Internet of Things for motion-impaired people

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1 Introduction

1.1 Requirements

According to World Health Organization (WHO) an estimated 1.3 billion people, or 16% of global population worldwide, experience a significant disability today[1]. People with disabilities generally experience poorer levels of health, fewer achievements in education, fewer economic opportunities, and higher rates of poverty than people without a disability.

Assistive technologies (ATs) have a main role in promoting participation and inclusion in society, and supporting access to health, social services, education, work and other important life experiences for persons with disabilities, older people and those with chronic conditions. The Global Report on Assistive Technologies, launched in May 2022 by WHO and UNICEF, calls for concrete actions to improve access to ATs globally, in order to make a further step in the achievement of rights of persons with disabilities. The UN Convention on the Rights of Persons with Disabilities (CRPD) of 2006 is the most widely ratified human rights convention, affirming the right to participation in society on an equal basis with others. Many articles of the convention can be satisfied with pre-existing technologies and political commitment. However ATs with the support of new technologies can improve a lot the respect of the convention and they have a main role in ensuring the respect of the Article 19 that states the importance of "Living independently and being included in the community". ATs for independent living includes products which, among others, assist in daily living, communication, computer access, and environmental control systems. They are also important to promote an equal and effective enjoyment of the right to live independently and participate actively in the community by promoting inclusion and reducing isolation. Today, as never before, Article 19 can be adequately respected.

Among all disabilities the most prevalent one is mobility disability. Motion-impairments affect more than 15% of adults aged 65–74, 26% of adults aged 75–85, and 48% of adults aged 85 and over[2]. This is why this project will focus on people with motion impairments.

Mobility disabilities can preclude from carrying out Instrumental Activities of Daily Living (Instrumental Activities of Daily Living (IADLs)) : housekeeping, accessing informations, cooking. They are necessary to maintain independence for living and avoiding mental health problems. Challenges to conduct everyday activities could come from an individual's functional limitations and the environment wherein they conduct the activities. For example it's important to identify where and how individual's functional limitations coincide with the physical environment's barriers that create accessibility problems for people with long-term mobility disabilities.

On the web we can find testimonies like the one of *JDRoberts*, a quadriplegic person, who wanted to share his experience and the challenges he faced in searching for and putting together technologies to overcome the difficulties he encountered in his everyday life. The main challenges for him were opening the front door lock, turn on and off the lights from the living room to the bedroom in a smart way, turn on and off the television[3]. He wanted to create an intelligent ecosystem with a lower budget and he shared with other users his attempt to buy and use new technologies for his house.

These are not problems related only to adults and older people, but also to children and young people. It is estimated that about 54.3% of under 18 years old people affected by disabilities consider a difficulty the only fact of participating in daily tasks at home[4].

1.2 State of the art of IoT for motion-impaired people

Products and technologies are required to facilitate these life situations with a particular focus on the process that has to be performed in order to detect and overcome in an efficient way the problems, the barriers that separate inequality from equality.

Processes should: (i) in addition to assessing difficulties and needs, seek transversal explanatory particularities such as lack of accessibility and mobility; (ii) consider the points of view of the individuals concerned, their relatives, and professionals to build a complete picture and (iii) develop

public (rather than personal) products and technology to remove barriers for as many people as possible. Public, modular and flexible technologies, as we will see later, are the keys for carrying out this task in the best way.

What are these new technologies that will help ATs to improve a lot?

Objects around us have been connected for decades. Devices like TV remote controls and garage door openers have been part of our domestic landscape for generations. Industrial applications of these technologies, for example, through remote monitoring and control of production, are also nothing new. In fact, even the phrase "Internet of Things" is not a recent invention; it was coined around twenty years ago. However, recent developments in both networks and devices are enabling a much greater range of connected devices and Internet of Things (IoT) functionalities. Today, the phrase "Internet of Things" refers to the world of smart connected objects and devices. Gone is the remote control, replaced by an intelligent device that will automatically fulfill its task based on its analysis of user behavior. All of this is made possible by the miniaturization of electronic devices, accompanied by a huge increase in the availability of internet connectivity.

The potential applications of this new IoT are virtually limitless, and they have the ability to greatly improve quality of life. This is why the IoT impact on persons with disabilities is so important. For example in the area of home automation, where a quadriplegic person can monitor and control a thermostat through voice commands or can have his door automatically unlock when he approaches it. The final objective is to use IoT and 5G and its key capabilities, together with neural networks, to build smart homes that can allow motion-impairment people to live in autonomy.

People needs in daily living are many and of different kinds, they can change with respect to the single person or different disabilities. It's necessary to offer a wide choice of devices and technologies, that are meant to be at service of the individual person. Once installed they have to be controlled in an easy way by using a dedicated software.

Modularity and flexibility are, once again, the keys to the best service, to the best smart home. They are the keys to equality.

2 Technologies

2.1 5G technology

The advent of the IoT has revolutionized various aspects of our lives, and the integration of smart devices in homes has opened up new possibilities for improving accessibility and enhancing the quality of life for individuals with disabilities.

The emergence of 5G technology brings a significant advancement in the integration of IoT devices within smart homes. Designed as an upgrade to its predecessor, 4G, 5G technology offers numerous advantages that address the limitations experienced in managing a multitude of devices with low latency.

One of the significant improvements of 5G is its ability to provide faster and more reliable connectivity. This allows for seamless communication between smart devices in a smart home environment, enabling control and interaction with the home systems more effectively. Another important enhancement is the introduction of low latency communication, which holds immense importance for individuals with disabilities. The ability to achieve real-time responsiveness enables swift and timely actions for critical applications, including home security systems and emergency alerts.

Additionally, 5G provides the ability to handle a huge number of connected devices simultaneously with a great improvement in performance. This scalability and capacity enable the seamless integration of diverse IoT devices in a smart home setup, accommodating the specific needs of people and promoting a more accessible living environment.

Thanks to these features it's possible to use real-time services that allow people with disabilities to live independently in connected smart homes. So combining 5G with Neural networks is a

turning point to improve home automation, comfort, security, and health care for people with disabilities in their smart homes[5]. Neural networks can implement virtual sensors to replace temporarily unavailable physical sensors for indoor localization systems. These systems are helpful for monitoring and assisting people with disabilities during critical situations, such as wandering or falling. Neural networks can learn the users' habits and activities, in this way, their next moves are predicted, and alerts are sent (e.g., time to take a given medicine, fire alarm). The faster speed and lower latency of 5G improves security camera systems significantly and provides enough capacity to connect faster and more efficient IoT devices.

2.2   Voice Assistants: Empowering Control and Accessibility

The integration of voice into IoT devices creates a new user experience that many consumers enjoy, and it assumes paramount importance for people with motion impairments as it enables hands-free operations and grants these individuals the ability to independently control their living environment.

Intelligent Personal Assistants (IPAs) play a valuable role by providing voice-based interaction and control over connected devices. IPAs leverage natural language processing, machine learning, and voice recognition technologies to understand user commands and perform tasks.

By connecting with a smart home platform, an IPA can control devices, retrieve information, and perform actions on behalf of the user. IPAs can be particularly beneficial for people with physical disabilities by providing assistance, convenience, and accessibility.

Examples of well-known IPAs used in IoT are Amazon Alexa, Google Assistant, Apple Siri and Microsoft Cortana. These IPAs are designed to process specific voice commands or queries that follow a predefined syntax or format. Therefore, they excel at processing structured and semi-structured commands, but their ability to handle unstructured or highly contextual commands is still relatively limited.

Ali et al. [6] propose a new Intelligent Personal Assistant (IPA) system integrated with IoT, called *IRON*, to help the elderly and disabled people control their home devices remotely through IoT, based on their voices. The IRON system is designed to overcome the cons of the previous methods of understanding unstructured commands by adding a machine learning algorithm with NLP to classify these commands as positive or negative for turning on or off a device. IRON, which can work both online and offline, detects the user's voice from different microphones spread around the home to ensure that disabled people can access IRON from their locations.

In addition to voice assistants, visual assistants can further enhance accessibility in smart homes. Combining voice and visual interfaces, such as smart displays, can provide a more inclusive experience by offering information in both auditory and visual formats. Visual assistants can display real-time data, such as weather updates or calendar events, and provide visual feedback for voice commands, making the interaction more engaging and accessible.

2.3   IoT protocols

IoT protocols are essential for the seamless communication and interoperability of devices within a smart home environment. There are many communication protocols that can be used for IoT and the integration with 5G technology further enhances the capabilities and accessibility of smart homes.

Wi-Fi for more capable devices, Zigbee and Bluetooth Low-Energy (BLE) for battery-powered ones are the most famous and widely used. They allow broad compatibility and interoperability, with secure and reliable communications.

All of this protocols can be implemented using 5G technology, for example in the central hub of the smart home, to prevent the risk of down connection and making the communication to the environment more reliable and keeping the same speed and latency as a cable connection.

With the growth of the market, nowadays there are hundreds of companies that build and sell their own IoT devices and create different ecosystems which are independent and can not inter-operate with others.

Matter is an emerging open-source smart home connectivity standard that aims to improve interoperability and simplify the setup and control of smart home devices. It is backed by major technology companies, including Apple, Google, Amazon, and the Zigbee Alliance, among others. The key features of this new standard is to improve interoperability among smart home devices from different manufacturers, providing a unified standard that allows devices to seamlessly communicate and work together, regardless of their brand or underlying technology. Matter builds upon existing technologies both for low-power and full-power devices. It is designed to support a wide range of smart home devices and enables devices from different categories to inter-operate, allowing users to create integrated and flexible smart home environments.

Interoperability and flexibility in a context of smart homes for people with disabilities is crucial because different disability requires different needs, and different devices too. Using Matter it is possible to build a smart home that responds perfectly to the needs of any person, by inserting IoT devices of any kind and for any purpose.

2.4   IoT devices for Smart Homes

Flipping on lights, turning on a fan, adjusting a thermostat, and even opening and closing a door are common tasks that can become immensely challenging for those living with a disability.

Smart home automation devices are a valuable component of IoT solutions in home-assisted living for individuals with motion impairments. These devices are designed to automate and simplify daily tasks, making the living environment more comfortable and manageable.

Smart plugs are the easiest, most inexpensive way to automate almost any plug-in appliance or device. By simply plugging one into any outlet and pairing it with a smartphone, users can turn devices on or off and create customized schedules. Obviously, it is possible to configure a smart plug to be controlled by voice commands. When paired with lights, smart plugs even offer a bit of added security: putting them on a schedule can act as a deterrent to burglars. Pairing them with a motion sensor to turn on a plugged-in lamp when someone approaches, residents won't have to wander down dark hallways.

Outdoor security cameras and smart video doorbells are an especially good solution for those with mobility issues because they provide smartphone alerts when there is movement and enable the resident to talk to the visitor through the built-in speaker.

One of the daily limitations faced by people with mobility problems is stairs. In the study at [7], a *"barrier-free staircase"* was designed to overcome the problem for wheelchair users and improve the accessibility of spaces for disabled people. The designed stair structure can become a ramp by using a servo motor. The user can choose from 3 options to operate the stair-ramp conversion: by a user-issued voice command to Google Assistant, with the use of the button in the user interface by a smartphone, and with the physical button located near the stairs.

Another category to consider is the one of wearable devices like smartwatches, smart glasses or smart clothing. Being in close contact with the person, these types of technologies are used to collect data and monitor the user's health.

The integration of these devices, a central control system with voice assistance like Amazon Alexa, and a distributed audio system can collectively create an optimal home environment for individuals with motion impairments.

In addition, the incorporation of Socially Assistive Robots (SARs) or specific medical equipment, such as smart wheelchairs, can further enhance the living space.

Luperto et al. [8] discusses the integration of Ambient Assisted Living (AAL) frameworks with SARs. Specifically, the article presents the *MoveCare* system, a platform that, by integrating SARs with monitoring and stimulation platforms, can provide a long-term support to older people. Some features of the proposed system, such as finding lost objects or calling for help, would certainly be

helpful to people with motor impairments as well.

IoT-enabled smart wheelchairs are another technology that has the potential to greatly help people with mobility disabilities by providing them with greater independence, mobility and advanced safety features. These IoT-enabled devices can incorporate features like obstacle detection, navigation assistance, and remote monitoring, ensuring safer and more efficient mobility within the home. However, the cost of these innovative devices can be a significant barrier for many users. Al Shabibi et al. [9] proposes a cost-effective Smart Wheelchair-based Arduino Nano microcontroller and IoT technology.

3 Software

3.1 Importance of IoT platforms

To fully leverage the benefits of IoT devices in a home-assisted living environment, an effective and robust IoT platform is crucial.

An IoT platform serves as a software infrastructure that interconnects, controls, and enables the programming of IoT devices within a unified ecosystem. It acts as a central hub that facilitates seamless communication between various IoT devices, collects and analyzes data, and provides intelligent automation and control capabilities.

In the context of home-assisted living, an IoT platform plays a pivotal role in creating an accessible, safe, and supportive living environment for individuals with physical impairments. The interconnectivity and programmability provided by an IoT platform enable proactive interventions, automated and personalized routines and tailored assistive services that enhance independence and quality of life.

3.2 Matter and Home Assistant

Before the advent of Matter, choosing the right platform required careful consideration of factors such as device compatibility, scalability, security, ease of use, and integration capabilities. The proliferation of different communication protocols and proprietary systems often posed challenges in integrating devices from multiple manufacturers. To date, Home Assistant has played a crucial role in bridging this gap, offering a versatile platform that supports a wide range of devices.

Home Assistant is a software platform that acts as a virtual hub, enabling the integration and control of various smart home devices and services. Using Home Assistant, you can integrate platforms that would otherwise not communicate with one another [10].

This platform offers several advantages compared to others available in the market. Firstly, its local connectivity approach is one of the key differentiating factors and strengths. By minimizing reliance on cloud services, it enables greater control, privacy, and reliability within the home environment. In contrast, having devices connected to cloud services not only introduces unnecessary security and privacy concerns, it also can make them useless if your internet cuts out [10]. Another advantage of Home Assistant is its flexibility and customization options which allow individuals to tailor the system to their specific needs and preferences creating a personalized and supportive environment. This level of customization is crucial for people with physical disabilities, whose needs may diverge noticeably. Another aspect to be considered is that Home Assistant is an open-source platform, which means it benefits from a large and active community of developers and users continuously contributing to its advancement and expansion of its capabilities. This community-driven nature ensures ongoing improvements, bug fixes, and the addition of new features, making it a robust and future-proof solution.

However, in terms of roadblocks or potential challenges, as an open-source platform, Home Assistant may require a certain level of technical knowledge and expertise to set up, configure and fully leverage its capabilities.

The emergence of the Matter standard aims to address these challenges by establishing a unified framework that promotes seamless interoperability among smart devices. By adopting Matter, device manufacturers commit to a common standard, simplifying the integration process and improving compatibility between devices. This standardized approach allows for easier setup and configuration, making it more accessible to a broader range of users.

While Home Assistant has been an exceptional platform for device integration and automation, the adoption of the Matter standard adds an additional layer of simplicity and compatibility. With Matter-certified devices, users can expect a smoother and more streamlined experience when integrating their smart devices into their Home Assistant ecosystem.

The Matter smart home standard also addresses another common pain point with current IoT devices: it allows devices to work offline without requiring continuous access to the cloud and various cloud services [11]. This improvement also ensures a higher level of protection and security measures.

When discussing Matter, it is essential to mention Thread as well. Thread is a wireless networking protocol designed specifically for smart home devices. As a low-powered mesh-based wireless protocol, Thread creates a low-latency offline environment that instantly sends and receives data across devices [11]. Its integration with Matter further enhances the seamless and efficient communication between smart devices within a unified smart home environment.

While Matter holds great promise for the future of smart home connectivity, it is essential to note that adoption of the standard by existing devices may take some time. This could create a transitional period where users may face compatibility issues between Matter-certified devices and their existing smart home devices. Moreover, the success of Matter relies on widespread industry adoption and support. While many major companies have shown their commitment to the standard, the transition to Matter-compatible devices and systems will take time.

As we embrace this evolving landscape, with Matter becoming the future solution for connecting, controlling, and programming IoT devices, its integration with Home Assistant ensures a seamless transition, combining the best of both worlds and offering users an even more comprehensive and user-friendly smart home experience.
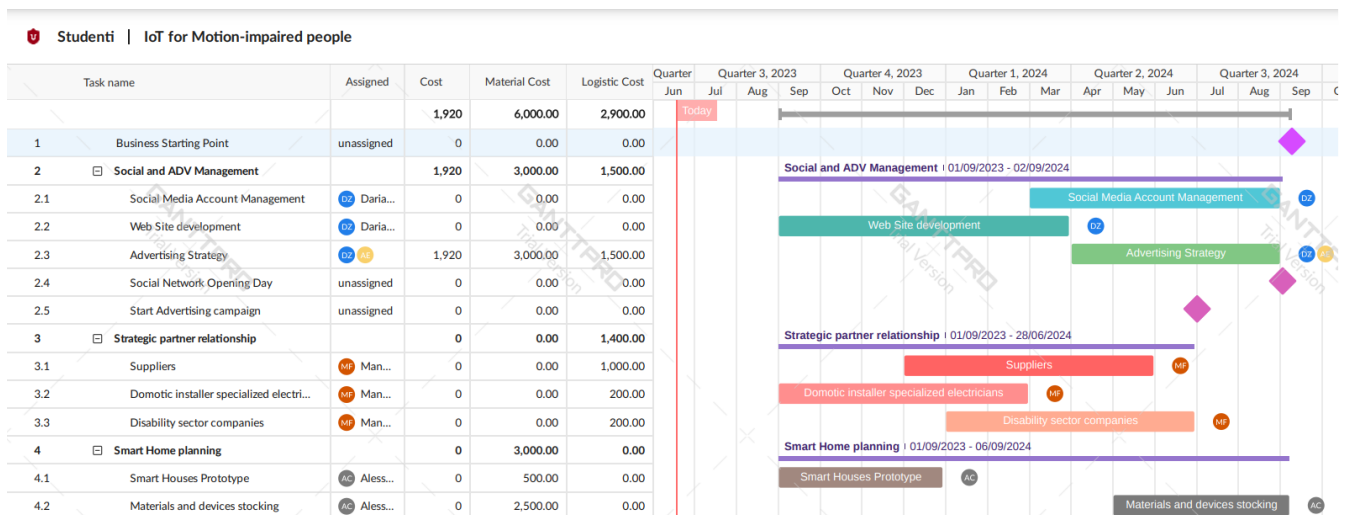
4   Budget

Figure 1: Business Tentative Timeline

4.1 Potential market and business proposition

By doing a brief search, it can be seen that the sector concerning the IoT for motion-impaired people is not yet very developed in Italy. Most of the companies that offer a home automation design service don't focus enough on disabled people sector, or they simply offer high-priced or out-of-date proposals for emerging technologies. The main proposals of a business in smart houses for motion-impaired people are clear: modularity, flexibility and interoperability.

Modularity and flexibility grants to the client the possibility to choose the devices based on personal needs and the possibility to add new modules whenever the customer wants. Another important business part is to guarantee different price ranges in order to address different economic conditions. Customer care has a very important role in a modern business. Recurring and close contact with customers is very useful to satisfy any needs, in particular in the first days/weeks of use of the IoT system installation. The system will be based on the Matter standard to guarantee a latest generation system with the possibility of adding new modules of different types and brands.

4.2 Future vision

The figure presented in *Figure 1* illustrates the initial tentative timeline for the business, outlining key milestones and activities. It provides a preliminary overview of the projected initial progression of the business over time.

The initial stages of the business will primarily focus on establishing the necessary infrastructure, such as securing suppliers and partners, marketing and advertising, and initial inventory acquisition. Once the business gains traction and starts generating revenue, further investment in infrastructure becomes crucial to accommodate the increasing demand. Acquiring an office space will provide a dedicated location for administrative tasks, client meetings, and team collaboration. Additionally, a warehouse facility will be essential to manage inventory storage, order fulfillment, and efficient logistics operations.

The main cost contributions for the business investment are:

CAPEX (Capital Expenditures)

- Advertising Strategy: cost of online advertising, participation in industry events and hiring marketing expert.

- Expenses to find strategic partners (business travel costs).

- Smart home planning: cost of devices and material for prototype design and stocking.

OPEX (Operating Expenditures)

- Marketing and advertising costs.

- Rent and utilities for office space and warehouse.

- Domotic installation services.

The main sources of revenue for the business will come from charging fees for the provided services. These include design of home automation systems and management of IoT devices, ongoing maintenance and support, possibility to tailor the system to individual needs. In addition, the business will have the opportunity to receive compensation from value-added services such as remote monitoring and management of the home automation systems, emergency response services or data analytics and insights for optimizing energy usage and enhancing comfort.

It is important to note that the specific timeline and associated expenses may be subject to adjustment based on market conditions, business growth, and strategic considerations.

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