# Development of a smart post-hospitalization facility for older people by using domotics, robotics, and automated tele-monitoring

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## Abstract

Recent studies showed that about the 8% of beds are occupied by patients who experience a delayed hospital discharge (DHD). This is attributed to a delay in the arrangement of home-care assistance or in admission to long-term care facilities. Recently a lot of technologies have been developed to improve caring and monitoring of older people. The aim of this study is to design, implement and test a prototype of a technology based post-hospitalization facility for older people at risk of DHD by using domotics, robotics and wearable sensors for tele-monitoring. A sensorised post-hospitalization facility has been built inside the hospital. Thirty-five healthy volunteers aged from 20 to 82 years were recruited. Clinical and functional assessment, *i.e.* motility index (MI), and human-robot interaction satisfaction were measured. A significant correlation was observed between automatic MI and the Gait Speed, the time sit-to-stand, and the Timed Up and Go test. Domotics, robotics and technology-based telemonitoring may represent a new way to assess patient's autonomy and functional and clinical conditions in an ecological way, reproducing as much as possible a real life at home.

## Introduction

Recent studies conducted in different countries showed that a significant proportion of hospital beds (about 8%) are occupied by patients who experience a delayed hospital discharge (DHD).[1] Usually, prolonged time in hospital is due to a delay in arrangement of special assistance at home or in admission to long-term care facilities. A DHD may have two main consequences, *i.e.* the development of new disabilities associated with prolonged hospitalization[2] and an increase in hospital costs related to the inefficient occupation of hospital beds.[1]

Hospitalization is one of the main causes of functional decline, especially in older adults. During hospital stay, 30 to 60% of older patients lose their independence in basic activities of daily living (ADL).[3] Indeed, beside the disabling effect of the acute event, hospitalization itself might represent an additional stressor in terms of environmental hazard, reduced caloric intake, immobilisation or prolonged bed-rest, depressed mood, poor quality of life and social isolation.[4] For all these reasons, reducing DHD is crucial to guarantee better recovery chances and to decrease hospital costs.

Recently a lot of technology has been developed, but its possible clinical impact on DHD remains unclear.

Given this background, the aim of our project was to design, implement and test a prototype of a smart and technology based post-hospitalization facility from different aspects in terms of organization, architecture/technology, and of clinical impact. To this purpose, a sensorised post-hospitalization facility that included domotic and telemonitoring technologies to monitor motility and clinical conditions of older subjects at high risk of DHD.

## Materials and Methods

This pilot study was carried out according to World Medical Association's 2013 Declaration of Helsinki and approved by the Ethical Committee of the Region of the study (Ethical Committee of the Region of the study Register Number P.R. 499REG2015 acquired with RP/186/UCS - prog. 5556/15 on 12.16.15). Informed consent was given by all participants in the study. All data and information were anonymized before the analysis.

### Prototype description

The prototype of a post-hospitalization protected facility was built within the hospital, where the patient can be monitored by a system of sensors, while physicians and nurses have the opportunity of monitoring the patient remotely. Safety has been guaranteed by the possibility of a remote monitoring and by the fact that the facility is hosted within the Institution with easy access to all emergency and hospital facilities.

The post-hospitalization facility is equipped as a comfortable apartment, where volunteer patients at risk of DHD may spend some days after hospital discharge. The system includes the possibility for the doctor to access live information remotely.

As shown in Figure 1 the apartment consists of two bedrooms, one with a bed and a sofa-bed (for an accompanying person) and one with two beds (patient and caregiver), a gym, and a common area with kitchenette and living room.

The choice has been made to experi-

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Key words: Elderly; smart home; design for all; delayed hospital discharge; ambient assisted living.

Contributions: CP1 coordinated all the necessary activities to build and activate the prototype in the hospital and wrote the manuscript; CM coordinated all the tests for the technological point of view and collected and analyzed all the data from the sensors; AC and RF performed all the clinical tests; AB followed all the healthcare sensors and the wearable ones and FO the visual based ones; NC supervised all the project from the architectural and design point of view; SP achieved the design for the prototype apartment; CP2 carried out the experimentation with telepresence robot.; MP performed the statistical analysis; AV supervised the technological aspect of the project; AP was the Principal Investigator of the project. All authors contributed to the final manuscript.

Conference presentation: part of this paper was presented at the 9th Forum Italiano Ambient Assisted Living (ForItAAL), 2018 July 2-4, Lecce, Italia.

Received for publication: 20 February 2019.
Accepted for publication: 2 April 2019.


*Geriatric Care 2019; 5:8122*
*doi:10.4081/gc.2019.8122*

ment a domestic environment with materials, furniture, accessories and technology platforms already available in the market. Technological devices and sensors have been integrated as much as possible in the furniture set in order to give a familiar appearance to the environment. Starting from the detection of users' needs, all solutions and products adopted allow the integration of architectural environment with systems of monitoring, control and assistance (with particular attention to privacy), involving different technological areas such as: telecommunications, computer science, microsystems, robotics, new materials, according to the AAL (Ambient Assisted Living) approach.[5]

A telepresence robot has also been used to allow guests and caregivers to communicate with doctors and researchers outside the apartment with actions-reactions in real-time voice and video.

The integration of *passive* solutions (*e.g*. resilient floor surfaces, to reduce damage in the event of a fall or impact, shape and arrangement of furnishings, position of control devices *etc*.) and *active* hi-tech systems (integrated sensor panels for the control of posture and warning in the event of recognition of a fall) makes it possible to implement smart environments, which are still designed to be perceived as domestic and in which the comfort and safety of the guest and caregiver is guaranteed and at the same time monitoring and care facility is optimized.[6]

In order to monitoring the frail patient at home through smart environments, Cao *et al*. (2009)[7] presented a context-aware system based on video analysis and a reasoning mechanism. Zouba *et al*. (2010)[8] described the prototype of a smart home equipped with cameras and environment sensors, Bathrinarayanan *et al*. (2013)[9] evaluated an event recognition system also based on video analysis. In all these researches the main effort was to recognize actions and instrumental activities.

A *Design for All* principles-based design has guaranteed the best approach possible to all operating areas in the prototype.[10]

The apartment layout has been clearly divided in daytime and night time area and defined by the use of cold and warm colors, to separate clearly the public spaces from the private ones.[11,12] Color has been used as signage and orientation to accentuate the differentiation between the different spaces of the accommodation and the transition from one to another.[13]

The common area hosts most ambient sensors, cameras and RGBD sensors, pressure sensors on the chairs and light sensors on some cabinet door of the kitchenette. Health monitoring devices were located on a console table in the same area.

In our system, for privacy purposes, cameras and RGBD sensors were not located in the bedrooms and bathrooms but, thanks to position tags and presence sensors, it is possible to perform a unobtrusive monitoring of the patients in these areas.

The apartment is equipped with a set of environment and wearable sensors controlling the overall well being of the patients. A minimal set of vital parameters (including weight, blood pressure, heart rate, Oxygen saturation level, glucose) were collected daily through wearable and non-invasive devices, selected to guarantee the patient's freedom of movement (no cables, data were transmitted via wireless communication) and to allow for an automatic analysis on the acquired data. The available devices were all provided by iHealth Labs [https://ihealthlabs.com/]. The collection of all measures was done via bluetooth by an LG G3 smartphone, which sends the data to a software data collection platform, RiHealthy [http://www.rihealthy.com/] platform, which also allows physicians and nurses to remotely monitor the parameters.

The whole of the apartment was also



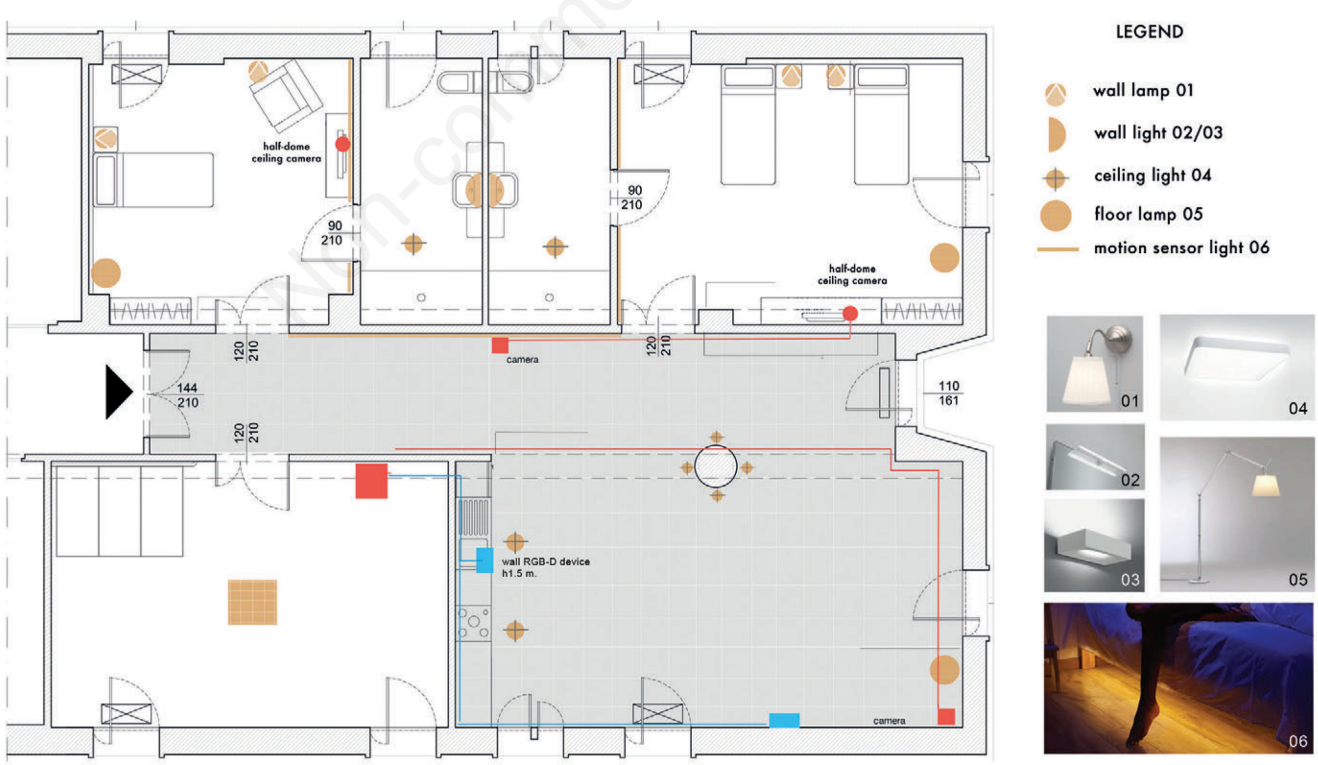


**Figure 1. The layout of the prototype apartment, where the environment sensors have been highlighted. Blue: RGBD sensors; green circles: localization tags; purple: PIR; red: video-cameras.**

equipped with: i) an indoor localization system (Eliko KIO RTLS; http://www.eliko.ee/products/kio-rtls/), for a continuous and unambiguous tracking of the monitored person; ii) passive infra-red (PIR) Sensors detecting whether there is movement in the sensed area, used for the unobtrusive monitoring of specific sensitive areas; iii) cabinet doors' sensors (SparkFun; https://www.sparkfun.com/; Luminosity Sensor), for the robust detection of cooking and eating activities; iv) chair occupancy sensors (SparkFun Force Sensitive Resistor), positioned on the kitchen chairs and the sofa.

The measurements could be further improved by integrating information obtained from sensors distributed in the environment with measurements obtained by wearable accelerometers. So far, we have adopted a LG G Watch R5 equipped with a triaxial accelerometer.

We achieve a continuous monitoring of the patient's location and activity by analyzing the measurements obtained by ambient and wearable sensors by means of appropriately designed signal processing and machine learning algorithms. The heterogeneous measurements are synchronized in time, but different sensors take care, in general, of specific aspects and no data fusion, up to now, takes place.

RGBD sensors are employed extensively in the analysis of the common area, mainly to evaluate motility and activities. In the literature, there are several approaches that use RGBD sensors to detect[14] and track people,[15,16] also for assistive purposes.[17,18] The 3D skeleton data obtained from the RGBD sensors are used to locate people in the visible part of the scene and to associate a coarse status, based on the estimated people height encoded in the measurements. This coarse status can take the following values: standing, sitting on a chair, sitting on the sofa, sitting on the floor. As a complement to these measurements, the localization sensor helped to locate one person on a wider area.

As for the rest of the apartment, we may detect bathing sessions, which can be associated with movement in the shower area, detected by a presence sensor. We may also assess sleep quality analysis based on PIR sensors located by the bed.

We also take into consideration more complex activities, such as cooking and eating, involving the interaction with a number of objects (such as the fridge, or any among the available dishes) and the execution of a number of gestures (such as pouring water in a glass, or opening a cabinet), in a variable sequence. The concurrent and independent monitoring of objects and gestures of relevance for the task allows for a richer representation of such activities, and therefore a more robust recognition.[19] Similarly, we rely on a single, wrist-placed sensing device equipped with a triaxial accelerometer for the recognition of human gestures.[20] In particular, gestures are represented in terms of the acceleration pattern they correspond to the recognition then involves the comparison of runtime acceleration data with the stored representations, to find the one more closely matching it, if any.

## Architectural and design solutions

The study is based on the principle that, passing a transitional period in an environment with perceptive, typically-domestic characteristics, patients can regain the ability to live actively and independently at their own home.

The patients in discharge frequently have sensory (vision, hearing) as well as motor (coordination) functions deficits, which heavily affect their ability to manage the environment and its spaces. The environmental incorporation of aids and carriers aimed at ensuring safety and fluidity of movements are desirable solutions on the level of the most complex smart technologies.

As mentioned above, the *home* model has inspired the prototype, which respects its dimensions, quality and familiarity, as well as a general sense of wellbeing deriving from: i) perception of space security; ii) compensatory possibilities spaces for memory disorders (large and clear signs) and behaviour; iii) avoidance of redundant and stressful stimuli; iv) respect for privacy and of the residual decision-making skills.

### *The colors: materials and interior design*

The colors and materials deeply influence human feelings besides determining and aesthetical effect. It is well known that perception of luminosity and coziness is influenced by predominant colors which define areas and furniture.[13] In the project a deep color study has been conducted. The study presupposition is that every sensorial stimulation source should be necessarily collocated in a defined area, coherently with its function. The materials and different colors use has allowed a much easier, accessible and intuitive interpretation of the environment. In particular, three main areas, differentiated by chromatic contrasts, have been individualised, resulting from the use of warm and cold colors: i) private areas (bedroom and bathroom): blue tones, with the purpose to relax and consequently favor a correct equilibrium, decreasing the states of nervousness both motor and emotional; ii) passage (corridor) and activity (gym of physiotherapy) areas: yellow tones, with the purpose to favor the dynamic activation in area dedicated to the rehabilitation of the motor and cognitive functions; iii) public areas (kitchen and living area): pink tones, with the purpose of communicating serenity and hospitality (meal moment and relations among relatives and guests)

## Experimentation with telepresence and telemonitoring robots at the prototype housing

Purpose of the experimentation conducted by the group of architects and designers in the semi-hospital prototype housing is the evaluation of the operational formalities related to the use of a telepresence robot in the assistance to elderly patients.

The evaluation by users, support staff and guests, has affected the interface of the robot, meaning the type of interaction with it and usability.

For this purpose, a Padbot, a low-cost telepresence robot developed by Inbot Technology Ltd., was used inside the accommodation. Like other telepresence robots, Padbot allows users to move and communicate remotely in a free way with action-reactions in real time, videos and audios, in a simple and natural manner.

This telepresence robot can be commanded by a remote through the appropriate application for smartphones (iOS or Android). Reassuming, the activities of the conducted experimentation have made possible to: i) test the Padbot technology; ii) identify the strengths of this type of remote assistance; iii) accentuate the technical problematic aspects; iv) identify the best interaction mode with the users.

For the experimentation a sample of 10 subjects has been enlisted. These people were: volunteers over 65, skilled and without cognitive impairment. The authors asked them to perform a series of ten exercises. The volunteers were sitting on the chairs during the activity.

For every experimentation exercise some illustrative images have been prepared. They have been sent and orally explained to the volunteer, before the beginning of every exercise. Through the video-call, as reported in Figure 2, it was possible to explain the training program and to guide the users step by step in the exercises execution, assisting them, from remote, in real time during the whole activity.

A guideline text has been previously implemented in order to standardize and the experimentation and to make it smoother. The same text, in its final part, had a questionnaire to submit to the volunteer at the end of the training program.

The deployment of these operations has

been measured (time) and valued through special cards and interviews. All the points of view of the team involved in this phase have been studied, starting from the patients to the assistance personnel in order to evaluate the use of the object and its users' perception.

The submitted survey is composed of 13 questions: i) 6 yes-no questions; ii) 7 range of answers questions (from 1 to 10); iii) one optional open question.

The filling out of the questionnaire consisted an average of 9 minutes and 36 seconds.

### Clinical assessment

Several tests were done for the clinical assessment of the patients: i) The standard Short Physical Performance Battery (SPPB) was administered to each participant to assess the lower extremity function.[21] It consists of three independent tests (balance, gait speed, chair stands time), each one scoring from 0 to 4, higher scores reflecting better performance; ii) The Multidimensional Prognostic Index (MPI)[22] was also investigated to identify the grade of multi-dimensional impairment, *i.e.* frailty, in included subjects. This prognostic tool includes 63 items distributed in 8 domains of Comprehensive Geriatric Assessment (CGA). This score ranges from 0 to 1, highest scores reflecting higher risk of frailty; iii) The Hand Grip strength[23] was performed to quantify the strength of the upper arm; iv) Overall motility assessment was evaluated combining data to obtain a motility index (MI).[24,25] This index, which is also included in the report, is in the range (0 to 1), approaching 1 when the motility of the subject is high.

### Statistical analysis

Descriptive statistics adopted for continuous parameters were mean, standard deviation (SD), median and interquartile range (IQR), minimum and maximum; as regard categorical parameters we used absolute and relative (%) frequencies. We primarily assessed graphically the correlation between motility index (MI) and other factors classically measured by mean of scatter-plots with the superimposition of a linear regression line and boxplots. Correlation was then measured calculating the Spearman's rank correlation coefficient and testing for statistical significance. All analyses were performed both in the overall population enrolled (n=35) and, separately, in subjects aged ≤30 years old (n=11), and subjects aged >30 years old (n=24). Two-sample Wilcoxon rank-sum (Mann-Whitney) test was adopted to test difference in MI age subgroups. To study the association between MI and any other single parameter, adjusting for age, sex and duration of the observation, we adopted a linear regression modelling approach. MI was the dependent variable and one model per each parameter was built and tested, testing also the interaction term with age group (under and over 30 years old). Due to the exploratory nature of the study, no correction for multiple testing was implemented: we reported two-tailed probabilities, and a P-value of 0.05 was adopted to define nominal statistical significance. All analyses were performed using STATA (version 14.2, StataCorp., College Station, TX, USA) software.

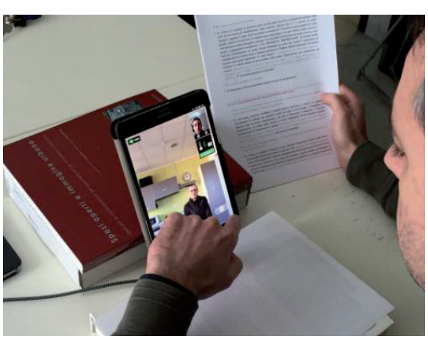

**Figure 2. Remote connection.**

## Results

From the measurements and the associated analyses, we derived a report of the patient welfare. More specifically, the physicians involved in the project were interested in obtaining a picture of the following elements, summarized in two daily reports covering morning and afternoon temporal spans: i) area occupation; ii) activities statistics; iii) motility estimates.

At each time *t* of the day, we were able to associate a patient ID with a position in the 3D space. Then this instantaneous information is summarized in two different ways: maps of the trajectories for each patient; statistics of the occupied areas obtained by integrating measurements from different sensors (Figure 3).

From the motion data, we computed different motility quantities, including: i) number of postural changes (sit-to-stand and vice versa); ii) total time spent moving, standing still, and sitting; iii) number of instances of walk and stop events.

Figure 4 reports a boxplot showing MI by age subgroup. Median (interquartile range) of MI in young subjects was 0.70 (0.67-0.87) *vs* 0.63 (0.37-0.80) in older ones: two-sample Wilcoxon rank-sum (Mann-Whitney) test was not formally significant (P=0.14) but not far from significance, considering also the small sample size.

A number of 35 healthy volunteers on voluntary basis were recruited. 11 volunteers were subjects below 30 years old whereas the other 24 volunteers were subjects with a mean age 73±5.4 years, females= 54.29%. A significant correlation was observed between the observation period and the MI (Spearman's rho = –0.40, P=0.02). Moreover, from a linear regression model adjusted by duration, age and sex we observed an interesting trend toward a significant correlation between MI and Gait speed (coeff.=0.13, P=0.20), the time sit-to-stand (coeff.= –0.02, P=0.14) and the test Timed Up and Go (coeff.= –0.04, P=0.10). Regarding the correlation between MI and handgrip strength, we observed a significant borderline interaction between hand grip and age group (P=0.08).

The telepresence robot has been tested on 10 voluntary basis volunteers. The 60% of them were male with a mean age 68.8±2.6 years whereas the female with a mean age 72.7±6.2. Figure 5 shows the results of the survey.

## Discussion and Conclusions

Our study successfully assessed the safety and the reproducibility of the prototype of a smart and comfortable apartment. The concept we are proposing has a potential positive impact both at the financial and at the medical level. In perspective it will improve the quality of life of patients and allow them for a faster rehabilitation and discharge from the hospital. The prototype facility we are developing be a living proof-of-concept, innovative from the point of view of the research workflow. Real patients were volunteering to spend a few days in the facility, carrying out their nor mal life, while sensors were acquiring data, performing analysis, and producing results, physicians were checking if the obtained reports were meaningful and appropriate for the task.

The remote assistance experimented was pleasant and entertaining for all the volunteers involved. The purposes of the analyzing the problems encountered in the use of robots, both by patients and by caregivers, and assessing the object's usability as well as the user's related perception[26] has been achieved. Some of them have reported that the device could be a good incentive to develop physical activity at home, that otherwise they would not do out of idleness and lack of will. Some technical problems such as the sound system, the echo, the video and the audio breaking up, fluidity and precision of movement of the robot could be easily overcome by using more updated communication devices and a more stable and faster internet connection.

Notably, a research group of designers are defining the most appropriate ergonomic solutions and the integration of sensors in a home-like environment also considering the possibility of shifting the research activity into the home environment.

The main advantage of employee of our model could be the significant reduction of

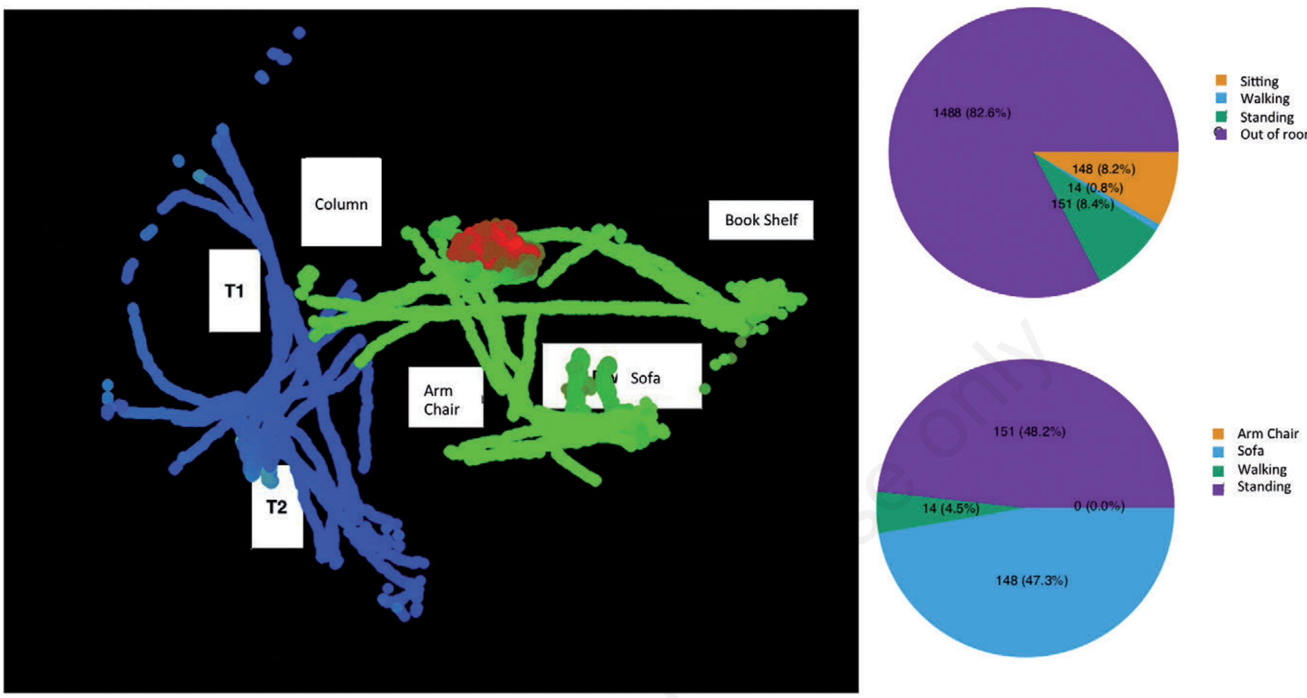


**Figure 3. Occupancy map and pie charts summarizing 30 minutes of activity of one patient. The map is acquired from two different environment sensors, with different field of view (acquiring trajectories color coded in blue and green respectively). Red area corresponds to the person sitting on the floor for some time. The pie charts summarize the statistics of the amount of time spent on different states; on top a coarser view, on the bottom a more precise statistics that excludes the time spent out of the room.**

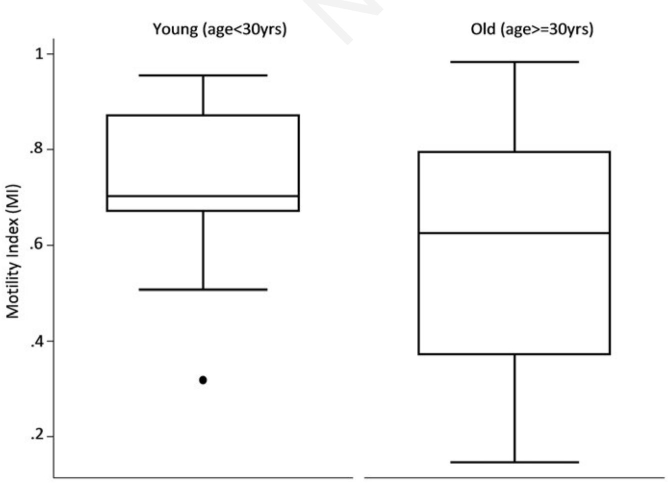


**Figure 4. Boxplot of the estimated motility index (MI) by age group.**

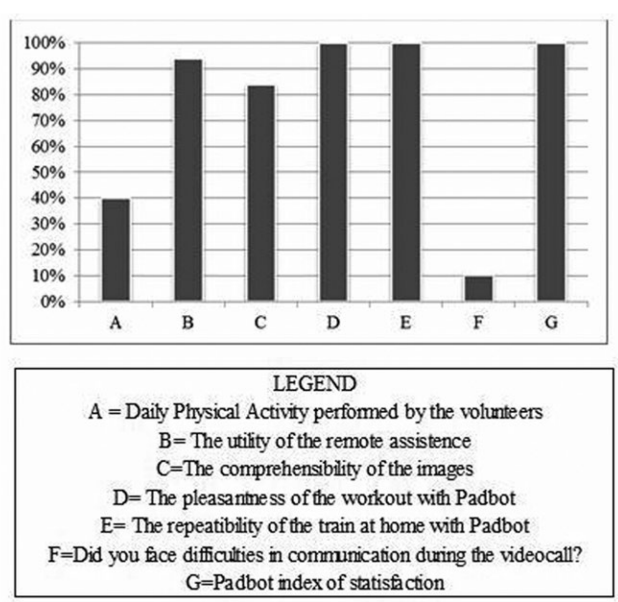


**Figure 5. Questionnaire results of the experimentation with telepresence robot.**

the length of stay of the patients and DHD. This allows in a lower functional decline due to the long-term hospitalization. Both of these results translate into a costs reduction. Using this model, we proposed a system generating early discharge of the patients, less related complications with employee of few resources.

The findings of our paper should be considered within its limitations. First, the limited sample size included. Second, the criteria for patients' recruitment are too restrictive due to the presence during the night of the caregiver in order to guarantee the safety requirement for the patient. Third, the technology adopted is not able to distinguish the movements belonging to different persons.

In conclusion, this system might allow to develop a new way to assess patient's autonomy and functional status in an ecological way, reproducing as much as possible an observation at home in real life. This will be useful to further improve the multidimensional assessment in older patients. Future studies with larger sample sizes are needed to confirm our promising results.

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