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# Helping and monitoring robots at low cost

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## Abstract:

*Through European countries the dependency ratio of elders and people with disability will rise in the next years. To avoid a degradation of the life quality of dependant persons, they may be maintained in their home. To ensure people safety and avoid isolation problems, some mechanisms are needed. We propose a new method, the X-development method, to guide generic product design from end-to-end. In this paper, the design is focused on robots for dependant people. To respect the environmental constraints and to reduce the amount of waste, the robots have to be designed properly. The aim of the X-development method is to ease the manufacturing process thanks to the tight association between the modelling and design phases of smart systems. Our robots are remotely controlled in order to achieve monitoring and social tasks. Caregivers or relatives can control each robot to interact with the dependant person. The robots increase the social interaction of dependant people. During the design phase, we keep in mind to maintain the price of the robot as cheap as possible, because it is the key point in the generalization of this one.*

**Keywords:** companion robots, design methodology, eco-design of robots.

## 1 Introduction

Population ageing raises the dependency level of the elder people. The expected population of the EC in 2060 will reach 512 M inhabitants, 30 % will be over 65 years, 12% over 80. In the same way, some people are unable to move freely either momentarily or definitely from the shock of an accident. Dependant people face challenges living in a normal world. To realize a common action may become very difficult. Sometimes, they prefer to choose isolation over social interactions. To maintain in touch dependant people in their home, some mechanisms are needed to take care of them. Mobile Ubiquitous Devices (MoUD) such as remote controlled robots represents an interesting approach for Ambient Assisted Living environments (AAL).

For us, a first typical application is to help elderly people who live in their homes and sometimes have difficulties to move. A MoUD carrying a camera, speakers and microphones, could help them to monitor their home either indoors or outdoors, for example to see what is going on or simply to watch what their favorite pet is doing. A second typical application is the use of the MoUD by relatives or caregivers to check that everything is ok and to communicate with the inhabitants of a flat from everywhere.

Nowadays, the cost of remote controlled robots decreases a lot. These low cost robots are principally some toys. But the usage of these robots is limited. Hence, they cannot be used in our context due to their poor reliability, the limited security and services. However these toys can be manufactured in large quantity. Each day their number increases constantly. The lifespan of these robots is quite short so they have a huge environmental impact.

Since the Kyoto protocol, European countries have to limit their amount of CO<sub>2</sub>-equivalent emissions. To reduce the environmental impact of a manufacturing product, environmental considerations have to be integrated into the whole product's life cycle. To achieve these goals the design of a product has to take into account three parameters: the material reusability, the material recyclability and the energy efficiency. The material reusability is to give a second life at a product (or a part of this one) without necessarily transforming its appearance or properties. Recently, the European Commission introduced a directive to enable a reuse of a product instead of recycling. When a product cannot be totally reused, the waste is used into the production of different materials. The recyclability of a product prevents to use fresh raw materials and reduces the CO<sub>2</sub>-equivalent emissions. The energy efficiency is to minimize the energy consumption needed to manufacture and use a product.

To reach these constraints, the MoUD has to be designed properly. We propose the X-development method to identify design changes in a smart product to reduce environmental impact. The material specifications and selection phases are correlated in order to minimize the environmental impact. In respect of the MoUD price, it also eases the process to find the more valuable components and materials to compose it.

Except the environmental considerations, engineers have to face several challenges to design such a MoUD. First, they have to define a robotic base adapted to home context. The MoUD has to avoid obstacles and go through different surfaces without sliding. Second, they have to provide communicating systems for the local and distant users (dependant person and its relatives or caregivers). Third, safety and security has to be ensured. The failure of a system is unavoidable. The key point is to detect it as fast as possible and react appropriately to avoid putting the dependant person in danger. In the same way, the system has to support a high level of security. To guarantee privacy of the dependant person, the control of the robot has to be restricted to authorized persons (relatives or caregivers). The last but not the least challenge is to offer a precise positioning of the MoUD, in order to help the control of its displacement.

The rest of the paper is organized as follows: a brief description of existing robots is given in section 2, the design challenges are presented in section 3, a new process to design a system is presented in section 4, the section 5 presents our robot architecture and we conclude in section 6.

## 2 Related works

Many robots (and by extension, robots are MoUD) have been designed for assisted living. They are often known as companion robot such as those built by the IRT Research Institute in Tokyo and presented in [1]. These robots look like humanoids and are able to open doors, to clean rooms or to use wash machine. In [2], a robot is used to support cognitive stimulation and therapy management. Many other projects may be found in literature. These robots have generally the size of a child, can move inside their environment if this one is not too dense, are able to catch objects and are wearing multimedia interfaces.

The companion robots are generally financed by insurances due to their high prices. The insurances need to guarantee the reliability of the robot. Robot malfunctions may put people life at risks and engage the company name. To reduce malfunction probability, all components are redundant. Due to the redundancy, they are equipped with dozens of sensors. Hence, energy is an important issue for them.

In AAL environment, the total cost of the MoUD is a key point. It must be kept as low as possible especially in the case of elderly who often have tight budgets. This means that the MoUD must be built by using low cost commercial components. Moreover, as network, software or mechanical failures are unavoidable, reliability is another major key point as well as the capability to easily fix them. The robots presented in the previous paragraphs do not meet these constraints.

In case of low cost robot, dependant people buy their own robots. The insurance only pays to keep an eye on the dependant person. Some commercial solutions, such as Rovio [3] or Spykee [4], are more suitable to be used as a low cost robot. These robots have many issues restricting their use in AAL environments. The platforms are not totally open so it is very difficult to integrate new services. Due to limited battery lifetime, the robot has to go back to its charging dock. These robots can automatically come back to their charging dock when the battery is low. Another problem of these robots is that the privacy cannot be guaranteed. Caregivers should never take unauthorized pictures of patients or other sensitive information without permission. It is illegal to take pictures in places where they have expectation of privacy. The last problem of these robots is that engineers have not made environmentally responsible choices during their design.

## 3 Methodology

A MoUD associates a mechanical platform, electronics and information and communication technologies. The first challenge is to manage several branches, mechanical engineering, electronics, computer sciences, etc. in the aim to design and integrate usable robots. The scheduling of the tasks could be modelled with a graphic description like a PERT. The definition of the borders of each task needs a methodology using a quantitative approach. Each branch uses specific design methodologies like TRIZ [5] in mechanical engineering, the V-cycle [6] in software engineering, etc. Since the rise of the microelectronics we see that functions are transferred from mechanical assembly and components to computer based systems. The problem should be transformed into an expression that allows this kind of transfer.

### 3.1 The X-Development method

The actual formulation of the X-development method was designed by members of our team [6].

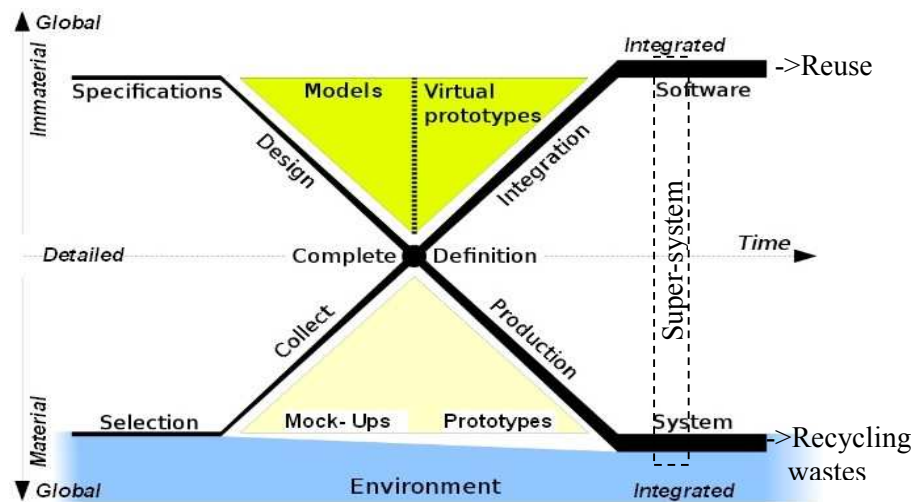


FIG. 1 – General scheme of the X-development method

The X development method [6] can be understood as a scheduling of tasks. The general scheme is presented on figure 1 where the time is the horizontal axis.

We have considered that each system could be produced only when its definition is completed. The materials needed to produce the system should be available when the production starts. By using the  $\backslash$  shaped representation of the well-known waterfall method [7], we have added a lower left task (selection & collect) to represent the fact that the bulk materials and the standard elements have to be collected before the production. At the bottom of the graph we have added a rectangle to represent the environment existing before the beginning of the process and still remaining after the whole lifecycle. The rectangular shape means that the environment is conservative, all the materials used to build the system and its consumption will go back to the environment at the end of the lifespan or will be recycled or reused. The result is that the system modifies the environment during its usage and after. If these aspects are not taken into account at the beginning of the design we can have environmental consequences. Furthermore, we have added the upper right task (integration) to include the famous V-cycle [8], which leads to the X shape.

We consider that the crucial node of the graph is the meeting point of the branches. Above this point, it is the field of the information, data, software and others whereas, below this point it is the physical and material field. We have drawn a horizontal arrow through the central point to represent time. The whole scheme could be understood as a PERT - each line as a task, and each node as a transition between tasks. The process of the design begins on the upper left branch by the definition of the specifications.

Early during this stage the designer should specify the environment in which the system will work and the borders between this environment and the system. The super-system is the set composed by the system and the elements of the environment that interact with it. It is symbolized as a tall rectangle surrounded by a dashed outline, it can be considered as a temporal window that follows the product along its life cycle and after. Then the exchanges between the system and its environment will be mostly known and so is the geometry of the interaction. This knowledge is sufficient for choosing the resources (materials, components, etc.) that should be used to build the structure of the system [9]. So it is possible to start the task of the selection of the materials and real elements to be used, in parallel to the engineering design process. There are vertical arrows not drawn in figure 1 matching on these information exchanges. These quantities are physically dimensioned below the middle horizontal line, and above they can be transformed as dimensionless variables and parameters.

On the right of the central node of the scheme, the production process of the parts and the assemblies starts below the middle line, beyond the integration process of the software is performed. At both right ends, each result forms an integrated set. The software is commonly embedded inside the whole system.

### 3.2 From the method to the system

We write the interactions in the super-system and the characteristics of the system as presented in the expression (1), inspired by the Lisp language:

$$\{P\} := (\{S\}, \{F\}, \{G\}, \{M(p)\}) \quad (1)$$

Where  $\{P\}$  is the set of performances,  $\{S\}$  the functions,  $\{F\}$  the constraints temperature, pressure, etc.,  $\{G\}$  the geometry of the device and its components,  $\{M(p)\}$  the properties of the materials. The symbol  $:=$  means that the performances are resulting from the design and the constraints. From the designer's point of view, the constants of the problem are the environment and the requirements. He translates these into performances, functions and constraints. In respect of these he chooses the components, the materials and eventually adds functions that improve the value and the services without extra-cost or impacts. We cannot think in terms of functionality, length, time, mass, joule, etc. but in a metric space where all the variables and parameters are without dimension. Using the dimension analysis applied on the parameters and variables introduced previously, many dimensionless ratios can be forged. For the eco-design other dimensionless parameters can be found in the environmental documentation of the Global Reporting Initiative (GRI) [10] like the EN2 indicator "Percentage of materials used that are recycled input materials". The indicators having a physical dimension could be adimensioned. Our method is a global approach that includes both software and hardware developments. Hence, traditional methods as TRIZ are compatible with our model (in the next sections the TRIZ principles will be pointed out). At this stage the designer of the mechanical part could use the TRIZ method to search a scalable principle of innovative solution.

#### 4 Analysis, design challenges

The aim is to offer new services to the assisted people living at home, using as well as possible the information and communication technologies. The system has to be interactive: the mobile devices are not autonomous, but wireless connected to the Internet, through a local cloud. The mobile devices are mobile elements of a wired and wireless sensors-actuators home area network (HAN). The expected population of companion robots in the EC will be in the range 50M to 100M units. We have to identify and quantify the needed services these constitute the set  $\{S\}$ . After that we define the functionalities and the performances of MoUD. We will end this section giving a description of an Ideal Final Result of MoUD.

In our case the super-system is composed by the robot, present people, remote people, the network, and the near environment. Elderly people's homes do not have stairs or are restricted so the MoUD does not need to climb up and down them. In cases where different floors have to be monitored, we put a robot on each floor (TRIZ-principles 12, 26a, 1a). They can communicate between them in order to extend the control in the whole habitation. The communication between robots is not the subject of the paper, but could be performed through the HAN. We consider that two people maximum use the robot at the same time, one locally, the other remotely. The robot is connected to a teleservice provider, linked to the healthcare insurance and / or to the rescue and emergency services. People communicate with sounds and gestures. The first need is to catch the sounds and images and to communicate in both directions. People are supposed to move, the second need is to be able to follow people. People are supposed to be awake two third of the day and to be idle the rest of the time. The need is that the services should be available at least 16 hours per day in a mobile mode, and 8 hours per day in a static mode. People can use walking sticks or walkers or carry small objects. The mass  $M$  of the MoUD has to be smaller than the mass of a walker, less than 3 kg. The maximum speed of the MoUD is normalized ( $V < 1m/s$ ). The size of the robot if it is on the floor should not exceed the size of two shoes, because the robot should follow the people in motion. At least the robot should be able to move forward, backward, turn right and left in place, and obviously stop. The lifespan of the robot should be long, because we suppose that the targeted people are not able to accept great changes in their life. The need is between one year and twenty years, because one year is the typical period for a contract with a teleservice provider, and twenty years is within the maximum lifespan of a pet. The yearly production should be between 100M and 2.5M units depending on the reliability and the size of the population of robots.

We consider that failures are unavoidable, even if the system contains a lot of redundancies. We take into account the MTBF (mean time between failures) and the MTTR (mean time to repair). The MTBF should be equal to the warranty period, this is a psychological argument based on the acceptability of the failure. It appears that a MTBF of one year at least, or two years is acceptable. The distance range  $D$  of the mobile unit should reach 4 km per day, it represents 3000 km during a MTBF period of 2 years. The MTTR issue is rather different, because it is not acceptable to loose the help of a companion robot more than few hours. But dependant people are visited daily by caregivers. The proposed solution is to adopt a design permitting an easy maintenance done by the caregivers. The robot should be dismantled quickly. Each element, can be replaced, reconfigured and tested during the daily visit. The energy autonomy is the big issue. We can consider that the robot will move less than 70 mn per day, but the communication system should be on 24 hours a day. The robot can be refuelled when people is idle. We consider that the robot will interact with

people, the robot has to inform about the level of energy, but the decision to refuel remains to the people present or far away. One important role of the robot is to stimulate the dependant people to do common acts, like feed the pets or recharge the batteries of the devices. There are others ecological issues, for instance reduce the waste of rare earth elements used by the microelectronics, reduce the carbon footprint, reduce the wastes, recycle copper, plastic, etc.

All of these aspects give us a minimal “functional unit” of one year of usage, 1500 km, permanent monitoring, a mass of about 3 kg, the size of two shoes on the floor, an ideal  $MTTR_i$  of few minutes, a minimum  $MTBF_m$  of 1 year, the ability to communicate images and sounds through a wireless connection with a bandwidth upper than 1Mbits/s, etc. We share these aspects in two sets, the first one of the performances {P} and the other one the constraints {F}.

## 5 Robot Architecture

The main idea behind the robot architecture is to build a modular robot whose the components can be reused when the MoUD reaches its lifespan. For instance the dimensionless ratio  $D/(V*MTBF_m)$  matches to the usage rate of the mobility unit, this ratio is smaller than the usage rate of the central unit of the robot.  $D$ ,  $V$  and the  $MTBF$  are characteristics of a component, for each present on the market we compute the ratios  $D/(V*MTBF_m)$  and  $MTBF/MTBF_m$  to compare them. The components may have a second life to rebuild another robot or to achieve another task (TRIZ-pr. 1b, 25b). It reduces drastically the EN22 indicator [10] “Total weight of waste by type and disposal method”, to use it we introduce the ratio  $((\text{weight of waste})/gM)$  where  $g$  is the gravity. We have decided to separate the robot into sub-sets. One is the mobile platform made of plastic, copper, magnets and rubber, we can hope that in the near future all these materials will be nearly 100% recyclable, and that the market of mobile platform will form a circular economy. We propose a low cost robot in regard to the main constraint of AAL environment i.e. dependant people buy their own MoUD.

### 5.1 Entities

The architecture of the system is composed of several entities, each has a particular task in the super-system.



FIG. 2 – The Robot and its entities, the central-unit, the battery pack, the Phidget board, and the mobile platform.

In the aim to increase the reliability and reduce the prices, the robot (figure 2) is built with a basic off-the-shelves hardware component, a robotic platform (Rover 5) with tracks, an electronic component (Phidget board) and a Tablet PC embedding camera(s), microphone(s), speaker(s), GPS, compass, wireless communication components, etc.(TRIZ-pr. 5, 6) The Phidget board is used to connect the Rover 5 motor to the Tablet PC. In case of failure of one component, it can be replace very easily, as this system is almost plug and play. The robot can be controlled remotely by a distant user or by the dependant person himself. The distant user can control the robot with its Internet browser and the dependant person can take the Tablet to give orders. The interface on the Tablet PC is designed for elder people. They can control it very easily by clicking on big virtual buttons. The total cost is estimated around 250 € (TRIZ-pr. 27). The tablet PC could be of second use, to reduce the cost and the environmental impact.

A distant server is the interface between the distant user and the robot. The system is modular due to the distant server. It can translate the commands sent from the distant user (respectively the robot) to be understood by the robot (respectively the distant user). Some changes on the interface of the robot or the web browser do not interfere with the other part. The last role of the distant server is to ensure some security mechanisms. There is no direct access on the robot so each command goes through the distant server. The end user is as relative, caregiver or sometimes the dependant person. This one gives orders to the robot that performs them. At the same time, it receives the view in front of the robot. The robot sends to the distant user a picture periodically. The pictures help the distant user to control the robot and know where it is. Smart devices are used to communicate. Data are carried through several media: wired or wireless networks, sounds, infrared. Each entity needs to communicate with each other. To ensure the reliability and the security of the system, a direct access between the distant user and the robot is forbidden.

## 5.2 Communications

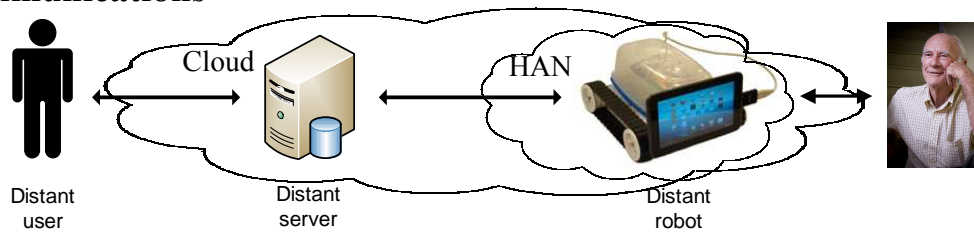


FIG. 3 – Architecture

In AAL environments, the architecture (figure 3) has to be easy to deploy and to secure. We also take into account that old people do not have to configure the MoUD. This one has to be a plug and play system and able to communicate with a distant server, using a classical Internet connection. The robot uses the Wifi card or 3G access of the Tablet PC to communicate with the Internet. In our proposal, our robot will send HTTP requests to a distant server and will wait for HTTP responses from a distant server. The only configuration needed is the Wifi access configuration (or 3G access configuration if needed). On the user side, the distant user only sends HTTP requests and waits for HTTP responses. The only thing required on the user side will be a Web browser, for example, running on a Smartphone, a Tablet PC or a classical computer. No configuration has to be made. To make the whole system work, the distant server is either in the cloud or in the local cloud. The difference between the cloud and local cloud is quite easy to understand. The local cloud offers the same services than the cloud but the servers are in the habitation of the robot's owner. It increases the privacy because only the robot's owner can access to the data stored on the servers. The distant server will connect both sides. The distant user has no direct access to the robot and sends a robot command to the distant server through the web interface. The distant server then forwards the command to the robot.

## 6 Conclusion and perspectives

In this paper we explain our work about low cost companion robots for dependant people, in terms of the problem, the hypotheses, or the methodology. Our robots whose the components may be highly reused is eco-designed and built based on the X-development method. At the moment some partners in France, Finland and Austria are building the same system to test these in laboratories and in home situations. Some tests, which include robot and interface acceptances, will be realized in both cases. We will increase the details of the analysis to make more efficient choices of components. We will evaluate the environmental impact of the usable solutions when we will have enough data about the lifespan, the MTBF and the MTTR. Important issues are still remaining, the indoor positioning, the energy consumption, and the reliability of the remote control. At the moment some of us are working on the problem of indoor positioning using the UWB technology, others are working on the reliability of the remote control.

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