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Internet of Things Applied on Assistive Devices and Rehabilitation Robotics

Jason Liu [1,*], Wei Shi [2], Ahmet Turkmen [2] and Jeff Leismer [3]

[1] dept. of Operations and Management, University of Wisconsin-Stout, Menomonie, USA
[2] dept. of Engineering and Technology, University of Wisconsin-Stout, Menomonie, USA
[3] VibeTech Enterprises, LLC, Sheboygan, USA
* Correspondence: Jason Liu, dept. of Operations and Management, University of Wisconsin-Stout, Menomonie, USA

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Abstract: This paper reviews the latest studies of assistive devices and rehabilitation robotics applied in healthcare using Internet of Things (IoT) as a base technology. The utilization of IoT in assistive devices and robots empowers elderly people and individuals with disabilities through advanced assistive technology solutions, highlighting its potential benefits and applications. The review explores the intersection of IoT sensors, assistive devices and rehabilitation robots showcasing the transformative potential of IoT in enhancing accessibility, independence, and quality of life for people with diverse abilities. Various types of smart sensors are discussed and illustrated by IoT applications in healthcare. By comparing different types of IoT sensors, we conclude the data they can measure, algorithms, principle, and applications. The other contribution of this review is to present summary research of assistive devices and rehabilitation robotics with IoT sensors. Additionally, improving the quality of life for the elderly and people with disabilities requires enhanced support through IoT technologies. Key areas that need further improvement include security, reliability, and data privacy. In the future, this work will serve as the basis for further research work in the related area. Further advancements are necessary to improve assistive devices and robotics through IoT applications.

Keywords: assistive device; robotics; smart sensors; IoT; rehabilitation; intelligent control

1. Introduction

The world's aging population results in a larger population of elderly who require assistance and rehabilitation in their daily life. A huge demand for new approaches to deliver care services and perform effective assistance services for elderly people is desperately growing. A 2015 study found that 46% of individuals aged 21-64 with a disability were employed [1]. However, a significant portion of these individuals worked part-time. In contrast, the employment rate for individuals without disabilities was 84%, highlighting the lower likelihood of employment for those with disabilities. As a result, there is an urgent need to provide a wide range of assistive and rehabilitation devices to address the growing demand over the next two decades.

Internet of Things (IoT) has been defined as the network connection of physical objects or things and it's enabled as software or objects, sensors, network connectivity, for collecting and exchanging data. One key component is the usage of IoT devices – a family of sensors to gather and analyze data in real-time in healthcare environments. With IoT technology, physical objects are able to cooperate together to collect real data from environments without the needs of human interactions [2]. The advancement of IoT technology has led pervasive connections and smart services. It is now being utilized widely in smart applications and creates the wide range of opportunity in assistive devices. IoT enables autonomous and secure data exchange over the Internet [3]. It has been applied in various applications, such as, smart home, healthcare, smart manufacturing, and industrial automation [4]. Health care (such as, assistive technology and rehabilitation) indicates one of the most critical applications with IoT platform [5]. Many of the IoT devices embed multiple sensors which can sense, compute, and transmit collected data over the Internet [6-8].

The paper reviews the most recent studies regarding assistive technologies and rehabilitation devices with IoT employed in the applications. This paper also discusses different types of sensors with IoT technology to create a smart healthcare environment. The recent development, innovation, and application of various IoT smart sensors used in assistive technologies are summarized and compared [9,10]. The contribution of this review is to present a summary research and comparison of various assistive devices with IoT sensors. By comparing different types of IoT sensors, we conclude the data they can measure, algorithms, principle, and applications. The paper surveys how to advance assistive devices and robotics with smart sensors.

2. Assistive Technology and IoT

2.1. Assistive Technology

Assistive technology refers to a generic class of devices, equipment, technologies, services, interfaces, and system used by people with intent to overcome the barriers for elderly or disabled people, which means to live autonomously, communicate and enable recreation activities to increase the quality of everyday life [11]. Various assistive technologies have been applied into assistive devices to minimize the disability and enable smooth functioning [11]. This term includes a wide range of new products and related services, from spectacles and wheelchairs to adapted keyboards for computers, and even assistive robotic systems [12]. The elderly often have the fear of having accidents or being unable to call for help. It is crucial to provide them with devices that can support them. The device can automatically trigger an alarm and call for assistance in case they cannot call for help on their own. Effective use of assistive devices in home monitoring helps to identify changes in health and behavior in home settings [13].

The World Health Organization (WHO) reports that around 1 billion people may benefit from the application of assistive technology [12]. However, only 10-15% of them have access to the appropriate solutions based on assistive technology because the large gap between need and access exists in both low and middle-income households. The limited access to assistive technology or devices may have many different reasons, such as high costs of technology, lack of expertise among professionals, lack of awareness, absence of policy and legislation. The following categories marks multiple types of assistive devices in different applications, such as Daily Living Activities, Medical Devices, Mobility Assistive Devices, Communication Assistive Devices, Computer Application Assistive Devices, Recreation, Adaptive Play and Leisure Assistive Devices [11].

2.2. Internet of Things

Deficiencies in the assistive technologies are increasing significantly. However, IoT supplies an efficient solution to continuously monitor the health status remotely with sensor readings used [14,15]. IoT is also able to provide intelligence and connectivity to convert small assistive devices into smart objects in order to integrate and transfer enriched data from wearables or embedded sensors to provide necessary assistance to disabled people and support them to achieve independent living and good quality of life. IoT applied in assistive technology adds the characteristics of autonomous monitoring remotely and eases the process to follow-up the elderly accurately, quickly, and periodically for medical staff [16]. In the smart environment of IoT, devices can exchange information and provides many convenient services.

IoT consists of various areas including RFID, cloud, virtualized environments, mobile devices, sensors and Artificial Intelligence (AI). Also, various intelligent services can be offered through IoT-based network that leads to cloud-based IoT networks. Sensors can detect physical changes and process the collected information in order to automate the devices in a smart environment. IoT integrates different types of devices and sensors with the capability to communicate without any intervention [17]. For example, light detection and ranging sensors (LiDARs) are commonly used for detecting distance data over long range precisely, and localizing objects through the 3D reflections accurately [7-8]. In any IoT applications, sensors will bring physical world very close to digital world that can be implemented by leveraging computing; they collect and process data to detect changes in smart environment [18]. Figure 1 illustrates how IoT collaborates with various technologies to identify and track data.

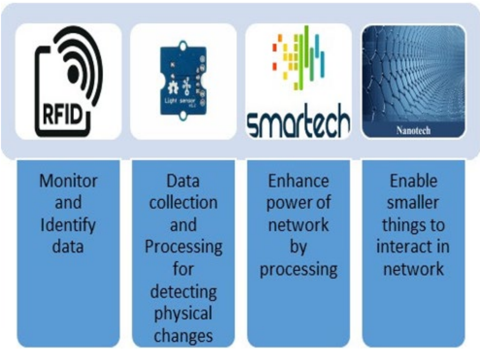

Figure 1. IoT Collaboration with Multiple Technologies.

3. IoT Sensors Applied in Assistive Devices

IoT sensors vary widely in both function and complexity, ranging from very simple to highly sophisticated types. IoT sensors can be classified based on their conversion methods, specifications, materials used, measured properties, sensing mechanisms, and application domains. Figure 2 shows various types of IoT sensors which are explained below.

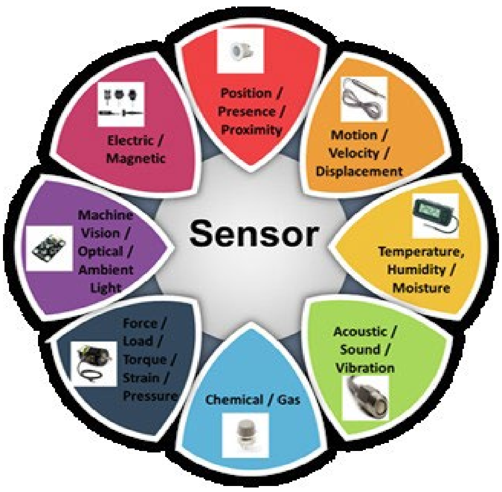

Figure 2. Types of IoT Sensors [18].

3.1. Position Sensors for Indoor Localization

An indoor localization system was proposed in in order to locate terminals, compute, and select the optimal path between terminals. A fingerprinting algorithm with Wi-Fi estimates deterministic and probabilistic location to locate the moving targets was also proposed in [19-21]. The indoor localization can be realized with the lighting infrastructure of a building [22]. A localization approach was proposed in to accommodate those systems without a need of additional infrastructure [23]. Different sensors have been investigated, such as cameras, smart phone sensors, LiDARs, and depth sensors, to recognize human activity and implement indoor localization in assistive devices. Kaló proposed a simulation framework by using a genetic algorithm and the multilateral method to define optimal anchor placement for given pathway in indoor environment. This research shows that higher accuracy of position estimation can be achieved by using optimal sensor placement [19]. However, Mihcin proposed that an ideal monitoring system shouldn't interfere with the users' daily routines and privacy and work continuously without requiring any on-body device. Based on the results of the test, the proposed system can continuously monitor the motion of patients with walking difficulties in age-care and hospital settings [20].

3.2. Optical Sensors Used in Assistive Robots

Assistive robots are capable of self-configuration, self-management, self-adaptation, and self-optimization through autonomic sensing, self-managed, self-adapted, and self-optimized with autonomic sensing. Optical sensors are utilized with proximity during grasp adjustments. They detect the orientation of an object surface using the infrared (IR) sensors that fit inside the fingers for the current algorithm [9]. However, the system is currently limited to controlling a single dimension of the end-effector. It can only adjust the fingers, restricting its overall grasping capability. The new design requires IR sensors on a gripper to fit the griper for a normal force to the object boundary. The IR sensors are utilized on an assistive robot in order to control the robot for objects grasp with the information collected from sensors. The IR sensors sense the object distance proximally and provide a corrective output signal to close in on the object with the robot hand [10].

A typical home environment can be considered as a relatively short-range sensor network. In this study, a novel self-organizing sensor network was proposed for home monitoring application with the wearable and ambient sensors based on cluster network architecture [22-25]. If one of the three sensors detects the object, the robot has the capability to autonomously move to a suitable pre-grasp position, and directly close the hand to grasp the object. The system also performs collision avoidance by maintaining a safe distance from objects as it keeps a specific distance to an object. KINECT is utilized as the sensor in the system to track a mobile object and acquire joint position information [21]. The robot imitates human behaviors after mapping between the joint coordinates.

3.3. Fall Detection Sensors

Research estimates that nearly 30% of elderly people incur in falls in the U.S. each year, and falls is a major concern for the elderly. In order to minimize distress associated with injury, it is imperative that the medical staff or caregivers are alerted in the event of a fall. Many of the assistive devices monitor an assisted person's status or activities, and provide active support in use of smart sensors. The iLife fall detection sensors proposed in recognize and react to falls, which measures and records vital signs [26-28]. The sensors are triggered when detecting abnormal body movements or extended periods of inactivity. Two other fall detection sensors were described in, including embedded video-sensor and a wearable accelerometer [29]. To enhance tracking and health monitoring capabilities, supplementary sensors can be integrated into the system, such as vibration sensors for fall detection in privacy-sensitive areas, RFID for object localization, and infrared cameras in smart home.

3.4. Sensor Network

It's very important for hearing-and speech-impaired disabilities to perform non-verbal forms of communication. Assistive devices for hearing and speech-impaired disabilities have been developed by using BSN technologies (Body Sensor Network) [30]. In the proposed system, real-time recognitions of ASL (American Sign Language) fingerspelling gestures are performed according to input signals that acquired from the gloves equipped with wireless sensor. By using speech synthesizer, the recognized gestures are then converted into corresponding speech using a synthesizer.

Based on data collected from wireless BSN sensor gloves, researchers proposed a framework for developing a fingerspelling gesture recognition model [31]. Each glove contains five flex sensors and a 3D accelerometer to measure finger bending, hand motion, and orientation. These data are transmitted to the processor via a BSN node located on the wrist. In addition, researchers proposed a machine learning-based algorithm to reduce posture estimation errors in wearable robots by combining data from wearable-robot sensors [32,33]. The algorithm significantly improved posture estimations across different walking speeds and assistance force levels. Fasola et al. proposed the We-Care system, which uses IoT technologies to monitor elderly individuals' health conditions and send alerts regarding their status [34].

Jardine et al. developed a health monitoring and check-up system for the elderly, which measures key vital signs including blood pressure, heart rate, and body temperature [35]. The system consists of two components: a programmable module and a measurement module. The programmable module features two interfaces — one for the elderly and another for medical professionals — while the measurement module (as shown in Figure 3) monitors and records the vital signs [35-44].

Figure 3. Smart IoT Healthcare Prototype [35].

4. IoT-Based Assistive Devices and Robotics

IoT applied in assistive technology is expected to efficiently, quickly, and cost-effectively support new healthcare models that integrate telemedicine and proactive healthcare principles. References present extensive reviews of smart home applications and devices from a robotics perspective [45–46]. Security is one of the major concerns for assistive devices and smart homes. Several serious vulnerabilities of IoT technologies include lack of encryption, weak authentication, cross-site scripting (XSS), lack of device isolation, as well as SQL injection attacks [47].

4.1. Assistive Smart Glasses

Smart devices (such as Google Home, Amazon Alexa, and smartphones) have included powerful speech recognition algorithms in recent years, allowing them to understand spoken language and accept voice instructions. Users can use their voices as inputs to communicate with their voice assistant (VA) systems and perform a variety of daily tasks. The accelerometers and sensors are used to precisely read the movements and convert them to the suitable auditory or visual format. The author has proposed the smart device which can be reconfigured, and it has a microcontroller fixed into it so that the data is collected, processed and the data is transmitted and saved in the cloud storage to monitor regularly [48]. Chugo has proposed a smart healthcare system called Smart glasses, which used the Google API in conjunction with a speech recognition system to understand a command from an English speaker based on the user's predefined locations [49]. The system assists the user with localization and object detection; can also detect obstacles that a visually impaired person cannot visualize. Using visual recognition and ultrasonic sensors, the obstacle detection system supports visually impaired users in receiving alarms. The smart glasses consist of ultrasonic sensor, camera, LDR sensor and visual recognition. It offers a smart solution for visually impaired users to locomote using visual identification via a camera, as well as a speech recognition system to assist the user in providing the system with the desired location.

4.2. Assistive Robotic Chair

Due to the chronically ill or age-related progressive conditions, the individuals with disabilities or elderly might have to change their chairs to enable them to sit down or get up as the conditions worsen. However, most electric chairs in the market only simply follow fixed set cycle to the user and are not able to offer personalized services or muscle resistance, which results in their condition deteriorating faster. To deal with this issue, IoT sensing techniques have been proposed for assistive robotic chairs such that the user's intention or postures in terms of sub-conscious signal extracting, different significance and pattern recognitions can be captured.

Wheelchair-based depressurization model is designed in the research of the sedentary patients to mitigate the risk of pressure sore by reducing the pressure concentrated points [50]. Moreover, in term of rehabilitation point, motion assistance will be provided for those patients can't manage their own physical strengths to change a posture. The changing of patient's center of gravity (COG) demonstrates the tendency of user's movements, which will be captured by pressure distribution sensors based on the certain algorithm. To manipulate motorized wheelchair based on the patients' own upper body inclinations, pressure sensing films are designed and mounted on the seat back and seat pan respectively. Therefore, the patients are able to drive the wheelchairs along longitude directions by moving upper body back and forth, while leaning right and left function as steering wheel.

4.3. IoT Based Human-Machine Communication for Assistive Robots

Assistive robotic systems have been applied into the healthcare domain and shown great potential. Since the inception of robotics technology, there have been continuous efforts to improve human-robot interaction. The study of human-robot interaction is one of the most important fields in assistive techniques and rehabilitation, and mostly the interactions are through sound and visual channels [36]. However, the users who are elderly and the patients who need healthcare accommodations frequently may lose partial or complete auditory or visual capabilities, thus there may be challenges for them to operate or interact with the robots' using voices, even locate the assistive robots visually [37]. Therefore, it's essential to develop human-robot communication systems to help people who have a disability or are elderly, especially for the patients with upper limb limitation. NAO has been using as exercise trainers in a senior living community, which calls Golden Oaks in Oklahoma, USA [38]. The designed small robots have the capabilities to interact with elderly people and deliver exercise sessions. A novel human-machine interface (HMI) has been developed for performing activities of daily living using gesture and position tracking systems via infrared cameras and optics [39-40]. An adaptive and intuitive manipulation scheme with optimum mapping between the operator hand movements and the JACO-2 robot arm is developed on the more natural human robot interactions and smooth manipulations of the robots. The JACO-2 arm could be installed to the tables, powered wheelchairs, or other places at home, and provide the users with the required items as shown in Figure 4 [40].

Figure 4. Robotic Arm System Setup [40].

4.4. Personal Assistive and Rehabilitation Robot

A scalable multi-layered mapping framework is used to represent various data and contexts gathered through advanced IoT sensors, facilitating ambient intelligence for adaptive control algorithms in designing personal robot systems for assistive technologies and rehabilitation. Mobile robots were introduced with using the multitude of smart sensors to understand and perceive its environment or contexts. These sensors include ultrasound sensors, cameras, LiDARs and Radars [14]. Most of the powered wheelchair incorporates the forms of joysticks as the default control devices for the wheelchair navigations [41]. Some studies proposed that the trackball can be used as the pointing devices, which consist of some sensors and a ball to detect two axis rotations of ball [42-43]. Trackball is easily controlled by the user through the palm of their hands. However, some users may not be able to operate proposed trackball interface due to the problems with triceps/biceps controls since they are just able to lift lower arm up and down for a very short time.

The assistive robot with the capabilities of haptic interactions can compensate well in this regard. Moreover, considering the safety of device operation is critical in the design of user-friendly haptic interfaces for a assistive robotic system because any software or hardware failure might place the user at high risk [44]. The end-user groups of assistive robots are primarily individuals with disabilities and seniors who may lose partial or complete sensory capabilities or mobility. Due to tight physical attachments, potential danger would be a main threat for the user's operations while dangerous scenario happens [44]. Therefore, the requirements and considerations for safety should be well build-in while designing assistive robots.

5. Security of IoT-Based Assistive Devices

IoT devices are able to integrate with a wide range of smart sensors to support and monitor the system. There is a huge array of smart sensors can be applied in assistive and rehabilitation devices in the market, including Lower Power WAN Smart Sensor/GPS tracker; humidity, motion, light, sound, and temperature sensors, etc. However, these smart sensors may be vulnerable to attacks by adversaries, leading to safety and security threats due to the increasing complexity of software or communication interfaces. Even the major sensors, such as the global positioning system (GPS) signals, LiDAR signals, and so on can be compromised, which may cause a serious threat to the assistive devices. Cybersecurity breach in such system may be likely to incur several security and privacy issues. Effective and robust cybersecurity and appropriate safety measures and solutions should be mandatory to deal with any threat or attack in a modern healthcare system. Most surveyed healthcare systems based on the use of IoT technologies highly rely on specialized central technology and the use of large-scale cloud storage methods, which might pose security threats that could negatively affect the health of elderly individuals or even endanger their lives [25]. Yacchirema proposed to utilize blockchain techniques to develop the systems that are decentralized and more secure [26]. Below lists some common security risks related to IoT where machine learning algorithms depend on the data collected from the systems. Attacks on Cloud-based Network devices: IoT will process a large volume of data that stores in the cloud frequently. These devices communicate with different mediums, such as cellular network or Wi-Fi, to send and receive cloud data. These communication mediums are vulnerable to be attacked, and attackers might forge or intercept the data being exchanged [24].

6. Conclusions

The integration and application of assistive devices and rehabilitation robots are increasing along with the rapidly growing population of elderly individuals and people with disabilities. IoT has been applied in the implementation of assisted living. This review summarizes multiple types of IoT-based technologies, smart sensors, and robotics applied in assistive and rehabilitation domains, and discusses how smart decision-making and controls are utilized in assistive/rehabilitation robots, as well as human-robot interaction and communication in IoT-based assistive devices. Additionally, support for independent and active living requires addressing the main challenges of IoT devices and systems, such as reliability, data veracity, privacy, and security.

With IoT-aided devices and robotics, three main societal issues or concerns should be further investigated in future studies:

1) Developing and applying personalized and smart human-robot communication systems on IoT platforms.
2) Designing assistive robotic systems with safety motion controls, machine learning, and artificial intelligence, which can assist in generating meaningful and accurate output from IoT sensor data.
3) Enhancing security, user privacy, accuracy of data collection, analysis, and adequacy of decision-making for IoT-based assistive devices.

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