A Systematic Approach for Design a Low-Cost Mobility Assistive Device for Elderly People

Omar Salah, Ahmed A. Ramadan, Salvatore Sessa, and Ahmed A. Abo-Ismail

Abstract**—**Walking and sit to stand are activities carried out by all the people many times during the day, but physical disabilities due to age and diseases create needs of assistive devices to help elderly people during their daily life. This study aims to study the different types and mechanisms of the assistive devices. We will analyze the limitations and the challenges faced by the researchers in this field. We will introduce the Assistive Device developed at the Egypt-Japan University of Science and Technology, named E-JUST Assistive Device (EJAD). EJAD will be a low cost intelligent assistive device to help elders in walking and sit-to-stand activities.

Keywords**—**Active walker, Assistive robotics, Standing Assistance, Walking Assistance

I. INTRODUCTION

THE world growth of the population ratio of elders who is 65 years old or more is growing by approximately 860,000 people per month [1]. This trend is clear on both developed and developing countries including Egypt, Japan, France, China, India, Italy, USA, and so on. In aging society, many elderly people cannot perform normal daily activities because they have not enough physical strength. For example, in Japan, about 23% of elderly people which have low mobility and do not stay at hospital cannot perform daily activity without the help of caregivers [2]. Therefore, nowadays, assistive devices have been introduced to improve the movement autonomy of elderly people. Usually, the most important activities for elderly people who have not enough physical strength are walking and sit to standing activities.

Several studies have been done for developing assistive devices. Two fundamentals requirements of robotic systems to be qualified as assistive devices for elderly persons are the guaranteed safety and the user comfort. The safety requirement is a primary point and, as introduced by Isaac Asimov's in the "Three Laws of Robotics", implies that the robot should not harm the human user in any situation. The comfort characteristic means that the robot operation should not be a source of fatigue and unrest for the user Therefore, it is important to choose a comfortable solution that can be used in daily life locomotion during the gait as well as during the change of posture i.e. sit-to-stand task. Currently, when the locomotion still remains but it is deficient, the most used technical aid is the Zimmer frame.

The assistive devices assist elderly people or patient in performing daily life activities due to the inability of relearning [3]. In contrast, the therapy rehabilitation robots assist patients to recover and reduce the task of clinicians on assisting the patients.

In this paper, a review of mobility assistive devices developed on the last years will be presented. We can classify the assistive devices in fixed and mobile platforms, as shown in Fig. 1. We will describe the fixed assistive devices in the section II, and the mobile assistive devices in the section III. Furthermore, in the section IV, we will introduce the design of the assistive device designed at the Egypt-Japan University of Science and Technology, named E-JUST Assistive Device (EJAD).

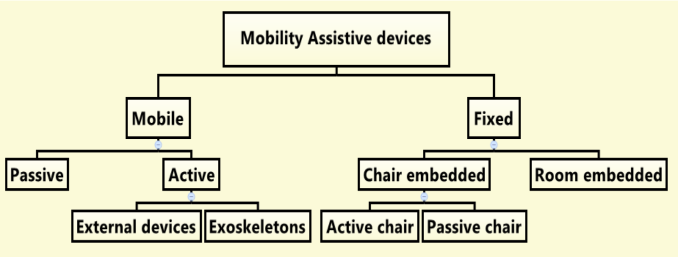

Fig. 1 Classification of mobility assistive devices

II. FIXED ASSISTIVE DEVICES

Fixed assistive devices perform the assistance task in a specific and predetermined environment. They can be classified in two types: the room embedded assistant and the chair embedded assistant.

A. Room embedded

Room embedded assistive device is a room with special equipments embedded to assist elders in the daily life activities [4].

Kiyoshi et al. [5] developed a power-assisting device which consists of two main parts; an upper part capable of motion in a horizontal plane and a lower part capable of motion in a vertical plane. This device assists the patient during sit to stand and walking.

SpiderBot-II [6] is a wire-driven parallel mechanism assistive device. It has a comfortable scheme for the user by measuring the reaction forces of the links during walking to synchronize the assistive device movement with the walking pattern and the speed of patients. A room embedded assistive device is not a mobile system; therefore, it can only be used in a single place, where it is installed. Furthermore, a lot of equipments and special arrangements are used and it takes

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Omar Salah, is with Egypt-Japan University of Science and Technology, New Borg-El-Arab city, Alexandria, Egypt (phone: 002014-701-4783; Zip: 21934; (e-mail: omar.mahmoud@ejust.edu.eg).

A. A. Ramadan is with Egypt-Japan University of Science and Technology, (on leave from Tanta University) New Borg-El-Arab city, Alexandria, Egypt (e-mail: ahmed.ramadan@ejust.edu.eg).

Salvatore Sessa is with School of Advanced Science and Engineering, Waseda University Tokyo168-8480, Japan (e-mail: s.sessa@aoni.waseda.jp).

A. A. Abo-Ismail, is with Egypt-Japan University of Science and Technology, New Borg-El-Arab city, Alexandria, Egypt (e-mail: aboismail@ejust.edu.eg).

large space in the room which may not be suitable for every place.

B. Chair embedded

Chair embedded assistive devices use a special mechanism embedded in the chair. We can classify them in passive chair embedded assistive and active chair embedded assistive devices.

1) Passive chair embedded

A good example of this kind of system is the Passive Gravity-Balanced Assistive Device for Sit-to-Stand Tasks developed at the University of Delaware [7, 8]. A hybrid method is used to identify the center-of-mass of the system robot-patient. To provide an appropriate support, auxiliary parallelograms and appropriate springs are used in this device. The mechanism will keep the potential energy constant during standing up.

2) Active chair embedded

Several prototypes of active chair were proposed; significant works in this field are the following.

Hirata et al. proposed a user adaptive support system for sit-to-stand movement from a bed, which consists of two main parts; a handrail and an electric bed that can move up and down as shown in Fig.2 (b) [9].

Kamnik et al. [10-12] proposed a rehabilitation robotized solution, which consists of two main parts: a robotized chair with 3DOF hydraulic driven and a force sensor instrumented handrail.

Mitsuru Sato et al. [13] proposed a special type of actuator passed on metal hydride (MH) for actuation of the seat to help the patient to perform sit to stand operation (See Fig. 2. (a)).

Chair embedded assistant system is not a mobile solution; in addition, it can be suitable only for one chair with specific arrangement.

Fig. 2 active chair embedded assistant (a)Sit-to-stand motion aid for a wheelchair using the MH air compressor.(b) adaptive support system for sit-to-stand movement from a bed

III. MOBILE ASSISTIVE DEVICE

A. Passive mobile assistive device

Passive mobile assistive devices are used by lower-limb disabled or elderly people to perform their daily activities and do not include any actuator, well known examples are the walker and the cane.

The Zimmer frame, for example, is a particular walker that provides walking stability and weight support. The user autonomously decides the magnitude of force/torque to apply.

Many conventional devices for walking assistance are already being manufactured to assist in walking but they do not complying with the varying grade of disabilities in elderly person [14]. This consideration includes all the types of walkers and canes even these tools are the most spread because of low cost solution.

B. Active mobile assistive devices

1) Exoskeletons

Exoskeletons assistive devices are controllable and wearable robot which can increase the speed, strength, and endurance of the operator [15]. The main purposes for developing robotic exoskeletons are rehabilitation, studying physiology of the human physiology, and active orthosis. A lot of institutes all over the world are currently developing many robotic lower limb exoskeletons assistive devices. Berkeley Bionics' BLEEX, Cyberdyne's HAL, and Raytheon Sarcos' exoskeleton are among the most advanced (See Fig. (3) [16-22].

Nowadays the problems of heavy weight and large size of exoskeletons are only partially solved. The Tendon-driven exoskeleton power assistive device for example uses a caster walker carrying heavy peripheral devices and maintaining stable balance of the user at the same time [18]. "Robot Suit HAL" embed all the necessary hardware (including batteries) and supports the wearer's weight during his/her standing-up motion so that sit to stand operation can be done without any physical effort (See Fig.3 (b))[23].

Fig. 3 Exoskeletons (a) BLEEX (b) HAL

The Active orthosis for lower limb developed by University of Michigan, Human Neuromechanics Laboratory have been focused to provide insight into human locomotion physiology and to use as possible motor training aids after neurological injury (See Fig. 4) [24].

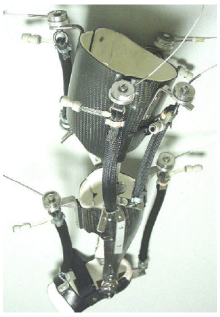

Fig. 4 University of Michigan Knee-Ankle-Foot Orthosis

Morichika et al. have developed a human walking assistance system which consists of a pair of shoe with a weight sensor and a pair of orthosis actuated by pneumatic cylinders [25].

Sugisaka et al. developed an ankle foot orthosis (AFO) using artificial muscle with two pressure sensor arranged in the bottom of the foot [26].

There are many drawbacks in exoskeleton system. First, it is difficult to calibrate and regulate for the user. Furthermore, the axis of rotation of the user joint it might be different of the exoskeleton, this condition may cause injuries or pain for the user. Finally, the exoskeleton could be uncomfortable for elderly people.

2) External devices

Nowadays, two main types of intelligent walkers have been proposed; active type [27-31] and the passive-type [32-36].

RT Walker is one of the passive walkers proposed by Hirata et al. and it is realized based on the distance between the user and the walker (See Fig. 5(c)) [34, 35].

Sabatini et al. developed an active walker that enhances the force of the user in the direct control mode, and the ability to follow the user at a distance, with or without collision avoidance [37].

Shi et al. developed Walkmate, an intelligent robotic walking assistance system with force sensor interface and motion control algorithm embedded [38].

Fujie et al. developed a new weight bearing mechanism supporting Ischia which help to relieve pain of pressure during walking [39].

Graf et al. presented Care-0-bot that is the prototype of a multi functional home care system. In addition, an intelligent behavior, for example autonomous obstacle avoidance and path planning, are included [40].

One of the new approaches is to use active walker to help in sit to stand. Chuy et al. used robotic walking support system to be stationary as the user executes the Sit-to-Stand movement [41].

Chugo et al. designed an active walker attached with a 3-DOF mechanism which assists in sit to stand motion of elderly people (See Fig.5.(b)) [42-45].

Saint-Bauzel et al. presented MONIMAD which is a rehabilitation assistive robotic device that with its fuzzy-based control is able to assist patients in sit-to-stand motions. The use of fuzzy-based control helps to determine the best strategy of sit to stand assistance (See Fig.5.(a)) [46].

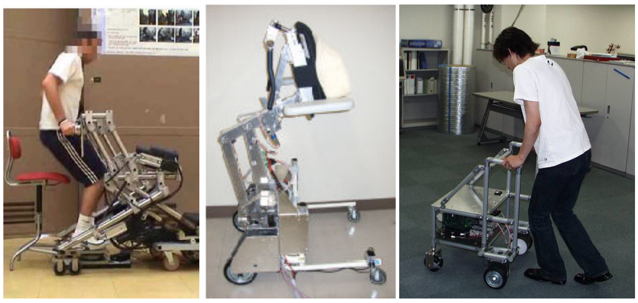

Fig. 5 (a) MONIMAD. (b) Standing assistance system (c) RT WALKER

The main disadvantage of the active walkers is that, if the servo motors of the intelligent systems are not controlled appropriately, they could move unintentionally causing dangerous situations for the users.

Finally, many commercial devices are already being manufactured [47] to assist elderly in sit to stand activity, including hoists and other lifting devices. Most of the physical burden of caregivers has been relieved by these devices. However, those devices still require that the caregivers have to be constantly accompanied with the elderly person.

IV. EJAD

The main original point of EJAD is the motion approach that will be based on the imitation of the caregiver's motion during the support tasks. The lower joint corresponds to the hip motion of caregiver; the upper joint is the shoulder movement; the passive joint is the caregivers' wrists, and the active walker is the lower limbs of the caregiver see fig (6). This mechanical configuration will help to maintain the stability of the patients in any situation. The mobile platform will compensate the patient movements to maintain the zero moment point inside the foot areas.

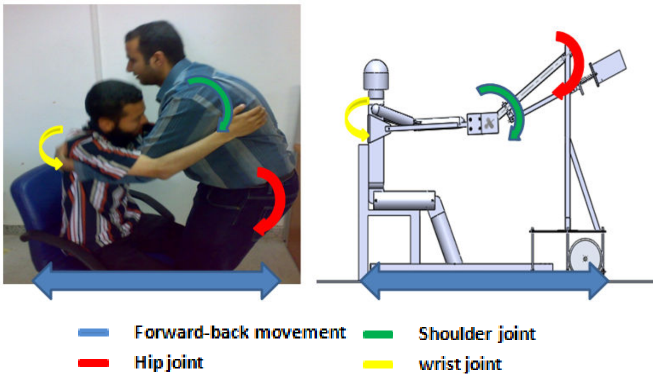

Fig. 6 (a) caregiver assistant (b) EJAD

A. Mechanical design

EJAD will consist of two main parts, a robot arm and a mobile platform (See fig. 7). The standing assistance robot arm has 2-DOF. In addition the back support with passive joint will support and adapt the back movement. The active walker system is a differential drive mobile platform. Two stepper motors actuate the wheels; two castor wheels provide the necessary stability to the platform.

The stepper motor is relatively low cost (less than 400$/unit), furthermore, they do not needed a feedback control to define a reference angle for the wheels.

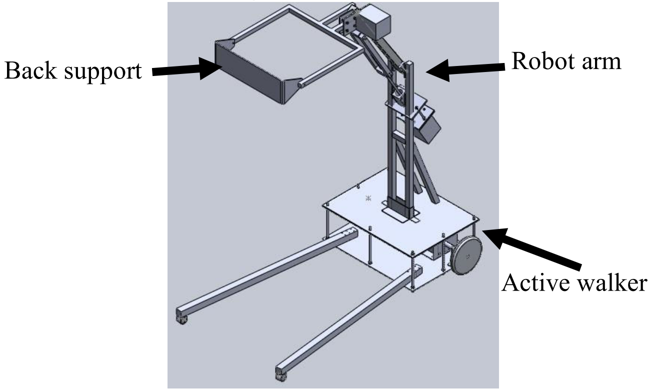

Fig. 7 Mechanical design of EJAD

B. Kinematic of EJAD

We simplified the kinematics of the EJAD. We considered only translation movement of active walker forward and backward. Furthermore, the passive joint of the back support in this analysis will be excluded because it has only a support function and does not play any role on the calculation of the end effector (center of the passive joint). The result of this simplification is shown in fig.8. We use a prismatic joint to represent the movement of the active walker; in addition, two rotation joints represent upper part of assistive device. We can describe the forward kinematics of EJAD with the following transformation matrix.

$$ {}^{0}T_3 = \begin{bmatrix} C23 & -S23 & 0 & L_2C2 + L_3C23 - L_1 \\ 0 & 0 & -1 & 0 \\ S23 & C23 & 0 & L_2S2 + L_3S23 + d \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

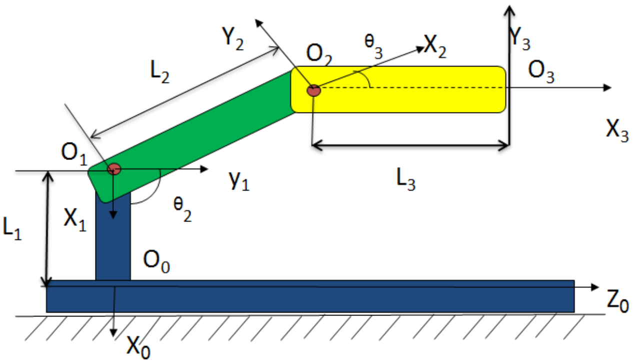

Fig. 8 Kinematic model of EJAD

Where L_1 is height of first link, L_2 is length of second link; L_3 is length of third link. From the design L_1=1.25 m, L_2=0.6 m and L_3=0.5 m.

To drive the inverse kinematics, the orientation and position of the end effector must be known. The following matrix will describe the position and orientation of end effector.

$$ {}^{0}T_3 = \begin{bmatrix} N_x & R_x & F_x & P_x \\ N_y & R_y & F_y & P_y \\ N_z & R_z & F_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

Where the P= $[P_x\ P_y\ P_z]^T$ are x, y and z components of O_3 in respect to base frame. The rotational part of transformation matrix gives the orientation of the frame $O_3x_3y_3z_3$ relative to the base frame. The joint variables can be calculated from the comparison between 1 and 2. The following equations describe how to calculate the joint variables.

$$ \theta_2 = \pm Acos \frac{P_x - L_3N_x + L_1}{L_2} \quad (3) $$

$$ \theta_3 = \begin{cases} Atan\left(\frac{N_z}{N_x}\right) - \theta_2 & at\ N_x \neq 0 \\ \frac{\pi}{2} - \theta_2 & at\ N_x = 0 \end{cases} \quad (4) $$

$$ d = P_z - L_2S2 - L_3S23 \quad (5) $$

For simplification, we will take only the positive value of θ_2. If the third link is always parallel to ground, therefore, the inverse kinematics equations become the following.

$$ \theta_2 = Acos \frac{P_x + L_1}{L_2} \quad (6) $$

$$ \theta_3 = \frac{\pi}{2} - \theta_2 \quad (7) $$

$$ d = P_z - L_2S2 - L_3 \quad (8) $$

C. Inertial measurement unit

Nowadays, several sensors have been proposed to measure patient posture in order to understand human intention and predict his motion behavior [48]. But, most of these sensors have still many limitations. For example, Vicon is a very precise device but, it required fixed place to set up certain number of cameras, in addition it needs a careful calibration every time we use it [49]. Direct method like potentiometer and encoder are also available but, they need mechanical arrangement to be place on the human that will be not comfortable for the user [50].

IMUs are recently becoming more and more popular because they are lightweight and compact. These characteristics are fundamental to provide a good wearability to the user. IMUs combine accelerometers, gyroscopes and magnetometers sensors to providing the attitude of the sensor on the space, linear accelerations and angular speed [51]. The installation of the IMUs does not required complicate setup and/or calibration; these characteristics make the sensor system easy to use also for the patient without any support from other people. To reconstruct the posture of the user and the walking pattern, we propose using two Inertial Measurement Units (IMUs). They will be properly fixed on the trunk and leg.

V. CONCLUSION

In this paper, we proposed a classification of the assistive device through a wide review of the state of art. We analyzed the advantages and disadvantages of each device. Finally, we proposed low cost solution for an assistive device that will allow elder people move freely in indoor environment. Inertial Measurement Units (IMUs) will monitor the posture and movement of the user for a proper interaction with EJAD. As future work, we aim to control the end effector position of the assistive device through use of IMUs placed on the trunk and legs of the user. The sensor system will be able to recognize the gait pattern, anticipate intentions, and predict dangerous situations for the user.

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