose-fitting clothes as in [58] proposed a proposal to address the problem of human posture detection by attaching sensors in loose-fitted casual jacket, they implement a conventional deep learning model convolutional neural networks (CNN) – long short-term memory networks (LSTM), to overcome the noise induced by the loose-fitting of the sensors compared to the human skin attached sensors. Bello *et al.* [59] a theremin musical instrument that is integrated into a typical man's blazer is used by the wearable system to identify body postures and gestures in a loose item of clothing like a blazer as shown in Figure 2(c), experiments were conducted on 14 participants and achieves average recognition accuracy between 86% – 97%.

A different approach was implemented by [60] to investigate the use of loose-fitted sensors effect on classification results, their approach involves a piece of fabric attached to the pendulum piezo-resistive sensors that are attached at three points – the tip of the pendulum, the center of the fabric, and the tip of the fabric – swing freely in gravity on a single plane. The results show contrast in different types of measured motion, results also show that it can be distinguished between different movements using support vector machine (SVM) and digital rights management (DRM) classifiers. Finally, a system with a fabric-based Sensor to overcome loose clothing obstacle (Tribexor) in [61] recognizes a variety of activities using inertial sensors on wrist-worn devices, experiments were conducted on 14 people, who were asked to wear a loose shirt with the proposed system sewn on. the results showed that the SVM classifier can successfully classify the activities with 91%. Table 4 highlights the main specifications of the aforementioned researcher.



(a) (b)

(c)

Figure 2. Examples of some recent works on loose fitting wearables: (a) loose long sleeve shirt, (b) loose pants, and (c) loose blazer with textile cables as capacitive antennas

Table 3. Summary of recent work on loose fitting wearables in health monitoring applications

Ref	Type clothes	Sensor	Sample size	Classification method	Accuracy (%)
[51]	Loose long sleeve shirt	Accelerometer	8	Nearest centroid	89
[52]	Loose long sleeve shirt	Accelerometer	7	Nearest centroid	75
[53]	Loose pants	Flexible piezoelectric	10	Rule-based	93
[54]	Loose patient scrubs	Flexible piezoelectric	3	Rule-based	88
[55]	Shirt loose-fitting	Accelerometer	5	Rule-based	96

Table 4. Summary of recent work on loose fitting wearables in posture and gesture detection

Ref	Type clothes	Sensor	Sample size	Classification method	Accuracy (%)
[58]	E-jacket	Optical-strain	12	CNN-LSTM	90
[59]	Blazer	Textile cable	14	DeepConv-LSTM	86 – 97
[60]	A fabric substrate loose-fitting	Piezo-resistive	1	(SVM) and (DRM)	70 – 95
[61]	Loose shirt	Inertial sensors	14	SVM	91.3

5.3. Automatic human pose annotation applications

Estimating the 3D shape of the human body in motion is important for many applications, including those dealing with loose-fitting clothing, to know the type of activity used in movements and activity tracking. The system presented in [62] is capable of determining the frame of the body and its movement or knowledge of the sex of the individual through several sensors placed in loose clothing such as accelerometers in slacks, skirts, and loose frocks, participant asked to do 4 different movements including walking, transitions, sitting and standing mounted two sensor pairs on the upper thigh and ankle, and one sensor pair on the waist to monitor upper body movements, and using the decision tree algorithm, classification accuracy is almost 88% for walking but it is much lower for other activities. In Viswakumar *et al.* [63] introduced a user-friendly, cost-effective approach to human gait analysis using CNN algorithm, experiments conducted with 10 people while they are wearing Indian attires (dhoti), using OpenPose system was able to reach an accuracy of 83%. A similar system for body annotation is presented in Matsumoto *et al.* [64] it proposed a framework to annotate the body key points under the loose-fitting clothes in the movement of people while doing several different motions to know the body position. Finally, in [65] Bayesian gait-based gender identification (BGGI) technique using deep learning in a different angles is presented several types of loose clothes that differ widely were tested but in summary comparable classification accuracies were achieved. Table 5 highlights the main specifications of the aforementioned researches.

Table 5. Summary of recent work on loose fitting wearables in automatic human pose annotation

Ref	Type clothes	Sensor/system used	Sample size	Classification method	Accuracy (%)
[62]	Loose frock	Tri-axial accelerometers	1	Decision tree	88
[63]	Dhoti	Camera with MoCap system	10	CNN	83
[64]	Loose-fitting clothes cover the body	MoCap system	1	Supervised learning	73
[65]	Scarf with a loose dress	BGGI technique	18	Deep learning	98

6. CONCLUSION

In this article, we presented a survey of research in the field of activity tracking and monitoring using wearable sensors in loose-fitting clothes in some application such as health, tracking, and automatic human pose annotation. Detecting and measuring human movement is one of the most urgent applications of wearable technology in loose-fitting clothes. Activity tracking and monitoring using wearables have been extensively studied in the last decade, and a plethora of surveys were presented. However, none of the surveys (to the best of our knowledge) tackled the topic of wearable sensors in loose-fitted clothes. In fairness, this topic is relatively new and the research done around it is scarce. On the other hand, the majority of our clothes can be classified as loose-fitting to some degree, so it is expected to see an increasing interest in this field within the next few years. Therefore, it is worth to review and accentuate the work in this area. Related papers show promising results, where postures and activities could still be recognized at reduced accuracy using the same typical sensors (such as accelerometer and piezoelectric sensors) and the same machine learning algorithms. Researchers used several machine learning algorithms (e.g., SVM, CNN, and decision tree) to classify several types of actions and movements, and achieved classification accuracies of more than 70%. One research used deep learning and achieved almost 100% classification accuracy. However, the results depend not only on the cloth material and garment shape but also on the placement of the sensor within the garment. In contrast to skin-mounted sensors, smart sensing in loose-fitting clothing can have benefits more than only being protective and aesthetically pleasing.

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BIOGRAPHIES OF AUTHORS

Maryam Adnan Fadhil is M.Sc. student in the Department of Control and System Engineering, University of Technology, Iraq, and holds a Bachelor's degree from the Department of Computer Engineering, University of Diyala, Iraq. She can be contacted at email: cse.20.07@grad.uotechnology.edu.iq.

Waleed F. Shareef is a lecturer in Control and System Engineering Department, University of Technology-Iraq, he received B.Sc. and M.Sc. in Computer Engineering from the Control and System Engineering Department, University of Technology, Iraq, and Ph.D. in Electrical and Computer Engineering from Newcastle University, UK. His research interests are mainly in wireless sensor networks, wearable technology, and monitoring system. He can be contacted at email: waleed.f.shareef@uotechnology.edu.iq.