Gait disorder rehabilitation using vision and non-vision based sensors: A systematic review

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Abstract

Even though the amount of rehabilitation guidelines has never been greater, uncertainty continues to arise regarding the efficiency and effectiveness of the rehabilitation of gait disorders. This question has been hindered by the lack of information on accurate measurements of gait disorders. Thus, this article reviews the rehabilitation systems for gait disorder using vision and non-vision sensor technologies, as well as the combination of these. All papers published in the English language between 1990 and June, 2012 that had the phrases "gait disorder", "rehabilitation", "vision sensor", or "non vision sensor" in the title, abstract, or keywords were identified from the SpringerLink, ELSEVIER, PubMed, and IEEE databases. Some synonyms of these phrases and the logical words "and", "or", and "not" were also used in the article searching procedure. Out of the 91 published articles found, this review identified 84 articles that described the rehabilitation of gait disorders using different types of sensor technologies. This literature set presented strong evidence for the development of rehabilitation systems using a markerless vision-based sensor technology. We therefore believe that the information contained in this review paper will assist the progress of the development of rehabilitation systems for human gait disorders.

KEY WORDS: Gait disorder, rehabilitation, sensor technology

INTRODUCTION

Gait is the general procedure of walking and a normal gait requires the integration of the cerebellar, sensory, visual, vestibular, muscular, basal ganglia, and auditory systems. Any abnormality in these systems can result in gait disorder, which can be rehabilitated through clinical treatment, exercise, and a few other rehabilitation systems. However, the appropriate rehabilitation system for a gait disorder requires an analysis of the gait parameters. In addition to the kinematic and kinetic gait data, it is essential to evaluate the temporospatial parameters to obtain a more accurate understanding of the gait disorder [1]. To explore the rehabilitation systems for gait disorders, we found 91 articles on human gait disorder for rehabilitation and on human motion tracking and analysis through a systematic search from the online database of highly reputable publishers. We scanned all the collected articles individually and identified and analyzed the key points of each article. We therefore discovered that the rehabilitation systems of gait disorders utilize different types of sensor technology based on the gait disorder classification. Gait disorders are classified as one of 7 types: peripheral sensory, peripheral motor, spasticity (hemiplegia, paraplegia), Parkinsonism, cerebellar palsy, cautious gait, and frontal-related gait [2]. According to the gait disorder classification, we found that, from the 91 originally identified publications, 7, 28, 21, 8, 7, 8, 3, and 2 articles discussed peripheral sensory, peripheral motor, spasticity (hemiplegia), spasticity (paraplegia), parkinsonism, cerebellar palsy, cautious, and frontal-related gait disorders, respectively. Furthermore, we determined that researchers developed the gait disorder rehabilitation systems using different types of sensor technologies, such as vision-based, non vision-based, robotics-based, and the combination of vision and non vision-based sensor technologies. In this review, we classified the sensor technologies used as vision-based sensor technology (VBST), vision plus other-based sensor technology (VOBST), and other-based sensor technology (OBST), where other refers to either non vision or robotics. We then sorted the developed rehabilitation systems according to this new sensor technology classification. We realized that some of the rehabilitation systems that use VBST utilize markers, whereas other researchers did not use any markers during the video recording. We then identified the gap in a rehabilitation system using markerless VBST for each class of gait disorders. Therefore, the future of rehabilitation research for gait disorder will focus on the use of markerless VBST.

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TABLE 1. Gait disorder classification

Gait disorder type	Conditions of gait disorder	Syndromes of gait disorder
Peripheral sensory	Sensory ataxia (posterior column, peripheral nerves)	Unsteady, uncoordinated
	Vestibular ataxia	Unsteady, weaving ("drunken")
	Visual ataxia	Tentative, uncertain
Peripheral motor	Arthritis	Avoids weight bearing on the affected side
		Antalgic Shortened stance phase
	Dystrophic or Myopathy or neuropathy or Slapping or Steppage	Waddling gait (pelvic girdle weakness)
		Waddling gait and foot slap (proximal motor neuropathy)
		Steppage gait and foot slap (distal motor neuropathy) with ankle dorsiflexion and foot drop
Spasticity	Hemiplegia/paresis	Leg swings outward and in semicircle from hip, knee may hyper-extend, ankle may undergo excessive plantar flex and invert
	Paraplegia/paresis	Both legs circumduct, steps are short, shuffling, and scrapinglegs scissor
Parkinsonism		Small shuffling steps, hesitation, festination
		Propulsion, retropulsion, en bloc
		Arm swing absent
Cerebellar ataxia		Wide-based with increased trunk sway and irregular stepping, especially on turns
Cautious gait		Fear of falling with appropriate postural responses
		Normal to widened base, shortened stride
Frontal-related gait disorders	Cerebrovascular disease	Gait ignition failure, frontal gait disorder, frontal disequilibrium
	Normal pressure hydrocephalus	May also have cognitive, pyramidal, and urinary disturbance

We organized our review paper as follows. We first discuss general information on gait disorder, including the associated classifications, conditions, and syndromes. We then describe the sensor technologies that have been used to develop rehabilitation systems for gait disorders. Following this, we discuss the different keywords that were used in our systematic article searching procedure and the resulting gap finding tree. Next, we summarize the number of scanned articles and organize them by publishing date and the type of sensor technology described in the article. We also summarize the rehabilitation system used in each article according to the gait disorder classification in this section. In the subsequent section, we summarize the key points of each scanned article and discussion. Finally, we focus on future research in the field of gait disorder using markerless VBST.

Gait Disorder

From the introduction, it is clear that our main aim is to present a rehabilitation system for gait disorders. A normal procedure of walking is called a gait. Any abnormality in the cerebellar, sensory, visual, vestibular, muscular, basal ganglia, or auditory systems can result in a gait problem, or gait disorder. It has been found that the exact nature of a gait disorder depends on the particular defect in the brain, spinal cord, peripheral nerves, muscles, or bone joints [3]. Moreover, in order to determine the proper rehabilitation system for a gait disorder, it is necessary to classify the gait disorder according to its clinical view. The clinical definition of the types, conditions and syndromes of gait disorders are described in Table 1 [2].

Gait Disorder Rehabilitation Using Vision- and Non Vision-based Sensors

In the previous section, we discussed the causes and syndromes of gait disorder. The causes of a gait disorder can be recovered using a proper rehabilitation system. However, the function of a rehabilitation system is to partially or fully restore the patient's physical, sensory, and mental capabilities that resulted in the gait disorder [4]. A more extensive longitudinal study, in which the patients with gait disorders are able to cross obstacles normally after rehabilitation, is recommended to determine whether functional balance control is attained [5]. A gait disorder is one of the most common medical problems that can be recovered using the proper rehabilitation system. The rehabilitation systems

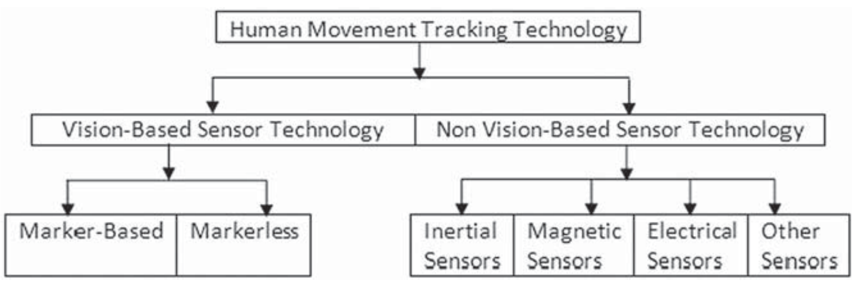

FIGURE 1. Classification of human movement tracking technology based on sensor technologies.

for gait disorder can be developed using sensor technology. Moreover, during the rehabilitation period, the movement of the gait disorder patient needs to be assessed to determine which gait parameters are not functioning properly. Therefore, it is vital and necessary to track the gait parameters of the movement of the patient during rehabilitation. These parameters can be measured using sensor technologies to generate real-time data that dynamically represent the patient's full or partial body [6]. In this paper, we classified the measurement of human movement tracking technology on the basis of the sensor technology used, as shown in Figure 1.

Vision-based sensor technology (VBST)

It is difficult to evaluate the gait parameters of a patient by observing the gait cycle with the naked eye. However, VBST is a type of optical sensor that utilizes cameras to track the human movement and thus more accurately estimate the movement parameters and position. Therefore, the video recording of the gait analysis has become popular in the clinical setting for the rehabilitation of gait disorder. The VBST tracking system has been used by researchers in 3 different ways, including technologies that are marker-based, markerless, or a combination of marker-based and markerless.

Marker-based VBST. The marker-based VBST is a technique to track human movement through the use of optical sensors (cameras) that capture the identifier points of the human body. The marker-based tracking system reduces the hesitation of the subject movements due to the unique appearance of the marker. The most popular marker-based tracking systems in the current market are Qualisys, VICON, CODA, ReActor2, ELITE Biomech, APAS, and Polaris. However, one the major problem of using these optical sensors and markers is that it is difficult to use these to determine the exact sense joint rotation, which leads to the infeasibility of creating an accurate 3-D model of the sensed object [7].

Markerless VBST. The problem with using marker-based techniques can be solved using markerless techniques, which use external sensors, such as cameras, to track the movement parameters of the human body. The camera used should have a high resolution to ensure high accuracy [8]. Therefore, markerless vision-based sensor technology has high accuracy and compactness, computationally inexpensive and low cost. The only drawback in the use of this markerless technique is occlusion [9] and this problem can be overcome by template matching, which carries both the spatial information and the appearance of the object [10].

Combination of marker-based and markerless VBST . The combination of marker-based and markerless VBST combines the marker-based and markerless tracking systems. Because this tracking technique is not studied again in our analysis, it will not be discussed further.

Non vision-based sensor technology (NVBST)

The non-vision based sensor technology is another technique that can be used to track the human movement parameters with a sensor. In NVBST, the sensors are attached to the human body to collect the data over time. Therefore, it is possible to develop rehabilitation systems for gait disorder using NVBST. In this review, we classified the various NVBSTs used as inertial sensor, magnetic sensor, electrical sensor, or other sensor.

3.2.1 Inertial sensor. The inertial sensor technology detects and measures acceleration, angle, vibration, movement, and multiple degrees-of-freedom. The most common uses of inertial sensors are accelerometers, gyroscopes, MT9, and G-Link. A 5 sensor module, consisting of two accelerometers and one gyroscope, has been used to capture the motion of a lower limb and the results showed that the knee replacement and rehabilitation systems improved the coordination score [11]. The MT9 inertial sensor can measure the real-time "three dimensional" movements of a subject [12].

Magnetic sensor. Magnetic sensors are used to measure the speed, rotational speed, linear position, and linear angle and position in automotive, industrial and consumer applications. It provides real-time data output, rapidly capturing significant amounts of motion data. The magnetic tracking system can be used to characterize the pendulum kinematics of the leg and thus to quantify the spasticity of the quadriceps femoris muscles of stroke patients [13].

Electrical sensor. Electrical sensors examine the change in electrical or magnetic signals that occur as a result of an environmental input. Therefore, an electrical sensor can be used for the measurement of the electrical activity of muscle contraction during gait. An EMG study was used for the clinical analysis of qualitative gait evaluation based on the repetition, symmetry, and smoothness characteristics of the activation patter of the walking muscle [14]. The EMG measurements showed that muscle weakness and lack of reflex adaptation can result in wrist joint stiffness during an active posture task [15].

Others sensors. The gait speed can be analyzed by using a sensor to assess the walking performance of gait disorder patients. The mean gait speed and the temporal symmetry ratio during each two-minute interval of a 6-minute walk test were examined using a pressure-sensitive mat [16]. The ground reaction force measurement platform (Kistler 9281B) sensor was used to apply artificial neural networks for the identification of gait malfunction [17]. The M3D sensor system, which integrates a mobile force plate, 3D motion analysis units and a wireless data logger, was used to obtain 3D motion and force data on the gait of a patient in various walking environments. A quantitative gait analysis method based on these ambulatory measurements is proposed for the implementation of human lower limb kinematic and kinetic analyses [18]. The pressure sensitive GAITRite system was used to determine the effect of muscle fatigue on gait characteristics under single and dual-task conditions in young and older adults. This study found that muscle fatigue significantly decreased the single-task gait velocity and stride length in young adults and significantly increased the dual-task gait velocity and stride length in older adults [19]. The temporal and spatial gait parameters, including self-selected velocity, cadence, stance time, swing time, double support time, step length, and width of the support base, were assessed through the use of an electronic gait mat (gait Mat II, EQ Inc.) [20].

METHODOLOGY

We used a systematic searching procedure to identify articles on gait rehabilitation from an online digital database of highly reputable publishers. We used a few keywords and their synonyms in combination with some logical operators in our searching procedure. These search terms are listed in List 1. We then selected those papers that were published in English from the year 1990 to June-2012. After collecting the articles, we scanned each article individually and identified its key points, which we then used to draw the gap analysis tree shown in Figure 2. We then analyzed all the collected articles according to Figure 2. From the bottom of the gap analysis tree, we determined which systems have been developed and found out that there is still a large amount of research required on the development of a system for the rehabilitation of gait disorder using markerless VBST.

List 1: Overview of the search terms used in the article collection procedure

- Gait Analysis-Review
- Survey of Gait Analysis
- Clinical Gait Analysis-Review
- Survey of Clinical Gait Analysis
- Gait Analysis AND Rehabilitation-Review
- Survey of Gait Analysis AND Rehabilitation
- Gait Disorder Analysis AND Rehabilitation-Review
- Survey of Gait Disorder Analysis AND Rehabilitation
- Gait Analysis
- Gait Analysis AND Rehabilitation
- Gait Disorder
- Gait Disorder Rehabilitation
- Gait Disorder Analysis
- Gait Disorder Analysis AND Rehabilitation
- Human Motion Tracking
- Human Motion Tracking AND Gait Analysis
- Human Motion Tracking OR Gait Analysis
- Human Movement Tracking
- Human Movement Tracking AND Gait Analysis
- Human Movement Tracking OR Gait Analysis
- Gait Disorder AND Clinical
- Gait Disorder Rehabilitation AND Clinical
- Clinical Gait Analysis
- Clinical Gait Analysis AND Rehabilitation

RESULTS

Using our systematic article searching procedure, we found 91 articles that have published in highly reputable journals between 1990 and June, 2012. These articles were then organized according to the publishing date and the sensor technology used; the numbers of respective articles for each category are shown in a tabulated format in Table 2. From the 91 articles collected, we found 84 articles that discuss gait disorders and 7 that were not related to gait disorders. Therefore, we did not consider the latter in further analysis. The outcomes of the 84 articles on gait disorder are summarized according to the gap analysis tree that was drawn (Figure 2).

"Peripheral sensory" gait disorder

There were 7 articles on peripheral sensory gait disorder. Of these, 3, 3, and 1 articles described rehabilitation systems for this disorder using VBST, VOBST, and OBST, respectively. The article that described the use of OBST involved a gait disorder with unsteady balance perturbation [9], whereas the articles that discussed the use of VOBST focused on gait disorders with symptoms: unsteady of fall control [1, 21], and unsteady of balance control [22]. In addition, out of the 3 articles that discussed VBST, 2 articles used marker-based technology and 1 utilized markerless technology. The articles that discussed the development of marker-based VBST discussed gait disorders with symptoms of unsteady balance control [5] and the inability to walk in a straight line [23], whereas the article on markerless VBST focused on an unsteady gait cycle [24].

"Peripheral motor" gait disorder

We found 28 articles on peripheral motor gait disorder. Of these, 10, 8 and 10 manuscripts reported the use of VBST, VOBST, and OBST, respectively. Those articles that discussed the use of OBST described the use of this technique in the rehabilitation of knee and hip neuropathy [11], muscle weakness dystrophy [14, 15, 19], ankle dorsiflexor slapping [25], foot slapping [26], spinal cord steppage [27], foot drop steppage [28], weight bearing motor control [29], and knee arthritis [30]. The articles that discuss the use of VOBST focus on the following gait disorder symptoms: steppage of central cord syndrome [31], motor control of foot control [32], slapping of toe clearance and velocity [33], motor control of Prader-Willi, Down syndrome [34], dystrophic of muscle

TABLE 2. Articles organized by publishing date and sensor technology

Year	Article	Vision Based Sensor				Vision + Other Based Sensor				Other Based Sensor			
		N	GD	J	C	N	GD	J	C	N	GD	J	C
2012	8	4	4	4		2	2	2		2	1	2	
2011	12	3	3	1	2	5	5	4	1	4	4	3	1
2010	12	6	6	4	2	4	4	3	1	2	2	2	
2009	15	4	3	3	1	2	2	1	1	9	9	7	2
2008	10	6	6	4	2	2	2	2		2	2	1	1
2007	5	1	1	1		3	3	3		1	1		1
2006	4	1	1	1		1	1	1		2	2	2	
2005	2					1	1		1	1	1		1
2003	2	1			1					1		1	
2002	2	1	1		1	1	1	1					
2001	2	1	1	1						1	1	1	
2000	4	1	1	1		1	1	1		2	2		2
1999	7	2	2	2		5	5	5					
1998	1	1	1		1								
1997	1									1			1
1996	1					1	1	1					
1994	1									1		1	
1993	1					1			1				
1990	1					1	1	1					
Total	91	32	30	22	10	30	29	25	5	29	25	20	9

N=number of article, GD=gait disorder related article, J=journal article, C=conference article

weakness [35, 36], neuropathy of motor fatigue [37], and neuropathy of chronic low back pain [38]. Of the 10 articles on VBST, 8 articles discuss marker–based VBST and 2 articles focus on markerless VBST. The articles on marker-based VBST discuss motor control of abnormal gait [39], neuropathy of ankle dossal-planter-flexion [40], motor control of weight bearing [41], neuropathy of lower limb joint [42, 43], motor control of cerebral palsy [44], arthritis of trunk control in children [45], and neuropathy of pelvis [46], whereas the articles on markerless VBST focus on the motor function after stroke [47] and the motor neuropathy of autism [48].

"Spasticity (Hemiplegia)" gait disorder

A total of 21 articles discuss the rehabilitation of spasticity (Hemiplegia) gait disorder. Of these 21 articles, 7, 9, and 5 describe the use of VBST, VOBST, and OBST, respectively, on the rehabilitation of this type of gait disorder. The latter 5 articles describe the use of OBST on the rehabilitation of the hemiplegia of the spinal cord [12], lower limb [49], ankle-foot [20], knee in the stance phase [50], and the ankle [51], whereas the 9 articles that describe the use of VOBST focus on the hemiplegia of the leg swing [52], multi-joint leg extension [53], lower limb [54, 55], knee ro-

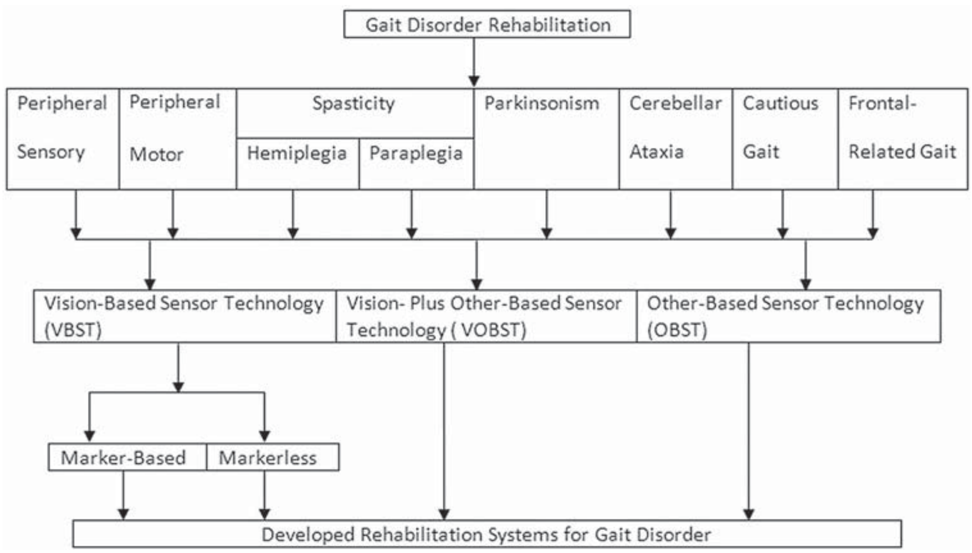

FIGURE 2. Gap analysis tree.

TABLE 3. The key points of each article

RN	Gait disorder Type	Application	ST	MB/ ML
9	Peripheral Sensory	Unsteady for Balance perturbation	OBST	N/A
1	Peripheral Sensory	Unsteady for fall	VOBST	N/A
21	Peripheral Sensory	Unsteady for fall	VOBST	N/A
22	Peripheral Sensory	Unsteady for Balance control	VOBST	N/A
5	Peripheral Sensory	Unsteady for Balance control	VBST	MB
23	Peripheral Sensory	Unsteady for walking in a state line	VBST	MB
24	Peripheral Sensory	Unsteady for gait cycle	VBST	ML
11	Peripheral Motor	Neuropathy for knee and hip	OBST	N/A
14	Peripheral Motor	Dystrophic for muscle weakness	OBST	N/A
15	Peripheral Motor	Dystrophic for muscle weakness	OBST	N/A
19	Peripheral Motor	Dystrophic for muscle weakness	OBST	N/A
25	Peripheral Motor	Slapping for ankle dorsiflexor	OBST	N/A
26	Peripheral Motor	Slapping for foot	OBST	N/A
27	Peripheral Motor	Steppage for spinal cord	OBST	N/A
28	Peripheral Motor	Steppage for foot drop	OBST	N/A
29	Peripheral Motor	Motor for weight bearing	OBST	N/A
30	Peripheral Motor	Arthritis for knee	OBST	N/A
31	Peripheral Motor	Steppage for CCS	VOBST	N/A
32	Peripheral Motor	Motor for foot	VOBST	N/A
33	Peripheral Motor	Slapping for toe clearance & velocity	VOBST	N/A
34	Peripheral Motor	Motor for PWS & DS	VOBST	N/A
35	Peripheral Motor	Dystrophic for muscle weakness	VOBST	N/A
36	Peripheral Motor	Dystrophic for muscle weakness	VOBST	N/A
37	Peripheral Motor	Neuropathy for motor fatigue	VOBST	N/A
38	Peripheral Motor	Neuropathy for chronic low back pain	VOBST	N/A
39	Peripheral Motor	Motor control for abnormal gait	VBST	MB
40	Peripheral Motor	Neuropathy for ankle dossal-planter-flexion	VBST	MB
41	Peripheral Motor	Motor for wait bearing	VBST	MB
42	Peripheral Motor	Neuropathy for lower limb joint	VBST	MB
43	Peripheral Motor	Neuropathy for lower limb	VBST	MB
44	Peripheral Motor	Motor control for cerebral palsy	VBST	MB
45	Peripheral Motor	Arihritis for trunk in children	VBST	MB
46	Peripheral Motor	Neuropathy for pelvis	VBST	MB
47	Peripheral Motor	Motor function from stroke	VBST	ML
48	Peripheral Motor	Motor Neuropathy for autism	VBST	ML
12	Spasticity (Hemiplegia)	Hemiplegia for spinal cord	OBST	N/A
49	Spasticity (Hemiplegia)	Hemiplegia for lower limb	OBST	N/A
20	Spasticity (Hemiplegia)	Hemiplegia for ankle-foot	OBST	N/A
50	Spasticity (Hemiplegia)	Hemiplegia for knee in stance phase	OBST	N/A
51	Spasticity (Hemiplegia)	Hemiplegia for ankle	OBST	N/A
52	Spasticity (Hemiplegia)	Hemiplegia for leg swing	VOBST	N/A
53	Spasticity (Hemiplegia)	Hemiplegia for multi-joint leg Ext.	VOBST	N/A
54	Spasticity (Hemiplegia)	Hemiplegia for lower limb	VOBST	N/A
55	Spasticity (Hemiplegia)	Hemiplegia for lower limb	VOBST	N/A
56	Spasticity (Hemiplegia)	Hemiplegia for knee	VOBST	N/A
57	Spasticity (Hemiplegia)	Hemiplegia for knee rotational	VOBST	N/A
58	Spasticity (Hemiplegia)	Hemiplegia for hip rotational	VOBST	N/A
59	Spasticity (Hemiplegia)	Hemiplegia for knee	VOBST	N/A
60	Spasticity (Hemiplegia)	Hemiplegia for knee & pelvis	VOBST	N/A
61	Spasticity (Hemiplegia)	Hemiplegia for leg	VBST	MB
62	Spasticity (Hemiplegia)	Hemiplegia for leg movement	VBST	MB
63	Spasticity (Hemiplegia)	Hemiplegia for ankle & subtalar joint	VBST	MB
64	Spasticity (Hemiplegia)	Hemiplegia for lower limb	VBST	MB
65	Spasticity (Hemiplegia)	Hemiplegia for lower limb	VBST	MB
66	Spasticity (Hemiplegia)	Hemiplegia for feet	VBST	MB
67	Spasticity (Hemiplegia)	Hemiplegia for intralimb	VBST	MB
13	Spasticity (Paraplegia)	Paraplegia for lower limbs	OBST	N/A
18	Spasticity (Paraplegia)	Paraplegia for lower limbs	OBST	N/A
68	Spasticity (Paraplegia)	Paraplegia for cerebral palsy	OBST	N/A
69	Spasticity (Paraplegia)	Paraplegia for stiff legs	VOBST	N/A
70	Spasticity (Paraplegia)	Paraplegia for cerebral palsy	VOBST	N/A
71	Spasticity (Paraplegia)	Paraplegia for stiff knee	VBST	MB
72	Spasticity (Paraplegia)	Paraplegia for legs	VBST	ML
73	Spasticity (Paraplegia)	Paraplegia for lower limbs	VBST	ML
16	Parkinsonism	Parkinsonism for gait speed	OBST	N/A
74	Parkinsonism	Parkinsonism for body movement	OBST	N/A
75	Parkinsonism	Parkinsonism with motor fluctuations	OBST	N/A
76	Parkinsonism	Parkinsonism for shoulder joint	VOBST	N/A
77	Parkinsonism	Parkinsonism for stiff of lower limbs	VOBST	N/A
78	Parkinsonism	Parkinsonism for stride (length, duration, velocity)	VBST	MB
79	Parkinsonism	Parkinsonism for posture and gait cycle	VBST	MB
80	Cerebellar Ataxia	Ataxic for gestural	OBST	N/A
3	Cerebellar Ataxia	Ataxic for cerebral palsy	VOBST	N/A
81	Cerebellar Ataxia	Ataxic for trunk movement	VOBST	N/A
82	Cerebellar Ataxia	Ataxic for trunk movement	VOBST	N/A
83	Cerebellar Ataxia	Ataxic for trunk movement	VBST	MB
84	Cerebellar Ataxia	Ataxic for upper body	VBST	MB
85	Cerebellar Ataxia	Ataxic for stopped posture	VBST	MB
86	Cerebellar Ataxia	Ataxic for upper limb	VBST	ML
87	Cautious Gait	Cautious gait for fear of fall	VOBST	N/A
88	Cautious Gait	Cautious gait for fear of fall	OBST	N/A
89	Cautious Gait	Cautious gait for fear of fall	OBST	N/A
90	Frontal-Related Gait	Frontal gait for short step and speed	VOBST	N/A
91	Frontal-Related Gait	Frontal gait for foot clearance	VBST	MB

RN=reference number, ST= sensor technology, MB=marker-based, ML= markerless, N/A= not applicable, VBST=vision based sensor technology, VOBST=vision plus other based sensor technology, OBST= other based sensor technology.

tation [56, 57], hip rotation [58], knee [59], and the knee and pelvis [60]. All 7 articles that discuss VBST describe the use of marker-based VBST for the rehabilitation of the hemiplegia of the leg movement [61, 62], ankle and subtalar joint [63], lower limb [64, 65], feet [66], and intralimb [67].

"Spasticity (Paraplegia)" gait disorder

We collected 8 articles on spasticity (paraplegia) gait disorder. Of these, 3, 2, and 3 articles describe the use of VBST, VOBST, and OBST, respectively, on the rehabilitation systems used. The articles that describe the use of OBST on the rehabilitation of this type of gait disorder focus on the paraplegia of the lower limbs [13, 18] and cerebral palsy [68]. The 2 VOBST articles discuss the rehabilitation of the paraplegia of the stiff knee [69], and cerebral palsy [70]. In addition, there are 1 and 2 articles that describe the use of marker-based and markerless VBST, respectively, for the rehabilitation of paraplegia. The marker-based VBST was developed for the rehabilitation of paraplegia of the stiff knee [71], whereas the markerless VBST was used for the rehabilitation of paraplegia of the legs [72] and the lower limbs [73].

"Parkinsonism" gait disorder

A total of 7 articles were found on parkinsonism gait disorder. Of these, 2, 2, and 3 articles discuss the use of VBST, VOBST, and OBST, respectively. The OBST articles focus on the parkinsonism of the gait speed [16], body movement [74], and motor fluctuations [75], whereas the VOBST articles describe the rehabilitation of parkinsonism of the shoulder joint [76] and stiff lower limbs [77]. The 2 VBST articles describe the use of marker-based VBST for the rehabilitation of parkinsonism of the stride (length, duration, velocity) [78] and of the posture and gait cycle [79].

"Cerebellar" gait disorder

We found 8 articles on cerebellar gait disorder. Of these 8 articles, 4, 3, and 1 discuss the use of VBST, VOBST, and OBST, respectively. The OBST article focused on a gait disorder with gestural ataxia [80]. The VOBST articles describe the rehabilitation of ataxic of cerebral palsy [3] and ataxic of trunk movement [81, 82]. Out of the 4 VBST articles, 3 discuss the development of marker-based VBST, whereas 1 article described the use of markerless VBST. The marker-based VBST was used for the rehabilitation of ataxic of trunk movement [83], ataxic of upper body [84], and ataxic of stopping posture [85]. The article on markerless VBST discusses ataxic of the upper limb [86].

"Cautious" gait disorder

A total of 3 articles discuss the cautious gait disorder. Of these, one article reports the use of a VOBS system and the other two mention OBST technology. One important issue related to the use of OBST and VOBST in the rehabilitation of cautious gait disorder is the chance of the patient falling down [87-89].

"Frontal-related" gait disorder

We found 2 articles on frontal-related gait disorder, 1 of which describes the use of VBST and the other the use of VOBST for the rehabilitation of this type of gait disorder. The VOBST article focuses on the rehabilitation of the speed and short step of the frontal gait [90], whereas the VBST article discusses the use of a marker-based VBST for the rehabilitation of the foot clearance of the frontal gait [91].

DISCUSSION

We collected 91 published articles for the analysis of the current procedures used in the rehabilitation of gait disorder to identify future research in this field. We scanned all the articles individually and identified the key points of each. The key points of each articles only which related to gait disorder are summarized in Table 3. Finally the summarized of key findings of this paper are presented as follows:

1. Application area of rehabilitation systems for gait disorder are motor function, brain, leg, foot, ankle, knee, postural, finger, spinal cord, balance perturbation, hip, wrist, physical activity for overweight, upper limbs, and muscles.
2. Gait disorder types are peripheral sensory, peripheral motor, spasticity (hemiplegia, paraplegia), Parkinsonism, cerebellar palsy, cautious gait, and frontal-related gait.
3. Gait disorder causes are cerebellar, sensory, visual, vestibular, muscular, basal ganglia, and auditory systems.
4. A total of 84 articles were related to gait disorder out of 91 collected articles.
5. In 84 related to gait disorder articles, 25 were utilized OBST such as electrical, magnetic, inertial, robotic and different types of pressure sensitive sensors; 29 were utilized VOBST such as Qualisys, VICON, CODA, ReActor2, ELITE Biomech, APAS, Polaris motion capture system, and video camera with the differents types of presure sensitive sensor or OBST; and 30 were utilized only VBST such as video camera, and Qualisys, VICON, CODA, ReActor2, ELITE Biomech, APAS, and Polaris motion capture system.
6. Out of 30 VBST articles, 24 were utilized marker to track the interest point of the subject during motion capture whereas 6 were not used any marker.

We observed that most of the existing rehabilitation systems for the specific class of gait disorder were utilized vision and non-vision sensor technologies to track and analysis the motion of the patients. Most of these motion tracking systems need experts to perform calibration and sampling for developing the rehabilitation systems. Without good calibration and sampling, and also without the help of the experts, rehabilitation systems cannot work properly. These types of rehabilitation systems cannot be user friendly for the patients to recover their disorder. Another vital point is cost. People's intention is getting accurate result and reduces their cost. But researchers planned to build a complex motion tracking system with the aim of satisfy multiple purposes. This enforces costly mechanism to develop a rehabilitation system. These types of rehabilitation systems are not suitable for the people due to more expensive. We also identify that some of the existing rehabilitation systems of gait disorder required large spaces during the recovery period. As an importance, this is one more obstacle for the people who don't have more accommodation space for the rehabilitation of gait disorder. Another obstacle is real time, example, some patients with hearing problem may require visual advice, and other with visual problem may need auditory signal. In this point of view, it is also needed a simple system that require to specify accurate or wrong movement of the patients during motion capture. This system allocates the patients to adjust his movements right away for getting exact result. The application of a device is very important. Most of the patients, who had suffered trouble with gait, have significant loss of function of their affected part. In this case, it is recommended that device should be as easy as possible to be appropriate for the patients. This problem can be overcome by a good interface between patients and computer in both motion tracking and its application in rehabilitation system. From a practical point of view, an attractive interface can encourage patients to carry out device manipulation. In summary, for the rehabilitation system of gait disorder, it is needed to consider of cost, size, operation, device manipulation, using space, and automated monitoring system.

CONCLUSION

A number of systems have been developed for the rehabilitation of gait disorders. The evidence shows it is crucial to measure real-time movement data to determine the correct rehabilitation system for an individual gait disorder. The real-time data can be established using a proper monitoring system. A rehabilitation system was not developed for the monitoring of parkinsonism gait disorder patients using a markerless vision-based sensor technology. Therefore, we propose the development of a proper monitoring system for the rehabilitation of parkinsonism gait disorder using a markerless vision-based sensor technology. This proposed user-friendly, economical, portable and automatic monitoring system will potentially partially or fully rehabilitate patients with parkinsonism gait disorder.

DECLARATION OF INTEREST

The authors declare no conflict of interest.

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