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Smart Relax Armchair - A Solution for Active and Safe Ageing at Home

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ABSTRACT

The prolonged life expectancy poses social and economic challenges for developed nations, as ageing populations face multiple chronic conditions, loss of independence, and social isolation. Sedentary lifestyles and prolonged immobility exacerbate health concerns, contributing to postural changes and pressure ulcer formation, adversely affecting physical, social, and emotional well-being, and culminating in morbidity, disability, and premature death. To address these issues, the authors collaborate with an esteemed Italian furniture producer and health experts to develop an innovative solution – the Smart Relax Armchair - aiming to promote active and safe ageing at home. Through a comprehensive research approach, including benchmarking analysis and user-centred design, the authors identify and integrate smart functionalities dedicated to health and well-being. Utilizing expertise from biomedical engineers, 3D virtual models, and sensorised mats, the study identifies postural misbehaviours and proposes interventions for a commercial Relax Armchair. The research explores active and passive solutions to maintain correct posture and prevent bedsores, incorporating a sensorised mat for pressure distribution assessment. An Arduino-based anti-decubitus function is developed to induce automatic repositioning based on prolonged sitting detection. The protocol is validated on a preliminary prototype, supporting patenting. The Smart Relax Armchair also features an app with rehabilitation exercises. A final prototype undergoes forthcoming clinical trials for validation, with potential applicability to various armchair and sofa models, challenging the conventional notion of exclusive, expensive active ageing products for residential care facilities. This innovation aims to cater to those desiring affordable ageing in place.

Keywords: Smart relax armchair, Bedsores avoidance, Correct posture maintenance, 3D virtual manikins

INTRODUCTION

The fact that people are living longer is a social and economic challenge for developed countries in the 21st century. An ageing society leads to an increase in the number of people living with multiple chronic conditions, facing the loss of independence and autonomy. Among the many threats to the health and well-being of older people, home isolation and consequently home accidents are a significant cause and a major contributor to morbidity, disability, and premature death (EuroSafe, 2024).

One third of people over the age of 65 who live in the community fall each year and this proportion increases to 50% of those aged 80 years and older. Every year, about 36.000 fatal fall-related injuries are reported in EU-countries and an estimated number of 3.8 million older people are treated in an hospital after a fall and then at home (Directorate-General for Economic and Financial Affairs, 2021).

The increasing incidence of sedentarism as well as prolonged immobility caused by long-stay setting (care home) is also a growing health concern. Indeed, spending too much time sitting daily could increase the incidence of postural changes and pressure ulcer formation, further reducing physical, social and emotional well-being of older adults (National Institute of Aging - NIH, 2020) (Collins, 2002).

Such data underline the need to make the home a more comfortable and safer place for elderly, using not only medical devices but also smart furniture capable to improve people's lifestyle by simplifying daily activities and promoting independence, thus reducing psychophysical stress, and avoiding the onset of possible depressive states.

In this view, a lot of research has been conducted to develop and introduce Ambient Assisted Living solutions to monitor house routines of elderly patients (Sokullu, 2020) (Borelli et al., 2019) (Danielsen et al., 2016). In addition, robotic technologies have been widely exploited as tools to support mobility capacities, such as strength, balance and range of motion (Broadbent et al., 2009) (Robinson et al., 2014), or companions to assist older adults in functional and social activities (Bevilacqua et al., 2023). A comprehensive analysis of ICT research and development is provided in (De Angeli et al., 2020).

On the market, IoT products can be already found, mostly with surveillance (IP cams, etc.) or home environmental comfort purposes (air-conditioning, smart lights, curtains and/or windows, etc.) or aimed at simplifying the use or interactions with the so-called white goods (washing machine, dishwashing, etc.).

Few works can be found in literature focusing on the implementation of IoT in furniture such as armchairs, sofa, beds and/or wardrobes, to promote correct postures and avoid bedsores occurrence, while most of them focus on the development of wearables for posture monitoring (Sardini, 2015) (Borelli et al., 2019), rather than solutions to actively interrupt incorrect unhealthy behaviour.

Looking at the market, specific products have been developed for facilitating healthy ageing in residential care facilities (Collins, 2002) which cannot be afforded by whom willing to age in place.

Armchairs for elderly, also known as Relax Armchairs, can certainly be a very useful aid for promoting well-being in case of mobility issues, thanks to the possibility to integrate technological solutions to help users assume a variety of positions while reducing their physical efforts (Sanatex, 2024) (Relax Drive, 2024) (Sofarm, 2024).

This paper reports the results of the research activity conducted by the authors, in collaboration with a renowned Italian furniture producer to develop an innovative solution for promoting active and safe ageing at home using a Relax Armchair equipped with smart functions to maintain a correct

posture as well as to reduce the formation of bedsores by inducing frequent repositioning.

MATERIALS AND METHODS

The Relax Armchair model selected for the implementation of the results is composed by a frame made of conventional materials (wood, fabrics, foams) and a metallic recliner system. The Relax Armchair can reach two different positions, namely the "rest position" (completely horizontal with raised feet) and the "raised position" (seat raised and tilted forward to help to get up).

A user-centred design methodology has been implemented to identify the Smart Relax Armchair functionalities, by involving industry experts, researchers in active ageing, biomedical engineers, and potential users since the early design stage. A dedicated design thinking tool, based on an excel file, has been used for users' needs identification and translation into metrics (i.e. technical features).

The Quality Function Deployment (QFD) method and tool have been used to rank such metrics and drive the design of the final product to meet users' needs at best. Since the goal was to develop a smart relax armchair able to be certified as medical devices, the analysis of relevant technical standards has been essential to deduce mechanical and usability constraints (IEC 60601-1-11, 2020) (IEC 60601-1-2, 2021) (IEC 60601-1-6, 2020) (IEC 60601-1-8, 2020) (IEC 60601-1-9, 2020) (IEC 62366-1, 2020) (IEC TR 62366-2, 2016).

The expertise of researchers from the Physical Medicine and Rehabilitation Unit of the Rizzoli Orthopaedic Institute (IRCCS) has been used to identify postural misbehaviour in daily life, which have been simulated in a 3D environment using the Virtual Manikin Zygote® Human Factor (Zygote Media Group, Inc., 2024) and a 3D model of the selected armchair to identify possible intervention areas for active and passive solution for postural corrections (Figure 1).

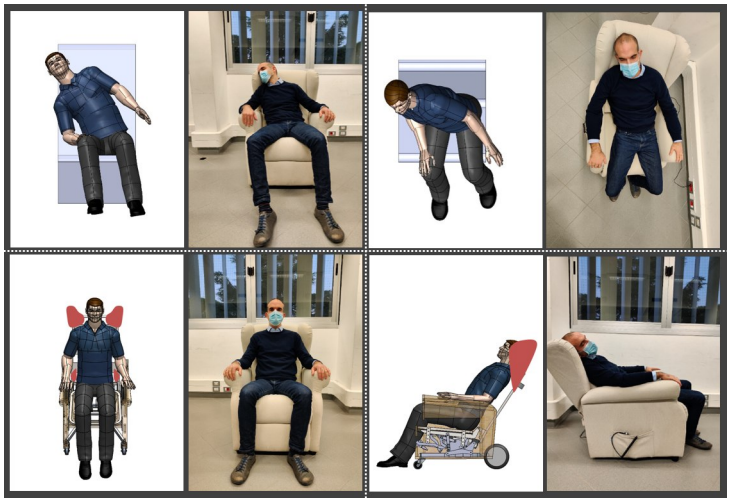

Figure 1: Evaluation and simulation of postural misbehaviour and potential corrections.

A wireless sensorised mat (BodiTrak2 Lite (BodiTrak, 2024)) has been used to assess the efficacy in terms of pressure reduction/variation introduced by the developed passive and active solutions with respect to selected postural positions.

Unity engine has been used to develop a customized APP for the management of the innovative functionalities of the Smart Relax Armchair (i.e. *Wi-Fi recliner*, *healthy routine*, *active ageing routine*), which have been implemented in the final prototype using Arduino®.

THE SMART RELAX ARMCHAIR: A COMBINATION OF ACTIVE AND PASSIVE SOLUTIONS

Fifty-five user needs have been identified, all belonging to the following classes: Aesthetic; Technical-functional; Manufacturing and cost; Safety.

The application of the QFD method allowed to rank the metrics in relation to the corresponding needs in order of priority and identify all the specifications that had to be included in the final design of the Smart Relax Armchair to meet user requirements. Table 1 reports per each of the selected user's need the corresponding requirement for the product design detailing the metrics where necessary.

Table 1. User's needs ranking and metrics.

No.	User's Need Description	Rank	Metric
5	Pinch points free	5	Protective carters
30	Low technological design	4	Embedded IoT technology
4	Full lay down position	4	Zero-gravity recliner
3	Semi-recumbent position	3	Automated recliner
22	Feedback on armchair status	3	Speakers/buzzers
47	Rest position	3	Headrest
50	Anti-decubitus properties	3	Aerated and soft materials
51	Active anti-decubitus systems	3	Automatic movements of the recliner
2	Support while seating/standing up	2	Elevating armchair
16	Portable controller	2	Smartphone and joystick
17	Removable controller	2	BLE & RJ11 plug
18	Redundant postures commands	2	Simultaneous use of smartphone and joystick
23	Safety stop	2	Reachable emergency stop
48	Comfortable and safe when sleeping	2	Actuated Backrest
6	Internal door compliance	2	Max with 75 mm

Starting from user's requirements, the author decided to develop different levels of solutions to be implemented in the final prototype of the Smart Relax Armchair, introducing the innovative features further described below (Figure 2).

Passive Solution for Bedsores Avoidance

The authors investigated and tested several materials for seat and backrest padding to modulate the softness thus minimizing local pressures on the skin (main cause of bedsores formation) and distributing user's weight over large surfaces. The author's idea was to combine memory foams in the padding and a surface layer of mineral gel, specifically designed for pressure distribution. The study of optimal stratification was carried out through specific ergonomic studies, and it has been validated through measurements carried out with a pressure monitoring mattress used in the orthopaedic sector (BodiTrak, 2024).

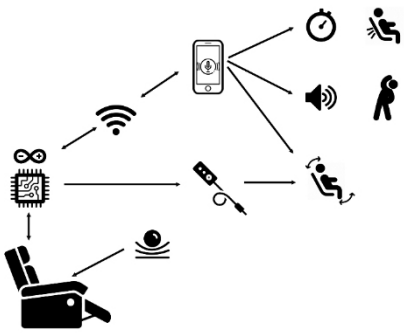

Figure 2: Smart relax armchair functionalities.

Active Solution for Posture Correction and Bedsore Avoidance – The Healthy Routine

The evaluation of postural misbehaviour conducted by the authors helped to notice that people sitting for a long time on an armchair, usually tend to slide forward thus changing the posture of their back, spine and especially pelvis.

To help people maintain a correct posture when sitting, the Authors designed an automatic posture support programme which pushes the users, through external stimuli, to independently change their posture thus correcting the position of their body segments.

Basically, when the Smart Relax Armchair is turned-on and the Healthy Routine (Figure 3) is activated on the dedicated APP via smartphone or a vocal assistant, if the user remains seated for a very long time the system can detect if no changes has been made by the user through the reclining system in a specific amount of time. Once detected, firstly the APP alerts the user with acoustic feedback, then ARDUINO actuates the reclining system automatically, thus inducing a slight change on the backrest and footrest position notwithstanding the posture assumed by the user on the armchair.

The user is, now, forced to straighten the back, rotate the pelvis, and improve the lumbar support to reach a comfortable position.

Such Routine does not require large movements of the armchair, since only few degrees of changes on the backrest and footrest are enough for the user to perceive the position assumed and therefore improve it autonomously.

Furthermore, this routine can be also useful to help people with reduced movement capabilities which spend many hours sitting at home or in assisted living facilities such as elderly but not exclusively. These subjects are often subjected to bedsores due to the local and continuous pressure on the skin, which does not allow correct ventilation of the area itself as well as blood circulation.

To solve this problem, the main commercial products known to the state of the art try to relieve local pressures in a cyclical manner by inflating and deflating special cushions to alternate the support areas, thus resulting in an expensive product which is perceived by the user as an invasive medical device and not a furniture. In the Smart Relax Armchair the automatic changes on the backrest and footrest, after a specific amount of time of no movements, help to relieve and alternate local pressures in particular on thighs, back and lumbar area, while maintaining the cost low and the design of a regular Relax Armchair.

In practice, when the Healthy Routine is on, it is possible to alternate and vary the posture over time and reduce the time spent in certain positions where the pressure on specific sensitive areas can be critical for bedsores formation.

Obviously, the use of breathable materials and padding capable of distributing pressure already explained in the Passive Solution for bedsores avoidance will facilitate the overall anti-decubitus effect obtained in the Smar Relax Armchair.

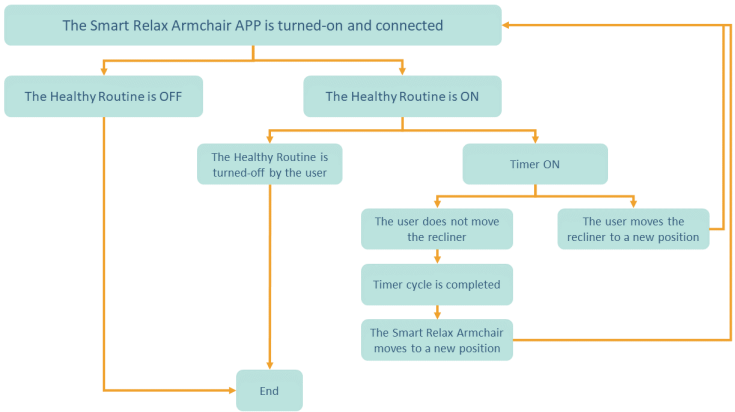

Figure 3: Flow chart of the healthy routine.

Interactive Solution for Active and Safe Ageing at Home – The Active Ageing Routine

To promote active ageing at home, a set of simple fitness exercises to be performed with the help of the Smart Relax Armchair has been designed and implemented in the APP.

The expertise of researchers from the Physical Medicine and Rehabilitation Unit of the Rizzoli Orthopaedic Institute (IRCCS) allowed to design a set of

four different exercises to help the user stay healthy, but safely, at home to be performed using the armchair itself as an exercise tool:

1) Ankles' flexion-extensions with feet higher than the hips to preserve the strength of the calf muscles, prevent ankle joint stiffness, increase the metabolic activity, and contribute to thrombus avoidance.
2) Core strengthening though isometric contraction, with the user semi-seated on a reclined armchair to reduce back pain and facilitate standing and walking resume.
3) Hands with fists forward extension in alternate way, staying seated to strengthen the upper limbs and avoid the occurrence of flexed posture while increasing the metabolic activity.
4) Assisted rising and seating at different speed to strengthen quadriceps and glutes, promote coordination and balance while facilitating standing and walking resume and increasing the metabolic activity.

Based on the repetition of the exercises defined by the experts of the Physical Medicine and Rehabilitation Unit of the Rizzoli Orthopaedic Institute (IRCCS), the Authors defined the average amount of time necessary to perform the single exercise and converted the exercises into a routine of different armchair positioning for a specific amount of time.

To guide the user along the Active Ageing Routine, the APP provides different level of instructions starting from a description of the exercise, up to a short animation of a character performing the exercise and a counter/timer to help counting the repetition or duration of the exercise.

The aim is to encourage postural exercises while sitting or lying using a proprietary therapeutic protocol that has been patented (Figure 4).

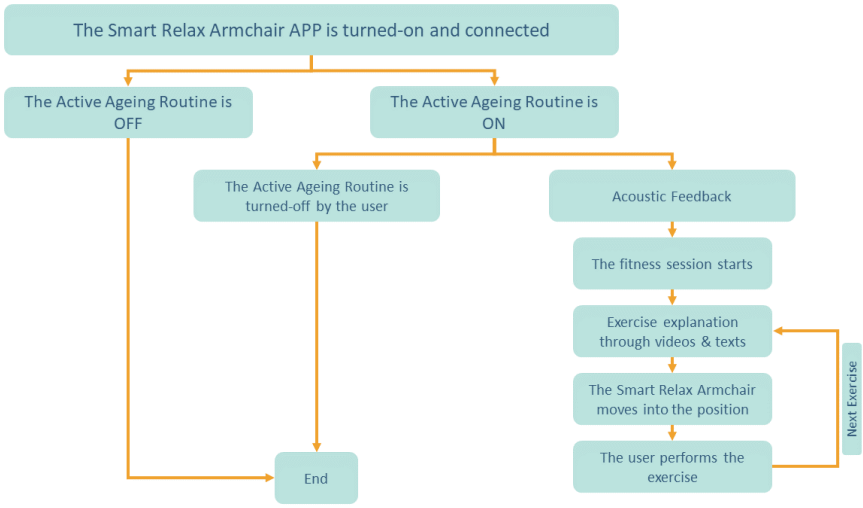

Figure 4: Evaluation of postural misbehaviour and potential corrections.

Basically, when the Smart Relax Armchair is turned-on and the Active Ageing Routine is activated on the dedicated APP via smartphone or the vocal

assistant, the user receives instructions on the set of exercises that are going to start (description and video) and an acoustic signal to indicate the start of the routine, then, after the countdown, the armchair set itself on the most appropriate position for carrying out the exercise. When the timing of the exercise is over, the user is encouraged to continue daily training.

The graphic interface of the APP has been developed to be as user-friendly as possible for non-expert users of the smartphone.

RESULTS AND DISCUSSIONS

A first release of the Smart Relax Armchair has been prototyped starting from a standard relax armchair frame. A commercial reclining system with a wide range of independent movements (completely laid, reclined backrest, lifted footrest and lifted) has been used to comply with most of the requirements reported in Table 1.

ARDUINO micro has been programmed to manage the power supply and equipped with a Bluetooth module to allow Wi-Fi connection to the Smart Relax Armchair APP for smartphones.

The Healthy Routine and the Active Ageing Routine, as well as the possibility to remotely control the movements of the reclining system have been compiled and uploaded in ARDUINO micro.

To define the acceptable amount of time in static position for the Healthy Routine the Authors conducted several tests on the prototype. The goal was to prevent the user from being annoyed by the routine and deactivating it, while guaranteeing the efficacy of pressure variation and posture correction. A thirty-minute timer has been selected and implemented in the final prototype.

The efficacy on pressure distribution variation induced by the Healthy Routine has been validated through the integration of a sensorised mat (BodiTrak, 2024) in the seat of the Smart Relax Armchair. As shown in **Figure 5**, by moving the reclining system from a seated position to a semi-reclined one (slightly lowered backrest and raised footrest) a reduction of 70% in peak pressure and of 10% in pressure area has been registered.

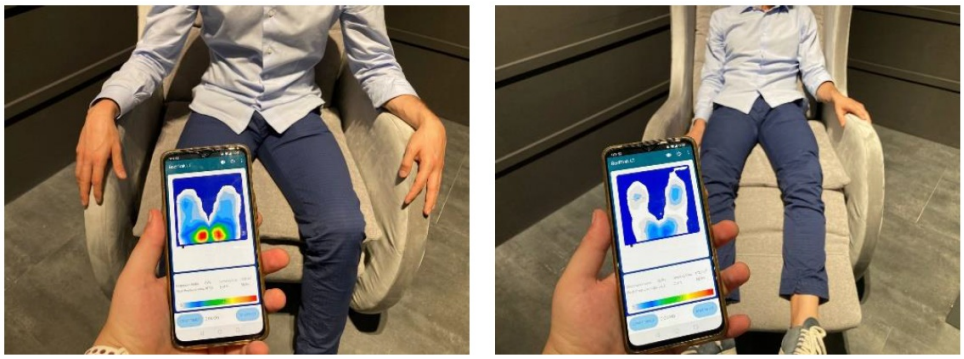

Figure 5: Pressure distribution and peak variation in two different positions of the smart relax armchair.

To define the acceptable amount of time necessary to perform each exercise included in the Active Ageing Routine, the Authors conducted several tests on the prototype. A panel of 10 blinded users has been asked to perform each exercise, while the reclining system was moved into the right position using the wired controller. The execution time has been recorded for each exercise and the average evaluated among users. These values, increased by 5% to encourage most users to complete the fitness session on time, have been implemented in the Active Ageing Routine uploaded on the final prototype.

Further tests will be conducted in the next months to validate the clinical efficacy of the Active Ageing Routine and to assess the usability of the Smart Relax Armchair APP among elderly.

CONCLUSION

The escalating prevalence of sedentary lifestyles and prolonged immobility resulting from extended periods of sitting has emerged as a pressing health issue. Prolonged sitting not only heightens the risk of postural changes but also contributes to the formation of pressure ulcers, substantially diminishing the overall well-being of older adults.

These statistics underscore the imperative to transform homes into more comfortable and secure environments for the elderly or people with reduce mobility, employing innovative solutions such as smart furniture to enhance people's lifestyles. In this context Relax Armchairs, can certainly be a very useful aid for promoting well-being in case of mobility issues.

The Authors exploited the potential of Relax Armchairs by embedding technological solutions on a commercial model to help users assume a correct posture while reducing their physical efforts and the occurrence of further complications due to bedsores formation. Moreover, thanks to a seamless integration of technology they reached the goal of promoting an active, but safe, ageing at home of the user which can easily perform simple workouts using the armchair itself as an exercise tool.

The solutions devised and integrated into the Smart Relax Armchair possess the capability to extend their application to any armchair or sofa model on the market. This transformative approach challenges the traditional paradigm of costly products tailored exclusively for active aging within residential care facilities, making them inaccessible to individuals aspiring to age in place. The innovative features of this solution not only democratize access to advanced aging technologies but also redefine the conventional boundaries of affordability and inclusivity in the realm of aging-in-place solutions.

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