Concept development and prototypes for robotic systems in active assisted living

I Todirițe, C Radu-Frenț, P-Al Cotfas and M Iliescu
Romanian Academy, Institute of Solid Mechanics, Constantin Mille 15, Bucharest, Romania
E-mail: mihaiela.iliescu@imsar.ro

Abstract. Active and Assistive Living, AAL, is a concept that attention have been focused on in the last decades. There are many young people with disabilities, such as visually impairment, missing limbs, AVC stroke problems. There are also many old people who have locomotion, eyesight and many other health problems that make their lives so very difficult. The authors of this paper present aspects of their research regarding new concepts, models and prototypes (virtual and 3D printed) of robotic systems intended to assist people with disabilities for an active and normal life. An innovative open source system for guidance of young people (but, also elderly ones) with eyesight problems has been developed. It is intended to be used indoors also outdoors, to provide audio guidance, haptic guidance, or both. Research aspects on a bionic prosthesis for the upper limb are evidenced. The focus is on a two fingers model that should be considered as the proof of concept. Innovative mechatronic system designed to help people, who can no longer stand and / or walk is further presented. A virtual platform concept aimed at the integration of all these devices, and similar others, to communicate by IoT is shown.

1. Introduction
Active and Assistive Living, AAL, is a concept that attention have been focused on in the last decades. There are many young people with disabilities, such as visually impairment, missing limbs, as well as old people who have locomotion, eyesight and many other health problems that make their lives so very difficult. In recent years, attempts have been made to integrate people with disabilities in social, school, university environment. In order to achieve this integration, it is not enough to define the concepts related to inclusive integration, it is necessary to be aware of issues, the specials needs they have, and the fact that these people need help.

In the case of visually impaired people, the fact that they need help with writing, reading or moving is envisaged. In order to help them, various systems have been developed so that they represent be helpful solutions for a small number of people, because they do not cover special needs, are not personalized and do not take into account the fact that in most cases these people have also other disabilities and cannot purchase a device for each disability. This explains the fact that the white walking stick solution [1], bracelet and belt with distance sensors have not become so popular among visually impaired persons. In [2] and [3] there are presented results simulation of a “white cane that blindfolded sighted participants control with a mouse to obtain a single-point depth information (through sound) of the virtual environment.
Missing upper limb is another disability type that, unfortunately, prevents people from having a normal life. There are many researches on prostheses, their structure, enabled motions, adaptability to the body of the person wearing it, availability and costs. The concept and design of low cost myoactivated prosthesis are shown in [4]. This prosthesis “consists of a low-cost embedded microcontroller (Arduino), a wearable stretch sensor, to detect residual muscle contraction as direct muscle volumetric shifts and a handful of common, not critical electronic components.” The authors mention that its “control is simple and customizable with access to a computer and minimal training.” The costs are much more than affordable. Clinical outcomes of the studies on a myoelectric hand prosthesis are evidenced in [5]. Conclusion is that “low-cost 3D-printed myoelectric-interface prosthetic hand with a single reliable myoelectric signal shows the potential to positively impact amputees’ quality of life through daily usage”.

Active Assisted living is an important issue for people who had strokes or, for old people whose locomotion problems are severe. There are many devices aimed to help them, as well as the person who takes care. One advanced patient lift and transfer device is presented in [6]. It is mentioned that it “is not designed to travel down steep ramps and transition steps from these ramps, but is meant to traverse doorway thresholds from horizontal surfaces.”

The authors of this paper present aspects of their research regarding new concepts, models and prototypes (virtual and 3D printed) of robotic systems intended to assist people with disabilities for an active and normal life. The scope is to implement useful solutions for people with visual impairments and / or mild or moderate cognitive impairments, as well as for people with missing upper limb or, with locomotion problems.

2. Research Method
In this scientific research there have been identified, grouped and analysed the special needs of people with disabilities mentioned above. After identifying the special needs, they were grouped into categories that follow:
- basic needs - the needs identified as common to most of the subjects who took part in the research;
- specific needs - the one that allowed customization of the solutions according to the multiple / conjugate disabilities of the subjects.

For each category of needs it was defined a solution that was implemented conceptually. So the basic needs led to a standard solution, and the specific need led to modular systems within the customized solution.

The scientific research was based on data collected from the subjects, as follows:
- by applying questionnaires to identify special needs;
- through roundtable discussions with subjects during face-to-face or online meetings;
- through practical field orientation activities indoors and outdoors; spaces whose configurations were known, but new routes unfamiliar to the subjects were also made.

The concepts and design of the mechatronic systems for active and assistive living are based on research results regarding body features and type of motions required to fulfil certain tasks (gripping, motion toward an object, controlled trajectories etc.). For example, the kinematic analysis of the mechanical structure of hand prosthesis was done considering Assur groups type – dyad and triad, aided by Matlab software. Modelling and simulation of mechatronic systems were done assisted by SolidWorks software.

3. Research Results
Within the scientific research we carried out different activities that were grouped in stages, as follows next:
Stage I - Data collection and grouping using different criteria in order to identify the special needs of people with disabilities already mentioned.
Stage II - Analysis of results
Stage III - Conceptual implementation of the solution
3.1 Stage I. Description of the research stage

During this stage we started the research by applying, within the working groups, questionnaires to identify special needs.

It should be noted that all subjects who were part of the working groups are students and follow a form of vocational, high school or post-high school education. The subjects’ ages are between 14 and 28 years old, grouped by age categories, as shown in table 1.

Face-to-face discussions or online meetings were necessary because it was found after applying the questionnaires that the results were not relevant and then we had to identify the cause. An important criterion chosen, was related to the fact that the person has or does not have multiple/conjugate disabilities because all disabilities hinder the person’s activity.

A list of criteria was added to detect special needs: the sex of the person participating in the research, the spirit of orientation in a closed space (Yes/No), the spirit of orientation in an outdoor (Yes/No), tactile recognition of compact objects (Yes/No), tactile recognition of transparent objects (Yes/No), use of white cane indoors (Yes/No/Occasionally), use of white cane in outdoors (Yes/No/Occasionally), color identification (Yes/No), environment origin (urban/rural), the environment in which he lives (family/institutionalized placement/family placement).

| Age category name | Coding Participant name | Number of participants with conjugate/multiple disabilities (Girls) | Number of subjects by age categories |
|-------------------|-------------------------|---------------------------------------------------------------|-------------------------------------|
| CtgA | A1...A12 | 3 | 12 |
| CtgB | B1...B14 | 10 | 14 |
| CtgC | C1...C10 | 2 | 10 |
| Total | 15 | 8 | 36 |

More of it, graphical representation of the target group disabilities and the problems they are facing (see figure 1 and figure 2) points toward the fact that there is a relatively equal number of subjects with multiple disabilities and so a wide range of specific needs are collected.

**Figure 1.** Graphical representation of the distribution, by age categories, of subjects with conjugate/multiple disabilities.

**Figure 2.** Graphical representation of the distribution of subjects with and without conjugate/multiple disabilities by age categories and genders.
Following the centralization of the data, it was obtained a database (see figure 3) that will be analyzed in order to discover the specific needs of the subjects involved in this study.

| Age category name | Coding Partici- pant name | With Multiple/ Conjugated Disabilities (Yes/No) | Sex (F/M) | Ability of orientation outdoors (Yes/No) | Tactile recognition objects (Yes/No) | Utilisation white cane indoors (Yes/No/Occasion) | Utilisation white cane outdoors (Yes/No/Occasion) | Identification colors (Yes/No) | Origi- nal environment (Urban/ Rural) | Living environment (family/institutional placement/family placement) |
|-------------------|---------------------------|-----------------------------------------------|-----------|----------------------------------------|----------------------------------|-----------------------------------------------|-----------------------------------------------|-------------------------------|-----------------------------|----------------------------------|
| CtgA A1           | Yes                       | M                                             | No        | No                                     | No                                | Yes                                           | No                                            | Yes                           | No                          | Urban family                     |
| CtgA A2           | Yes                       | M                                             | No        | No                                     | No                                | No                                            | No                                            | No                            | No                          | Urban family                     |
| CtgA A3           | Yes                       | M                                             | Yes       | No                                     | No                                | No                                            | No                                            | No                            | No                          | Urban family                     |
| CtgA A4           | Yes                       | M                                             | No        | No                                     | No                                | No                                            | No                                            | No                            | No                          | Urban institutional placement   |
| CtgA A5           | Yes                       | M                                             | No        | Yes                                    | No                                | No                                            | No                                            | Yes                           | No                          | Rural institutional placement   |
| CtgA A6           | Yes                       | F                                             | No        | No                                     | Yes                               | Yes                                           | Yes                                            | No                            | No                          | Rural institutional placement   |
| CtgA A7           | Yes                       | F                                             | Yes       | No                                     | Yes                               | Yes                                           | Yes                                            | No                            | No                          | Rural institutional placement   |

Figure 3. Questionnaire data centralization table screenshot.

3.2 Analysis of results

In this results analysis stage, it was meant to determine whether subjects with conjugate/multiple disabilities have or can develop a sense of orientation in an enclosed space, when they know or do not know the configuration of the space (see figure 4 and figure 5).

Figure 4. Graphical representation of the comparative study by age groups to illustrate the ability to orient indoors of subjects with conjugate/multiple disabilities.

Figure 5. Graphical representation of the comparative study by age groups to illustrate the ability of the subjects to orient themselves indoors.

Analyzing the data set it results that the majority of CtgB category subjects have conjugate/multiple disabilities. The research found that as the subjects have other disabilities with mild or medium forms, although they have the same space in which they work for two years, they still fail to orient themselves in a closed space, even when the configuration space does not change.
Figure 6. Graphical representation of the options of subjects by age categories who have conjugate/multiple disabilities and do not have the ability to orient themselves outdoor.

Figure 7. Graphical representation of the options of all subjects by age groups who do not have the ability to orient themselves outdoor.

Analysing the graphical representation of figure 6 it can be seen the subjects who were oriented in the open space were the people who can see in a percentage of 5%, with correction because they have a residual vision and the conjugate disabilities are in easy form. It can be observed by analysing the graphical representations of the results obtained in the research (figure 7), that in open space both subjects with multiple disabilities and those with visual impairments have great difficulty orienting in open space, even if the space is limited as an area and not necessarily unknown. In the case of the new routes, we noticed that the subjects did not manage unaccompanied, although few of them, used a white cane.

Figure 8. Graphical representation of subjects' options for using the white cane indoors.

Figure 9. Graphical representation of the comparative study by age categories of the subjects' options regarding the use of the white cane outdoors.

It is observed from the graphical representations of the subjects' options (see figure 8 and figure 9) that the white cane is used by them when they are in indoors much more than in the situation when they are in outdoors.

The shortcomings of the white cane are many, among which we mention: it does not offer the possibility to the one who uses it to identify if there are open windows on the route in indoors. In open places people with visual impairments use the cane if they have to travel short distances, over long distances they avoid walking unaccompanied, because the cane gives them a sense of insecurity by the fact that it is like it warns everyone that they do not see and therefore they become vulnerable people.
3.3 Concept and prototype of the mechatronic systems

The comparative studies conducted in the research helped us to delimit the needs of people with visual impairments and to decide what are the special needs common to these people and what are the needs that can be associated only with other disabilities. From a conceptual point of view, the mechatronic system for visually impaired people (named Visual RobCat) will be modular, enabling customization for each user. One important characteristic is that it enables guidance in narrow spaces, on flat, inclined or staircase surfaces. The 3D model, as it is in the present stage, is shown in figure 10.

![Visual RobCat 3D model](image)

**Figure 10.** Visual RobCat 3D model.

The system will be further developed and all the subassemblies for required modules integrated. Conceptually, there are developed two constructive variants: standard device and adapted device.

The standard device, through which we aim to meet the common special needs of visually impaired people, will include modules for measuring the distance to the objects in front of the subject. The person who uses the device will be notified (audio, haptic) if there are objects in front and, more of it, it will be able to differentiate between objects and beings that move or park. The detected objects can be at ground level (eg stairs that can be climbed) but also objects at head height, transparent objects (windows) or detect gaps in the ground: pits or stairs that go down (see figure 11).

![Standard device diagram for the visually impaired](image)

**Figure 11.** Standard device diagram for the visually impaired.

The adapted device will be built on the structure of the standard one, but as the name suggests it will be adapted to additional needs depending on the mild or medium cognitive disabilities of the subject. It would include modules capable of identifying colours, useful modules for the blind or visually impaired but who do not perceive colours (see figure 12). This feature can be activated when the user wants to choose clothes to wear, buy or wash them with the washing machine.
Research aspects on bionic prosthesis for the upper limb are evidenced. The fingers motion is to be initiated by the EMG sensors. There are also pressure sensors, tilt sensors, gyroscope sensor and temperature sensor. For the initial prototype, there has been designed two fingers model (see figure 13(a) and (c)) that should be considered as the proof of concept. Fingers trajectories, when considering the dyad structure open kinematic chain is also presented, for all the hand fingers (see figure 13(b)).

The concept and design of an innovative mechatronic system designed to help people, who can no longer stand and / or walk is presented. The most important aspect is that this system would be attached on an autovehicle’s frame (see figure 14) and enable people with locomotion problems to be got into the car.
A virtual platform concept aimed at the integration of all these devices, and similar others, to communicate by IoT is shown in figure 15.

4. Conclusions
The authors of this paper present aspects of their research regarding new concepts, models and prototypes (virtual and 3D printed) of robotic systems intended to assist people with disabilities for an active and normal life.

Initial stage of the research was aimed to identify the special needs of people whose life would be assisted and improved. Based on questionnaire result there have been identified, grouped and analysed the special needs of these people.

From a conceptual point of view, the mechatronic system for visually impaired people (named Visual RobCat) will be modular, enabling guidance in narrow spaces, on flat, inclined or staircase surfaces. It will be developed in two constructive variants: standard device and adapted device, depending on its degree of customization.

The concept of bionic prosthesis for the upper limb is evidenced, mainly by the two fingers model. It can be noticed the complexity of fingers motions, in two planes (horizontal and vertical). The fingers motion is to be initiated by the EMG sensors and each of the fingers phalanges would be independently driven by micromotors. Image of the 3D printed prototype is presented.

The model of innovative mechatronic system that enables people with locomotion disability to get into a car was also the objective of this research.
Finally, it has been developed virtual platform concept aimed at the integration and communication by IoT of all designed devices. This platform would be implemented and tested in virtual reality and, further, validated by the manufactured devices’ prototypes.

5. References

[1] Menikdiwela M P, Dharmasena K M I S and Harsha A M S 2013 Abeykoon Haptic based walking stick for visually impaired people https://ieeexplore.ieee.org/document/6718549/authors.

[2] Alexa F. Siu, Mike Sinclair, Robert Kovacs, Eyal Ofek, Christian Holz and Edward Cutrell 2020 Virtual Reality Without Vision: A Haptic and Auditory White Cane to Navigate Complex Virtual Worlds, CHI ’20, Honolulu, HI, USA, ACM 978-1-4503-6708-0/20/04, https://doi.org/10.1145/3313831.3376353.

[3] Maruricio Lumbreras and Jaime Sánchez 1999 Interactive 3D sound hyperstories for blind children In Proceedings of the SIGCHI conference on Human Factors in Computing Systems (CHI ’99) Association for Computing Machinery, New York, NY, USA, 318–325 pp. https://doi.org/10.1145/302979.303101.

[4] Sreenivasan N, Ulloa Gutierrez DF, Bifulco P, Cesarelli M, Gunawardana U, Gargiulo GD. 2018 Towards Ultra Low-Cost Myoactivated Prostheses. Biomed Res Int. 2018:9634184. https://doi.org/10.1155/2018/9634184. PMID: 30402497.

[5] Ku, I., Lee, G. K., Park, C. Y., Lee, J. and Jeong, E. 2019 Clinical outcomes of a low-cost single-channel myoelectric-interface three-dimensional hand prosthesis Archives of plastic surgery 46(4) 303–310 https://doi.org/10.5999/aps.2018.01375.

[6] Bostelman, R., Ryu, J., Chang, T., Johnson, J. and Agrawal, S. K. 2010 An Advanced Patient Lift and Transfer Device for the Home ASME. J. Med. Devices. 4(1): 011004. https://doi.org/10.1115/1.4001255.