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Author Index

Bock, Thomas	32, 39
Bulgakov, Alexey	1
Follini, Camilla	7
Güttler, Jörg	39
Mita, Akira	32, 39
Nakaso, Sayaka	39
Nandavar, Anirudh	7
Ogawa, Ami	32
Pozikidis, Leonidas	15
Rasul, Taha	15
Sayfeddine, Daher	1
Solcanu, Gabriela	24
Tsui, Hao	24

Keyword Index

Ambient assistant living	15
Ambient Assisted Living (AAL)	7
Assistive Technology	24
Automated Cooking	7
Automated Delivery System (ADS)	7
 BADLs	 24
 Concrete glazing	 1
Concrete treatment	1
 Elderly	 24
Eye detection	39
 Face recognition	 32
Fatigue	39
Fatigue detection	32
Fatigue monitoring	15
 Getaway	 39
 Home Care	 24
Home labs	15
 Intelligrated Kitchen Terminal (IKT)	 7
 Kinect v2	 32, 39
 Mass Customization	 24
Microcontroller	32
 Robotic surface finishing.	 1
 Smart environment	 15
 Work from home	 15

Preface

CIB Working Commission, W119 on "Customized Industrial Construction" has been established as the successor of former TG57 on Industrialization in Construction and as a joint CIB-IAARC Commission. Prof Dr Ing Gerhard Girmscheid, ETH Zurich, Switzerland (Coordinator of the former TG57) and Prof Dr Ing Thomas Bock, Technische Universität München, Germany are the appointed Coordinators of this Working Commission. The workshop is hosted by the Chair for Building Realization and Robotics located at TUM within the Bavarian high tech cluster, the Master of Science Course "Advanced Construction and Building Technology" and by IAARC-Academy representing the research training program of the International Association for Automation and Robotics in Construction (IAARC). The workshop will concentrate international researchers, practitioners and selected top-students coming from 8 different professional backgrounds (Architecture, Industrial Engineering, Electrical Engineering, Civil Engineering, Business Science, Interior Design, Informatics, Mechanical Engineering).

Industrialization in Construction will become more customer oriented. Systems for adaptable manufacturing and robot technologies will merge the best aspects of industrialization and automation with aspects of traditional manufacturing. Concepts of mass customization can be implemented via the application of robots in construction and building project/product life cycle as prefabrication processes, on site and in service as socio technical systems. Topics include, but are not limited to the following aspects of Automation and Robotics in Construction:

- Industrialized Customization in Architecture: Mass Customization on site, Factory Production, Logistics and Factory Networks, Production
- Logistics/ Site Automation and Robotics: Mass Customization on site, Site Automation, Site Robotics, Site Logistics for Automation, Systems and Technologies, Automation and Robot oriented Site Management
- Service Science through Automation and Robotics: Mass Customization of performance oriented environments, Automation and Robotic Assisted Living, Service Robotics, Personal Assistance, Demographic change design and management of socio technical systems by human ambient technologies in daily life especially for aging society.
- Automation and Robot Oriented Design: Design and Buildings Structures Enabling efficient use of Automation and Robotics, Modularization, Product Structure, Building Information Modeling
- Automation and Robotics Deployment Strategies: Innovative business processes, automation and robot oriented management, human-machine communication, socio technical aspects, socioeconomic aspects, history of automation and robotics

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Table of Contents

Simulation of laser glazing robot for concrete treatment	1
<i>Alexey Bulgakov and Daher Sayfeddine</i>	
A Modular Kitchen Terminal with Automated Food Delivery System for Enhanced Ambient Assisted Living	7
<i>Camilla Follini and Anirudh Nandavar</i>	
Modular Work Terminal for greater social inclusion and efficient production organization	15
<i>Leonidas Pozikidis and Taha Rasul</i>	
BCUBE – Assistive Customizable Bathroom Module for Physically Impaired Individuals	24
<i>Gabriela Solcanu and Hao Tsui</i>	
A Novel Knee Position Acquisition and Face Recognition System Using Kinect v2 at Entrance for Fatigue Detection and Automated Door Opening	32
<i>Ami Ogawa, Akira Mita and Thomas Bock</i>	
A Fatigue Detection System implemented in an Office Deployable Gateway based on Eye Movement	39
<i>Sayaka Nakaso, Jörg Güttler, Akira Mita and Thomas Bock</i>	

Simulation of Laser Glazing Robot for Concrete Treatment

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In construction, where the service or product to be delivered is directly related to human beings, quality assurance reigns supreme in terms of priority and importance. Construction project goes beyond handing over of the building. The upkeep of the building requires continuous monitoring to maintain the safety aspects as well as aesthetic elements of the building including facades and marble constructions. Laser scanning and photogrammetry can be used for inspection and detection of defects, which can be very valuable for preventive maintenance. In contradiction with facades, concrete slab inspection is harder to automate because of the variety of defects. Blisters, cracking, crazing, curling, delamination, discoloration, dusting, efflorescence are common problems, each of which needs special concrete treatment procedure hence specialized tools and algorithms. In this paper, we study concrete slab and walls glazing using robotic mobile laser. This allows decreasing the wear range life of the concrete and increasing its durability depending upon corrosive environment.

Keywords: Concrete treatment, concrete glazing, robotic surface finishing.

INTRODUCTION

Construction is one of the aspects of social development. Evolution of the construction concepts and arts depends of the needs and prosperity of the society. Historically, human was relying on hunting for day-to-day living. The cave was enough to protect him from climatic conditions and risks. Acquired the knowledge of agriculture, human had to store goods and products in permanent settlements: tents were set up from animal bones and wood, huts from leaves.

In Mesopotamian period, clay, plain and glazed bricks were introduced in Chaldea. While Assyrians used bricks and stones, the Persians preferred limestone and timber to build their communal houses. The Egyptians continue the tradition of using natural products and masonry materials (basalt, granite, limestone). Greek used the marble, while their successor the Romans used concrete, which continued as primary building materials until the industrial age introducing steel and glass.

With the development in nanotechnologies, engineers aim to achieve the hitherto difficult invention of long lasting, light (transportation), and flexible building materials.

The result appears in the 3D printing technology. These printers can create products starting from pens, guns or biological organs. With relation to construction, China is set to build in Dubai the first 3D office covering an area of 186 square meters using 6-meter tall printer. Already China is specializing in printing large buildings achieving recently 6-story apartments occupying 1100 square meter area. It is estimated that a single house can be con-

crete printed in less then one day. The concept art of 3D printing is shown in fig.1.

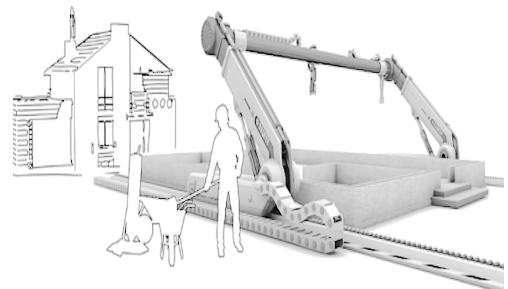


Fig.1. Concept art for 3D house printing

Concrete remains the primary construction materials worldwide. But it can be prone to many defects such as Blisters, cracking, crazing, curling, delamination, discoloration, dusting and efflorescence.

Blisters are bumps resulting from bubbles entrapping air or water trapped into sealed, airtight surface, An excess of the blisters causes the concrete to crust under dry wind. Delamination are type of blisters resulted by trapped bleed water or air permanently below mortar layer.

Cracking is the result of drying shrinkage, thermal contraction or applied loads. A minor shrinkage causes crazing. It is pattern of fine cracks on the top and bottom of the concrete slab.

Curling is distortion of slab edges due to thermal condition and moisture.

Discoloration is gross color change of the concrete caused by atmospheric or organic stains. Efflorescence is a type of discoloration resulting of white

harmless residue on the top of the concrete (exposed) slab.

Theoretically, it is possible to eliminate all these defects. Practically, the task is challenging. Technically preventions can be followed; repairs can be done to minimize the defects. The solutions are as explained below.

PREVENTIONS AND REPAIRS

Avoiding defects allows the concrete to endure climatic challenges and minimize periodic maintenance cost. Unfortunately, there is no single procedure to cure all the defects or to avoid them since the concrete layout is done in manual or semi automated form. On the other hand, it exists precaution instruction to deal with the concrete in order to avoid the aforementioned challenges. Some of them is described below.

To avoid blisters, appropriate cement contents between [305; 350] kg/m³ should be used; the subgrade should be warm in case of laying down the concrete in cold weather. Overtreatment of the concrete with vibrating machines can cause bleed water to rise and entrap under form of bubbles.

Cracks are easier to handle since they are related mostly to preparation of subgrade, controlling the moisture and minimizing the use of mixed water. The later contains calcium chloride, which is harmful to the concrete.

Regarding the curling defect, it is advisable to use thickened slab edges as well as large amount of reinforcement steel (50 mm). Similarly to the other defects, the slab should conserve uniform temperature and moisture.

Concerning efflorescence and discoloration, unwashed sand should not be used; clean acid-free mixed water not containing residues of Alkalies, salts nor minerals.

Some of the concrete defects patterns are illustrated in fig.2.

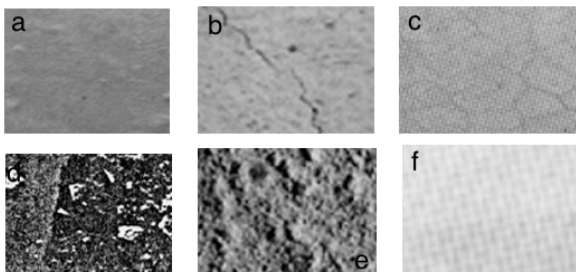


Fig.2. Forms of concrete defects
a-blisters; b- cracks; c- crazing; d- delamination; e-
dusting; f- discoloration

Relating to autonomous and robotic applications, various machinery for concrete slab treatment exists in the market today^{1,2}. Some of them operate with the concept of hydro-erosion, i.e. defected concrete

is detected and removed using high-pressure water in order to lay down new mixture. Per instance, the authors³ used such approach in order to repair concrete or paved streets without causing cracks and conserving the definition of excavation geometry.

The advantage of hydro-erosion consists of concentrating the breaking power continuously in contradiction with the powered percussion methods, which are slower and pulsating (periodic)⁴. One important advantage of such technique is that the supporting joints are not touched, which avoids all reasons to have cracks in other areas⁵. This is very important when studying the concrete behavior depending to the force applied on it^{6,7,8}.

In addition this technique had the option of selective removal. It eliminates also the chloride residues causing discoloration, efflorescence and cracks. Beside that it is dust-free and does not reduce lifting efforts and time as the water and debris can be removed using pumps.

The hydro-erosion method has lots of applications starting with creating profiles to total elimination of the concrete. The robotic version of the hydro demolition can remove concrete up to 60 mm depth at a working altitude of 6 meters. Hence it is ideal for bridge treatment and storage yards. The inconvenience of the robotic method is the setup time, the mobility challenge depending on the site status as well as high flow of the supplied water.

The robot mobility challenge was addressed by the authors in their published work^{9,10}. Their idea (fig.3.) was to mount the robot for hydrodynamic concrete and metal treatment on two tracks with the ability of carrying multiple water jet tools.



Fig.3. Mobile robot for hydrodynamic concrete and metal treatment

Concrete layout was its leveling affects as well imaging quality as introduced by the authors¹¹. In their study, they have introduced a scraping robot to level the wet concrete in magnetic resonance imaging room in order to achieve better image quality. The other advantage is to exclude concrete blisters by avoiding the use of the concrete with a high slump, which allows air to be entrapped.

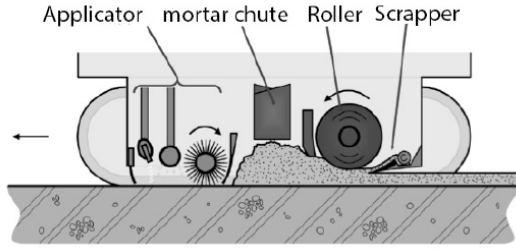


Fig.4. Conceptual design of scraping robot

The robot was auto piloted based on fuzzy logic controllers identifying the cutting depth of the scraper with reference to the moisture and cement condition. Concrete surface glazing is a precaution step introduced to toughen the concrete and increase its durability by covering it with amorphous glaze. This minimizes the climatic effects on the concrete. Glazing is done by interacting high power laser beam with Portland cement. This approach was studied by multiple authors¹² proving that the wear life of the concrete has increased from 1.3 to 14.8 times depending on the corrosive environment. The chart below (fig.5.) shows the wear effect on the concrete under different factors and compares it to laser treated concrete.

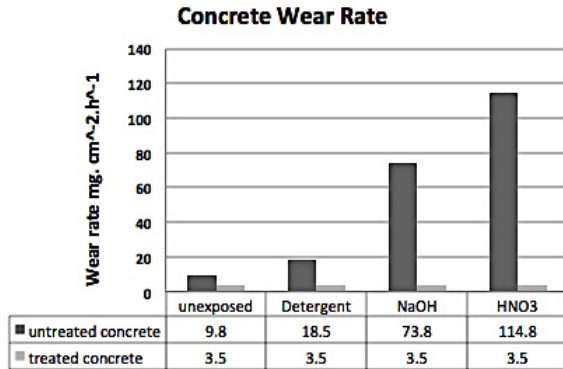


Fig.5. Wear effect of the concrete with comparison to laser treated concrete (Measured in $\text{mg.cm}^{-2}.\text{h}^{-1}$)

As it can see for the chart above, the advantage of the glazing is enormous. Automating the Laser scanning process and interaction with the Portland concrete will be of great importance. Thus it can decrease the wear rate of the concrete and save expenses on time and human resource.

LASER GLAZING ROBOT

In this paragraph, we will be describing the glazer robot, identify its mathematical model and control approach.

The robot consists of two major parts, the CO_2 Laser generator lifted by a mobile cart. The generator part has 2 water-cooled electrodes between them high frequency stimulating the laser gas. Alongside with couples of mirrors, the two electrodes form the reso-

nator. A concept of the CO_2 laser machine is illustrated in fig.6.

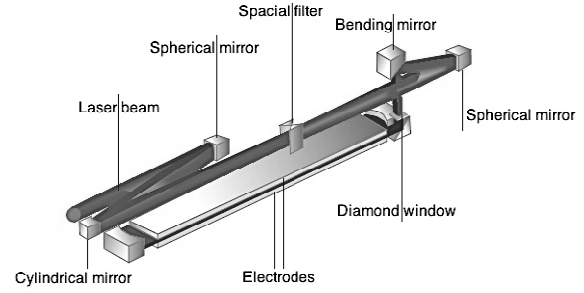


Fig.6. Concept of CO_2 laser machine

We aim to perform slab and walls concrete treatment. Hence the laser should reach different altitudes and corners. We can consider the cart and the lifting mechanism as a possible simulation for our case study. Therefore we will represent the setup as a two-dimensional problem of an inverted pendulum moving in the vertical plane as shown in the fig.7. below. While the cart is moving, it applies force F on the lifting mechanism, which in its turn will tilt around the fixation point by an angle θ . Hence the control input is the force F and the control output is the angle θ and the horizontal movement of the cart x .

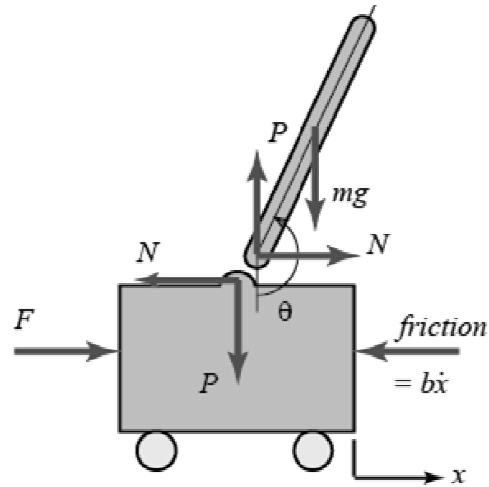


Fig.7. Two-dimensional inverted pendulum problem

In fig.7 are marked the forces applied to the body frame. Using Newton law of motion we can introduce the sum of the forces in the free-body diagram of the cart and pendulum in the horizontal direction:

$$M\ddot{x} + b\dot{x} + N = F \quad (1)$$

$$N = m\ddot{x} + ml\ddot{\theta}\cos\theta - ml\dot{\theta}^2\sin\theta \quad (2)$$

Where M and m are the mass of the cart and the lifting mechanism respectively; b is the coefficient of friction depending on the wheels and the floor type. Substituting equation (2) in (1) we obtain the following equation

$$(M + m)\ddot{x} + b\dot{x} + ml\ddot{\theta}\cos\theta - ml\dot{\theta}^2\sin\theta = F \quad (3)$$

Summing the force perpendicular to the pendulum we get the second equation of motion

$$P\sin\theta + N\cos\theta - mg\sin\theta = ml\ddot{\theta} + m\ddot{x}\cos\theta \quad (4)$$

The terms of P and N can be found by summing the moments about the centroid of the pendulum. Hence we can write:

$$-Pl\sin\theta - NlP\cos\theta = I\ddot{\theta} \quad (5)$$

Combining equation (4) and (5) we obtain the second governing equation

$$(I + ml)\ddot{\theta} + mgl\sin\theta = -ml\ddot{x}\cos\theta \quad (6)$$

Using the trigonometry law of small angles, equation (3) and (6) can be written in the following simplified forms

$$(M + m)\ddot{x} + b\dot{x} + ml\ddot{\Phi} = u \quad (7)$$

$$(I + ml)\ddot{\Phi} + mgl\sin\Phi = -ml\ddot{x} \quad (8)$$

Using u and Φ where replace the F value and small angle terms hereafter.

The next step consists in finding the transfer functions of the system. Therefore we need to introduce the Laplace transformation of the equations assuming zero initial conditions. The equations (7) and (8) can be written as follows

$$(M + m)X(p)p^2 + bX(p) + ml\ddot{\Phi}(p)p^2 = u(p) \quad (9)$$

$$(I + ml)\ddot{\Phi}(p)p^2 + mgl\sin\Phi(p) = -mlX(p)p^2 \quad (10)$$

Where p is the Laplace operator.

Taking into consideration that the transfer function is the relation between the form of single input and single output at one time and rearranging equations (7) and (8) using linearization method we obtain the following:

$$\frac{\Phi(p)}{u(p)} = \frac{\frac{ml}{K}p^2}{p^4 + \frac{b(I+ml^2)}{K}p^3 - \frac{(M+m)mgl}{K}p^2 - \frac{bmgl}{K}p} \quad (11)$$

Where $K = [(M + m)(I + ml^2) - (ml^2)]$; and $W(p) = \frac{\Phi(p)}{u(p)}$.

From the transfer function above we can clearly see that there is a pole and zero at the origin. Hence the transfer function can be rewritten using the following system of equations:

$$\frac{\Phi(p)}{u(p)} = \frac{\frac{ml}{K}p}{p^3 + \frac{b(I+ml^2)}{K}p^2 - \frac{(M+m)mgl}{K}p - \frac{bmgl}{K}} \quad (12)$$

$$\frac{X(p)}{u(p)} = \frac{\frac{(I+ml^2)p^2 - gml}{K}}{p^4 + \frac{b(I+ml^2)}{K}p^3 - \frac{(M+m)mgl}{K}p^2 - \frac{bmgl}{K}p} \quad (13)$$

Where $\frac{\Phi(p)}{u(p)}$ and $\frac{X(p)}{u(p)}$ are the pendulum and cart transfer function respectively.

The whole system can be represented in matrix form using state space equation. Hence we can write the following:

$$\begin{bmatrix} \dot{x} \\ \ddot{x} \\ \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & q_1 & q_2 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & q_3 & q_4 & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \theta \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} 0 \\ q_5 \\ 0 \\ q_6 \end{bmatrix} u \quad (14)$$

Where

$$q_1 = \frac{-(I + ml^2)b}{I(M + m) + Ml^2};$$

$$q_2 = \frac{m^2gl^2}{I(M + m) + Ml^2};$$

$$q_3 = \frac{-mlb}{I(M + m) + Ml^2};$$

$$q_4 = \frac{mgl(M + m)}{I(M + m) + Ml^2};$$

$$q_5 = \frac{I + ml^2}{I(M + m) + Ml^2};$$

$$q_6 = \frac{ml}{I(M + m) + Ml^2}.$$

The output of the system Y can be represented using the following equation

$$Y = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \theta \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} u \quad (15)$$

The matrix $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$ has two rows representing the cart position and the pendulum movement. For us, the most important is to control the movement of the pendulum as it represents the lifting effect and movement of the CO₂ laser beam. But still the cart has to reach the indicated area.

Results

The successful control of the inverted pendulum consists of stabilizing the lifting mechanism while the cart is moving smoothly in the horizontal plan. Hence by implementing the control approach the shape of the curve representing (X) should be ascending,

while the rotation of the pendulum (θ) should be consistent to a pre-assigned value representing the working angle or the reaching of the laser beam. The figures 8 and 9 represent the simulation results of resolving two-dimensional inverted pendulum control problem.

Figure 8 illustrates the horizontal movement of the cart as consequence to tracking force F . As it is seen the cart moved linearly smoothly.

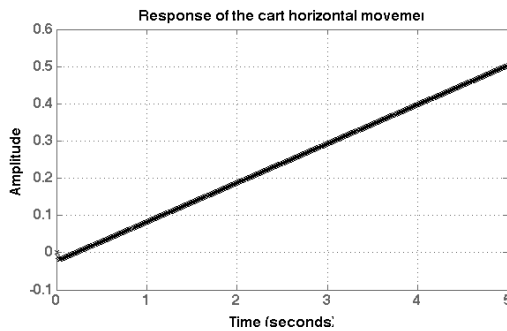


Fig.8. Cart movement from zero initial condition

On the other hand and following a sudden movement of the cart, the lifting mechanism curve has shown an overshoot then the working angle was stabilized.

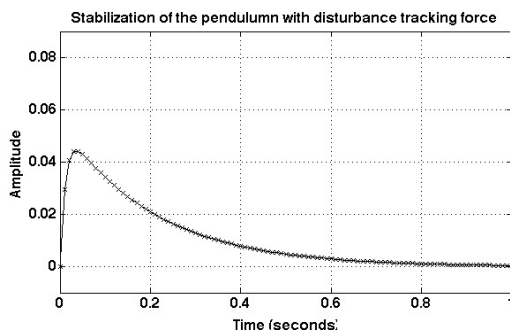


Fig.9. Lifting mechanism stabilization to desired position while the cart is moving

Conclusion

To wrap up, there are three points to recap. Firstly, it is about the idea of the glazing robot. We have seen the importance of treating the concrete in order to achieve better durability and minimize the wear range taking into consideration atmospheric and chemical factors. Maintaining the concrete is essential especially when knowing that there are around 900,000 bridges in the European union alone. While the hydro-erosion offers good and cheap solution,

laser glazing can be better alternative in terms of number of periodic preventive maintenance and technically in terms of improving the resistance of the concrete to detergents, minerals and acids causing multiple defects enumerated earlier. Secondly, in contradiction of the hydro-erosion technique, glazing does not depend on water availability and flow rate and pressure.

The second point is about the simulation of the glazing robot. As was discussed, the laser beam should reach the slab as well as walls. Hence lifting mechanism is supposed to orient the beams with reference to the vertical plan. We have selected the technical specifications of the cart and lifting mechanism in such way to be compared with the hydro-erosion robotic solution.

Later, the control task was formulated as two dimensional inverted pendulum problem. Assuming, that the cart is moving in a relatively smooth working site, the value of the friction coefficient between the wheels and the ground was chosen to be of minimal value. This coefficient plays important role in stabilizing the lifting mechanism as it can cause nonlinear curve form of the cart movement. Accordingly, the synchronization of the wheels rotation is an essential factor, which was not taken into consideration in our simulation. In case all these factors needs to be considered, adaptive control system is recommended instead of the classic PID regulators offered in this paper.

We have also considered that the rotational movement of the lifting mechanism is achieved without friction around the pendulum centroid. The lifting arm is considered to be ideally rigid. As it can be seen, this is an idealized scenario, which cannot be considered in real practice when lifting the laser beams to six meters height.

Taking into consideration all the aforementioned constraints in the simulation phase, it is believed that the control task was resolved in terms of stabilizing the lifting mechanism while moving the carrying cart smoothly on working site.

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A Modular Kitchen Terminal with Automated Food Delivery System for Enhanced Ambient Assisted Living

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The kitchen is one of the most used area in the home as eating is one of the most essential needs. Food preparation as a consequence, is one of the vital activities. In the current scenario of lifestyles and family living, often elderly people are left to sustain alone at ripe ages or even the dependents do not get the assistance required. Falls are one of the leading causes of domestic fatalities and injuries in people over the age of 70 years¹. Kitchen is therefore one of the most likely places where the seniors are vulnerable to domestic mishaps and injuries. The aim of the project is to create an Ambient Assisted Living environment (AAL) in a kitchen terminal that is assistive to the elderly people. The critical issues of the cooking process (such as ergonomics, storage management and buying assistance), all which progressively become difficult with the aging of an individual, are targeted to be solved, by means of ubiquitous technology and automation in the home environment. So far, significant efforts have been made and systems realized that are capable of making the kitchen a fully automated environment using concepts of pervasive computing. Anyhow, there hasn't been a system yet that autonomously manages the logistics of groceries and food at a physical level in such an automated setup, considering all the stages from food provision, to storage and management. This paper is an attempt to propose and develop an Automated Delivery System (ADS) as an integral part of the overall kitchen setup, the Intelligranted Kitchen Terminal (IKT), with the aim of creating a terminal to automate the cooking process. Apart from the elderly people, who are the primary focus group, the system also targets to benefit various segments of the society to expand the scope of utility.

Keywords: *Ambient Assisted Living (AAL), Automated Cooking, Automated Delivery System (ADS), Intelligranted Kitchen Terminal (IKT).*

INTRODUCTION

In the wake of ageing societies becoming a more significant part of the population in the developed countries (refer to the following section), it is a critical need to ensure the interests of these seniors both psychological and physical health, with minimal impact on their quality of life as well as public expenditure on solution to the demographic issues. Hence there is a necessity to include an autonomous material handling system within the already well evolved 'smart kitchen' environments. Therefore, it is explored here the possibility of using a synchronized system of ADS and the commercially available robot Adept 'Lynx' to create a system that handles the groceries and food items autonomously to ease the process of meal consumption in the users, primarily the seniors. The paper is divided in five sections: in the first part (1), the problem is introduced, together with the literature review. In (2) the system implementation is proposed in detail, while in (3) the modularity of the system and its possible time evolution is furthered. (4) is reserved to the scope of further work and research and (5) is the conclusion.

Ageing societies

As the European commission statistics read, there is an incline of old age population (>65 years) dependency from current level (in 2015) of 30% to around 40% by the end of 2030 in the EU27 region alone². On the other hand, it also predicts that the relatively

younger population (age group 15-64 years) is on a decline in general^{2, 3}. This means that there is going to be an increased demand for the homecare and empowering the elderly to remain autonomous in their times of dependency to lead a good quality life. Apart from disabilities, there are factors like reduced cognition and physical balance that could be potential risks of fall in these elderly people as per the WHO report on Fall Prevention⁴.

The advance of medicine and therapies permits us to live longer, but has brought new kind of problems, such as how to live with dignity after losing ability of performing ADLs (Activities of Daily Living) on their own. However, with the evolution of technology and mechatronics, many researchers are asking themselves if it is possible for a person with physical and cognitive problems to live by him or herself. This is backed up by the WHO-EUROPE report³ also supports by saying "Home-based solutions are advanced not only for health, social and emotional benefits but also because of the potential reduction in public expenditure, as home care provision has been demonstrated to be more effective and efficient than institutionalized care."

IKT System: A proposal

IKT is composed of several system all controlled by a central computer, which, in Fig. 1, is defined as the "Intelligrator". All these system are collaborating and working as one, and are all aimed to reduce the strain, both cognitive and physical, of working in the kitchen in daily life. The design, while containing all

the necessary appliances, is still compact, in order to prevent the user from performing unnecessary movements. The concept is generally based on the JIT manufacturing model: as a small scale factory, the kitchen could be optimized by rationalizing the act of cooking itself, in order to improve a rationalization of required movements of the user, logistics, safety, quality of food, and time saving.

The three main implementation of IKT that will be discussed in the second part of the paper are the Automated Delivery System, the sensor environment and the Assisted Cooking.

Physically, the terminal is composed of seven modules: (1) the ASMS, (2) the cooking module, (3) the preparation area, (4) the food delivery table, (5) the cleaning module, (6) the farming module and (7) the carousel storage (see Fig. 6 for an overall view).

The final aim of the terminal cooking automation. However, an essential preliminary step is to determine to which extent the automation should be used, so not to limit freedom of choice, together with how to adapt technology to the final user (elderly people). The second step would be to ensure a feasible technology to translate conceptual points into a preliminary design.

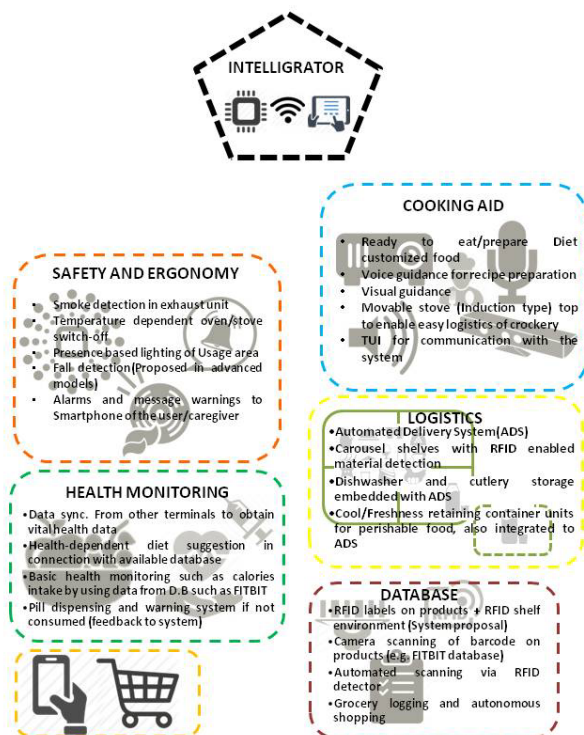


Fig. 1 System scheme

LITERATURE REVIEW: AUTOMATION OF THE COOKING PROCESS

A lot of research has been recently carried out in the cooking automation field. The research could be

categorized into three stages of automation that are being considered in this paper.

In the first level, the user is assisted during the meal preparation by audio and/or visual hints that explain every step of the recipe. Sato, A. et al.⁶ used a system composed of a projector and a depth camera to follow the user's movements and project in real time recipe instructions or cooking hints, which has been called "Shadow cooking". A similar system was developed by Schäfer, U. et al.⁷ in the "Kochbot". In this case the user is vocally guided by the system, while a LCD screen prints information about appliances status and ingredients needed. The assisted cooking interface that is going to be presented in this paper, is greatly inspired by the "Shadow cooking" one. However, while being very efficient, it is more oriented on beginner users that wish to learn new recipes, rather than on seniors, like the "Kochbot". Therefore, it would be interesting to adapt this case to the AAL context.

The second is an intermediate level, where some part of the cooking process are automated and some part are left to the user. In this case, research is very different, depending on the approach intended. The automation can interest storage cabinets⁸, food delivery⁹, or for the movement of the whole preparation area. Regarding the latter, K. Wada, et al.¹⁰ proposed a kitchen module for elderly housing, wherein the robotic module is a storage ambulatory dining module, which inspired the Automated Food Delivery System, later described. The total module dimension is a lot smaller compared to the IKT, and the whole module is capable to travel autonomously around the apartment. In order to reduce the size even more, folding furniture has been researched and implemented. However, this has the drawback of having a limited number as well as weight of appliances and the problem of bending, that may be difficult for a senior user, is not addressed. Very interesting is the automated cabinet proposed by Ficocelli, M., and Nejat, G.⁸. The cabinet has an internal mechanism embedded, which lowers the shelves to the user's reach basing on voice inputs. However, as mentioned, the IKT system aims to integrate all parts and rationalize the cooking process. Therefore, the cabinet served by the Automated Delivery System is so much broader than the one presented in this paper, that we opted for a single mechanism that serves all the shelves. The approach presented by Ficocelli and Nejat would be cheaper and more feasible for a small amount of storage area. In IKT case, the ADS approach would be cheaper and faster.

Finally, the last stage is a fully automated cooking process. Cooking robots currently being researched could be divided into two categories: (1) anthropomorphic and (2) non- anthropomorphic. The robots from the first category are usually composed of one or two robotic arms, literally mimicking human

movements during the cooking process. Undoubtedly, human shape would be the best for this purpose; however, a robot of this kind would require several years of development, since even the easiest gestures need a greatly complicated calibration and kinematic chain (see Yoshida et al.¹¹). Nonetheless, if developed, this kind of process would definitely surpass the second, in terms of quality of the final product. The second category is more result-oriented: the cooking process is divided in repetitive movements, which are simplified and replicated by a machine. For example a robot of this kind was developed by Fu Z. et al.¹² and efficiently embedded in a kitchen in a subsequent research paper¹³. The system presented in this paper shares many common points with IKT (for instance, the use of prefabricated ingredients, RFID and a robot for automated storage). However, compared to the IKT, the level of automation is higher, since it does not require cooking from the user. Nonetheless, this has the disadvantage that the recipes range is limited and that the user cannot cook by themselves if they wished so. Due to these reasons, the strategy for IKT is to have an intermediate level of automation, with the possibility of increase it during time, in order to make it more appealing to the market. Moreover, a way to deliver the food into areas different from the module surroundings is missing.

There has been immense research in the aspect of pervasive computing to make the kitchen a fairly autonomously functioning part to enable AAL to be accomplished. For example, Rubén Blasco et al, in their work¹⁴ present a comprehensive system of AAL oriented automation using ZigBee and RFID technologies for a wireless environment of sensors and autonomous computers that encompass (1) Integration of various functions of a kitchen, (2) Safety of the user and (3) Autonomy of the system at functional level. Karupiah Pal Amutha et al demonstrate a similar concept in their paper¹⁵. To address the limitation presented in their work we contemplate to explore the possibility of a passive, UHF long-range RFID system with the RFID antenna module connected to the "Intelligrator".

FOOD PREFABRICATION AND PROVISION

In a research conducted by FAO⁵, every German citizen throws away more than 80 kg of food per year, about 21% of their overall shopping, while USA loses 31% of its food to waste. The amount of food wasted in Germany is about 300 € per year per capita. The major amount of waste comes from the fact that ingredients are bought from the supermarket usually in a bigger quantity than required from recipes and a part of them expires before use. Food prefabrication would greatly help not only to reduce waste, but also to achieve a better optimization of

the system itself. Several companies in Europe and America already offer food prefabrication service. These companies, basing on a weekly schedule selected by the users, send pre-washed, pre-dosed and pre-cut food to private houses. Using this kind of prefabricated food will reduce complexity of the system, reduce the amount of time spent in supermarkets and finally economic and food waste. First, the meal chosen by the user or his/her doctor will be ordered online and received at home. The Automated Food Delivery System would approach the door, retrieve the food, and feed the box to the Automated Storage Management System. The meal is subsequently inserted in the terminal inside a box with a RFID tag. The system will then choose the right box and support the user in every step of the recipe. In this way, the terminal will achieve a nearly "zero waste" concept: ingredients will be all pre-dosed and come in a one-meal package, only a certain number of them will be stored based on the weekly schedule and the expiration dates will be reminded by the system.

PROPOSED SYSTEM IMPLEMENTATION

All the implementations are here presented as a concept for further development. The main goal is to integrate them in a singular physical terminal with a singular overall logic, in order to have a smoother cooking process that with require unnecessary movements both from the user and from the machines. Due to IKT modularity, the implementations can be all present in the terminal, partially present or singular, depending on the user needs and wishes. In this section, the main components of the system are explained: (1) the Automated Delivery System, (2) the sensor network, (3) the assisted cooking interface. Finally, the proof of concept of the ADS system is presented.

Automated Delivery System

The Automated Delivery System (ADS) is composed of two robots that collaborate with each other using wireless communication with the Intelligrator. The Automated Store Management System (ASMS) works in the back of the module and has the scope of the whole length of the terminal. The ASM system is responsible of the storage and retrieval of food boxes. On the other hand, the Automated Food Delivery System (AFDS) scope is basically the whole apartment. It first retrieves food directly from the door, then goes back to the terminal and feeds the ASMS. After food preparation, it may carry done dishes throughout the apartment, for example to the bedroom or the living room, to serve users with deambulatory problems. The logic of the system is supported by the use of prefabricated food boxes, each containing ingredients for a full recipe, as it greatly simplifies the cooking process and logistics.

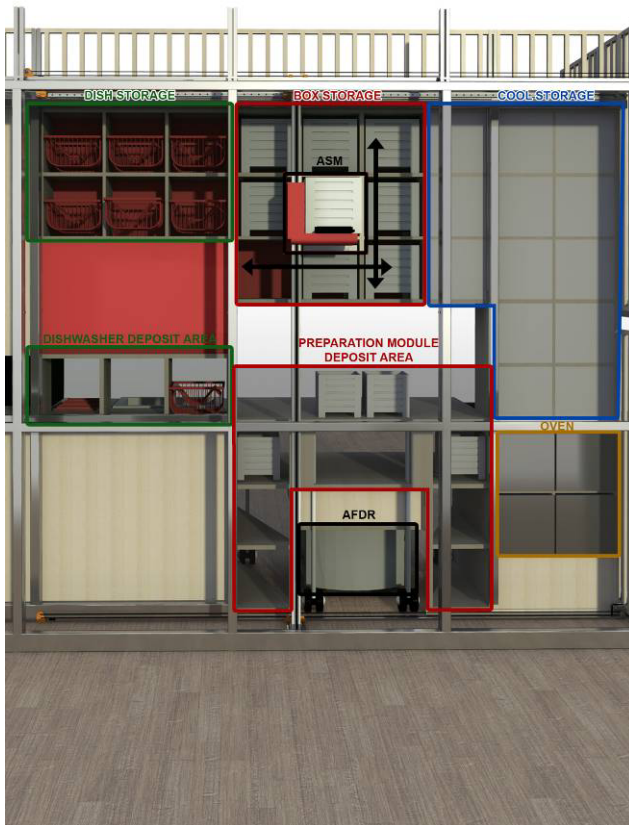


Fig.2 The Automated Delivery System and its components

Automated store management system (ASMS)

In order to reduce physical movements in the vertical direction as much as possible, the boxes stored in the upper part of the kitchen are manipulated by an autonomous delivery system.

The ADS is based on the existing technology of Mini load: it can travel along two axes and has a prismatic joint to pick the shelf and put it on the delivery designated area. The ADS lies in the back of the terminal and runs for its entire length. It is not evident in the kitchen design, to maintain the classic aura of the living space, but it is accessible from both sides for maintenance. The ADS serves 3 main areas of the storage: the box storage, for the prefabricated food boxes soon to be consumed, the cool storage, for boxes, as well as other ingredients, that require a longer period of depot, and the dish storage. The latter contains a certain number (in this particular layout: 6) of modular kits of dishes and cutlery, each of them assigned to specific recipes, in order to further rationalize the cooking process. The integrated mini-dishwasher can be used accessed both by the user and the ADS to allow easy transport of used cutlery into the dishwasher and top access for prevention of any physical strain. The shelves, as well as the internal boxes and washing machine plates, have been designed in order to reduce the complexity of the robot.

Automated Food Delivery System (AFDS)

The food delivery module has been designed with the purpose of being connected to the robot Lynx^a. With an autonomous mechanism of connection, the table can swivel about the food preparation module so as to have an easy transfer of food without much physical exertion on the user and bring the final plates in every ambient of the house. The module itself is a small kitchen table for everyday use in different areas of the apartment. The Lynx robot can be programmed to navigate a specific route in the apartment with effective independence and also is capable of docking itself to the charging station when the requirement arises. The use of the Lynx is aimed to exploit the autonomy offered by the Lynx robot to enable its usage elsewhere in the home, when not in use for the table (for e.g. as a mobility platform for other purposes in the home environment) and detach it from the table base to redefine its role (for e.g., as a mobile base for conveying a utility rack around the house for ease of access to the disabled). The kitchen module for preparation is designed to accommodate the conveyance table in such a position that the ASMS has access to the shorter edge to be able to deliver and pick-up the shelves from that particular area. When the table is ambulated by the robotic base, it can travel to the door of the house, from where a food packet or grocery box delivered can be placed on the deposit handling area by the delivery personnel. The package received by the table shall then be fed to the ASMS for storage in the appropriate area, after the table docks back into its position in the kitchen platform.

RFID based Storage module environment

The autonomy of the system is achieved by tagging a custom range of container family with RFID chips that are embedded into the containers in which groceries and food items are stored. This antenna module receives the inputs from the user or cooking assistance system to trigger the ASMS to fetch a particular item from the storage module. Also, it serves as a gateway to access the RFID tags when they need re-configuration of the contents of the container. The recipes used everyday are also stored in the main computer memory, together with their calorie intake, so that the system may give suggestions on meals choice, based on health requirements or user usual preferences. The system is planned to be elaborated in further work at the next stage of concept realization, with real time implementation of the system, tested with a full set of the components

^a The robot lynx is a product developed by Adept (see <http://www.adept.com/products/mobile-robots/mobile-platforms/lynx/general>)

and the networking. The below figure illustrates the system scheme as envisioned.

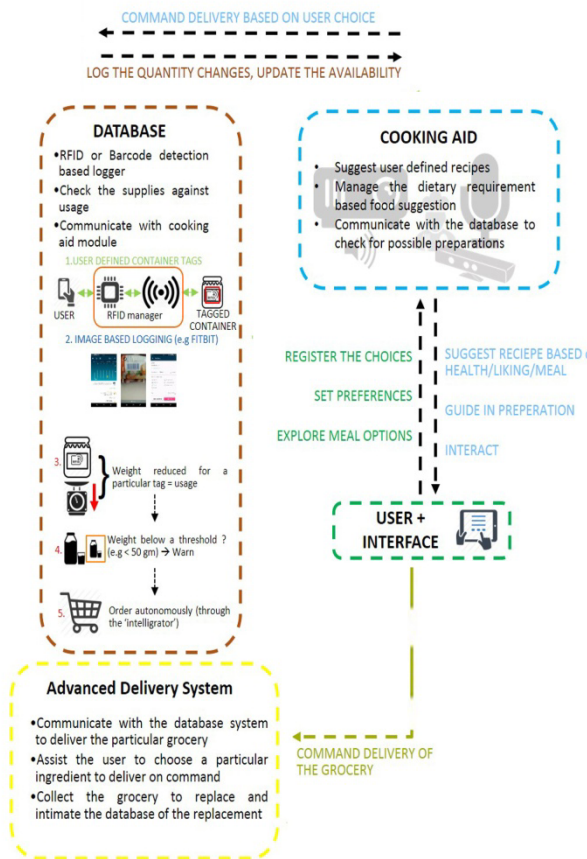


Fig.3 RFID environment concept in tandem with the ADS.

Assisted cooking and interface

The cooking interface is installed above the preparation module. It is composed of two main elements: a Kinect camera and a projector, both connected to the “Intelligrator”. The Kinect detects food items and ingredients as a feedback to cooking aid, together with the user movements. The projector, prints cooking instructions/illustrations onto the preparation counter, to guide the user during the cooking process. The reason of having projected information is to ease the ergonomics, as it may be more difficult to follow instruction printed on a monitor in vertical position. The next step is asked by the user by haptic feedback (f.i. placing his or her hand in an specific area of the counter) or vocal instruction to the system. Both Kinect and projector are connected to the main computer through wired connection network. Since different user groups are addressed in this research, the focus is having a interface that is flexible to adapt to all of them and ability to be changed and added as is the need. For instance, the system will serve the senior user group individuals at a more physically tangible level with little technological sophistication at the user's end. The interfaces will be more tangible, such as physical RFID cards with pre-

stored recipes to access the database and suggest the meal and/or call the ingredients in the shelves to the preparation area. It also may comprehend additional communication to caregivers via smartphone and other universal communication channels (emails, text messages, automated phone calls etc.). In case of seniors willing to use the Graphical UI via tablets/smartphone, the GUI will be more simplified with larger buttons and less autonomy of the device itself. In case of a younger user group, who are presumably more familiar and used to technological advances of the current era, the major factor would be the interface and interaction with the system. More common gadgets like smartphone platforms will be the point of interaction with the system rather than a physically tangible system like that in case of elderly users. So, for example, features could include control of kitchen electronics and devices remotely via the Internet and real-time communication with the system, Smart-phone apps on open-platforms (like Android, iOS, etc.), control of meal plans and orders with integration to the schedule-applications (such as smart phone calendars) to enable on-the move meal ordering and food-intake monitoring.

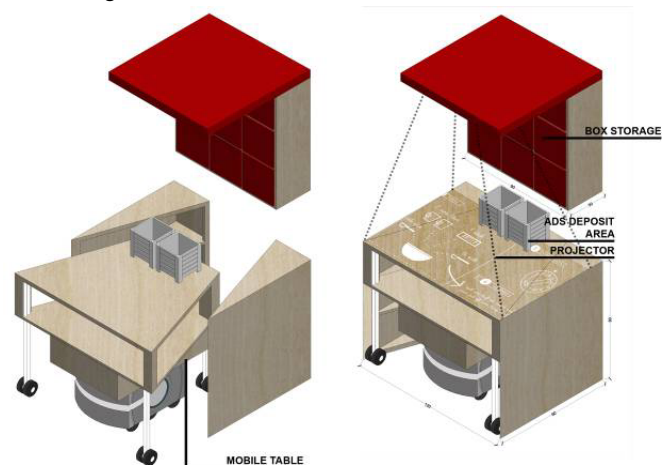


Fig.4 Representation of the Assisted cooking interface and the preparation counter.

Safety sensor network

The sensor network embedded in the terminal has mainly a safety function and it is composed of two main elements: smoke detectors and presence detectors. The smoke detectors are placed on the chimney hob. Their main function is to begin the exhaust at a particular smoke threshold and to trigger alarm and cut off power to cooking system in case of intense smoke and high temperature. They may also give a feedback warning to the user, sending incident data via the computer to them/caregiver on the smartphone. The presence detectors are composed of MEMS thermal sensors placed over the food preparation area and on the ceiling. They are used for two main functions. Firstly they detect

human presence to intensify the light at preparation area and to control overall lighting in the kitchen. Secondly, for safety, they may shut down the oven/cooking stove if user is absent for long after beginning of the cooking process, or trigger a warning if the user stays still for too long (in elderly users). All sensors are connected via wired network to the computer.

PROOF OF CONCEPT OF ASMS

The implementation model is a conceptual representation of the Automated Storage Management System (ASMS).

Methodology

The representative model is essentially a 2 axis motor system that works in tandem to point out the shelf chosen on the smartphone interface by the user, from a grid of 9 shelves emulated for the demonstration. The user interface is a schematic representation of 9 shelves numbered column-wise. The interface is developed using an existing android app, TOUCHOSC^b. This application basically transmits OSC (Open Sound Control) data in form of digital signals (floating values between 0 and 1 or Boolean 0 and 1) over an internet network through a single channel (port). The logic used here is to use GRASSHOPPER, a parametric design plug-in for RHINOCEROS^c, which is a design and modeling tool. FIREFLY^d, a further plug-in to GRASSHOPPER is what controls the Arduino, which drives the end effectors, in this the servo motors. The numerical data sent to the computer from the smartphone is remapped to angular values that are passed on to servo motors using the Arduino board, which is in real time integrated to the GRASSHOPPER definition. The mechanism, which is a simple rack and pinion is driven by a servo motor to emulate x-axis control and another servo mounted on the rack is a y-direction emulator, pointing to the shelf chosen with a LED lamp.



Fig.5 ADS proof of concept

^b TouchOSC was developed by Hexler (see <http://hexler.net/software/touchosc>)

^c Rhinoceros and Grasshopper were developed by Robert McNeel & Associates (see <http://www.en.na.mcneel.com/>)

^d Firefly was developed by Scott Davidson, Fireflyexperiments (see <http://www.fireflyexperiments.com/#home>)

BUSINESS MODEL

The IKT is aimed at serving and integrating different market segments and the user society as a single point of integration.

The primary user groups, depending on the user choice at the time of installation, would be elderly people, dependent and disabled or the young professionals with a busy lifestyle. The system installed as a solution to physical and psychological limitations of elderly or disabled people will be a system serving them at a more physically tangible benefits with little technological sophistication at the user's end. The interfaces will be more tangible, like voice inputs and outputs, a focus on health care and a dietary monitoring system based more on health requirements of the user, to highlight a few. In case of younger user group, who are presumably more familiar and used to technological advances of the current era, the major factor would be the interface and interaction with the system. More common gadgets like smartphone platforms will be the point of interaction with the system rather than a more physically tangible system like that in case of elderly users. The recent developments such as customized diet services, that can be delivered to door step, fresh everyday or indoor food planting systems that yield fresh vegetables in the kitchen environment etc., are fairly new to the market. The IKT system will serve as a synchronizer between these novel entries in the industry and the potential users who can benefit from these without having to access these as fragmented service streams.

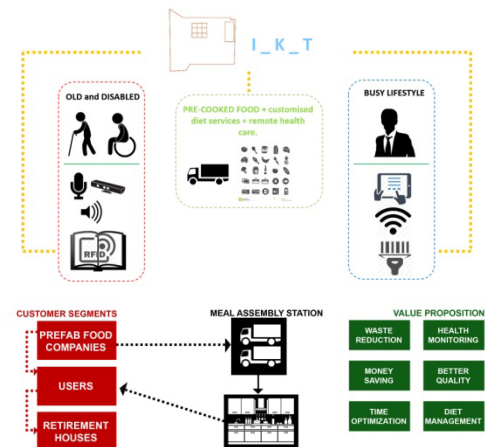


Fig.6 Business model

IKT SYSTEM

As mentioned, the terminal is composed of seven modules (refer to Fig.6). The ADS system (4,8), that has been already introduced, is composed of two modules, the (ASMS and AFDS). The cool storage (1) can be accessed by the ASMS, and contains both boxes or single ingredients which are to be conserved. The cooking module (2) is composed of a stove, an oven and a hob, which is equipped with a

smoke sensor. The preparation area (3), is where the instruction will be printed. It has the deposit area of ASMS and hosts the AFDS, if present. The cleaning module (5) contains the sink, an area for waste disposal and the dishwasher. The farming module (6), is an indoor farm, where the users may grow their own vegetables and the carousel storage (7) is an additional storage space, mechanically driven.

SYSTEM MODULARITY AND TIME EVOLUTION

Since the terminal is self-supporting, it can be installed near existing walls as in the center of the room. The structure is modular, so that the layout can be easily changed basing on the user's needs and wishes (e.g. the modules that compose the kitchen can be sold separately). The modular frame works as a platform to which all the modules are connected. It is composed of three different elements: an aluminum profile for load bearing and structural resistance, and two profiles produced to be connected to the structure and carry electricity and water. The latter are empty inside, in order to permit the passage of tubes or cables, while one of their sides can be opened, for maintenance. A similar kind of profiles that carry electricity cables is produced by the German company RK Rose + Krieger^e. The structure has only dry joints, so that it can be assembled and disassembled. Moreover, the elements don't exceed a certain length, in order to be easily transported and eventually mounted by a single person. The modularity permits also a pre-mounting of spatial elements, to quicken the construction process even more. The wooden frame has no structural meaning, but encloses the terminal and helps to hide the ASMS in the back. The elements have a certain scope in the vertical direction of circa 8-10 cm, so that the kitchen can be adapted to the customer's needs during installation.

Like in a conventional kitchen, the elements share the same or similar dimensions, to be easily relocated in case of different layouts. The dimensions are close to the common standards, so that the elements of IKT can be mounted in existing kitchens, as well as in new ones, with the number of modules the user prefers. The modularity of the elements is a functional type of modularity, since generally modules have more than one function embedded. The terminal has been designed to have modularity for different kinds of purposes, such as development, logistic, customer choice, lifecycle, adaptability, scalability, exchangeability.

The open structure gives the opportunity of evolution during time. The IKT was designed to evolve, according on the customer's needs and means. The

level of automation greatly weights not only on the functionality of the terminal, but also on its cost. Therefore, it was thought to pass through three basic steps which are: (1) Basic automation: the terminal has only mechanical features (e.g. the carousel, the sliding table). It comprehends only the sensor system for safety and health enhancement. (2) Middle level automation: the terminal here proposed. The automation interests mainly the logistic of food (ASMS), plates (AFDS) and the interface for assisted cooking. (3) Full automation: a kitchen with full automation basically means that the dish is completely prepared and served autonomously.

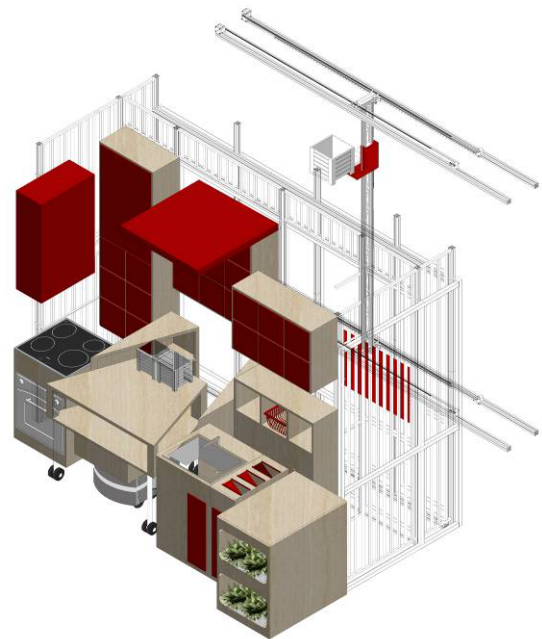


Fig.7 System modularity. From the left to the right: (1) the cool storage module, (2) the cooking module, (3) the preparation area, (4) the food delivery table, (5) the cleaning module, (6) the farming module and (7) the carousel storage; (8) ADS system in the back.

SCOPE OF FURTHER WORK AND RESEARCH

Since the work is based on a relatively small time frame for a comprehensive, system evaluation oriented results, the work is still an initial conceptualization with a relatively clear identification of the various components and systems to be integrated. However, there is immense scope of research and improvement on each front of the project.

For some components the focus would be on interfacing the various systems, that have been to an extent already developed, to an AAL context.

The physical modularity and shape could be also be improved.

CONCLUSION

In this paper, a modular kitchen terminal for Ambient Assisted Living was presented, that makes use of ubiquitous technology and an autonomous delivery system for storage management and food delivery.

^e See BLOCAN Cable channel system, deloped by RK Rose + Krieger (see <http://www.rk-rose-krieger.com/english/news/new-products/archive/blocan-cable-channel-systems/>)

Since the work is still on a initial concept level, generally the implementation proposed need to be further developed and validate through intense testing. Since some of the concepts have been well researched on already, (for e.g. the system to integrate various sensors and interfacing them¹⁷) the focus would be to improve the ADS system. The assisted cooking interface needs to be also developed and adapted to senior use. The overall system, when further developed, has to be validated by future potential users, through test and surveys involving different age groups individuals. A further step in the concept could be to improve the level of automation, in order to achieve full automation of the cooking process. Through a successful realization of this concept, the system could be able to offer substantial autonomy to the disabled and aged users, to whom activities such as fetching items from a highly perched storage area could prove risky. On one hand, addressing the physical ergonomics enables the user to independently prepare meals of their liking while on the other, it reduces the homecare costs and food wastages by creating a nexus of pre-dosed food compatible for use in the smart environment with sufficient autonomy.

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Modular Work Terminal for greater social inclusion and efficient production organization

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Abstract. Aging society, technological progress and the need for greater social inclusion along with the rising need of human resource mobilization has a major impact on the modern society and production organization. To overcome these difficulties and identify one of the possible solutions this paper proposes the idea of a household work terminal. The terminal corresponds to the requirements of the both sides: individuals and enterprises. While the work terminal is highly customizable as per the needs of disabled and elderly people and is capable to assist them in daily working from home environment, at the same time it allows companies to decentralize their production system and incorporate highly skilled individuals, such as retired professionals. The solution is developed through the concept of the home production lab, based on the main frame and modular components, which contribute to adjustable comfortable and individual smart home production station. This research makes an emphasis on the effectiveness of the work terminal and the development of a smart and modular working environment.

Keywords: *Work from home, Smart environment, Ambient Assisted Living, Fatigue monitoring, Home labs*

INTRODUCTION

Worldwide disabled or partly disabled people continue to occupy positions as entrepreneurs, engineers, doctors, teachers, researchers, artists, computer technicians etc. According to a research¹, in U.S.A. almost every 13th person 18 years old and above is unable to walk more than 400 meters, and every 7th has some kind of physical functioning difficulty. Other kind of disabilities (e.g. neurological, orthopedic etc.) or disabilities caused by accidents on permanent or temporary basis also influence these statistics. 44% of workers with disabilities are in some contingent or part-time employment arrangement, compared to 22% of those without disabilities². There might be various reasons behind this phenomenon, including but not restricted to special working conditions, need for therapy treatment and inability to travel. However one should take into consideration the fact that people with disabilities could perform well in majority of job positions if given the right environment. Working from home practice is getting well known nowadays as a productive and convenient method³. Despite that fact among all the positions offered there is no possibility to work from home for people who want to get involved in sectors like prototyping, electrical, mechanical or mechatronics engineering. Furthermore there are currently no such job offers available in the hardware field.

On the other side, demographical changes in the developed world lead to increased number of older population as compared to younger one, causing the phenomenon of aging society⁴. Retired professionals, however, constitute an important source of knowledge, which should be absorbed by the business world. The need for this is already recognized by large international corporations, which provide an

opportunity for retired people employment. Good example is Your Encore network employed by Procter & Gamble's⁵.

The paper is structured as follows. The first section gives a brief review of the research methodology and describes the literature review. The next section discusses the need of the Work Terminal and provides a case scenario to validate the system by showing how the proposed working terminal can respond to one of the most difficult scenarios – production line for individualized products. In further sections a detailed description of the whole concept as well as the proposed integrated systems are discussed and a representation of our mock up models and implementations are shown. Finally the last section presents our conclusion based on the achieved results and suggests future possibilities in furthering the research.

RESEARCH METHODOLOGY

In the initial stages of the current research we followed a qualitative approach, the analysis is based on secondary data (relative papers and articles were reviewed). At later stages we provided content and thematic analysis of the literature. After careful consideration of the above findings we proceeded with further development of the concept, provided necessary calculations and built a mockup model.

LITERATURE REVIEW

Working from home concept constitutes a great part of Ambient Assisted Living (AAL). In order to develop an effective automated and functioning environment in a smart home working space, it is necessary to enable technologies and include interfaces that allow residents to maintain a direct link with their col-

leagues and the required information⁶. Automation and technologies that provide assistance in manufacturing and storage tasks contribute significantly to an effectively functioning environment in case of working terminal; good example can be the publication regarding the Jaco robotic arm, which is controlled using the Graphical User Interface GUI and the Leap Motion controller⁷. The development in the cloud manufacturing technology allows a great opportunity for decentralized working environment remotely, without physical boundaries. With appropriate technology and automation it provides a platform where costs are reduced and collaborative design and project solutions are created⁸. Furthermore the ergonomics also play a crucial role in providing productivity. This includes the layout of the work terminal and ease of access to each section of the layout. The layout follows a series of processes, specifications of the equipment and the ergonomic rules⁹. Increased size of the terminal results in more spacious working environment but creates difficulty in easy access.

THE WORK TERMINAL

The work terminal (Fig. 1) concept is developed based on existing studies on similar topics and takes a deep inspiration from an existing project USA² (Ubiquitares und Selbstständig Arbeiten in einer alternierenden Gesellschaft). The terminal is designed to fulfill the ambitious needs of people working from their abode. It is specifically designed for production or prototype development of small products with complex design and requirements, for example ear phones, gear boxes, shoes etc.

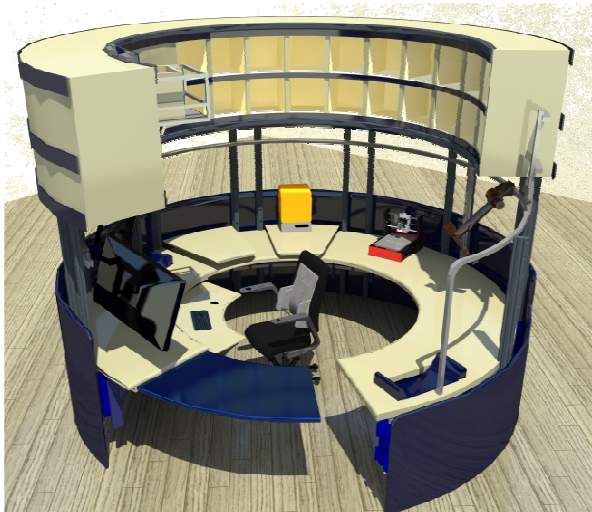


Fig. 1 View of the full version of the proposed working terminal

ADVANTAGES AND NEED OF THE WORK TERMINAL

To respond to the aforementioned needs and trends of the modern society, the work terminal can be proposed as one of the possible solutions. The home working terminal can provide significant advantages to both: enterprises and individuals. From the point

of view of an individual, the work terminal can offer an opportunity for greater social inclusion and professional realization to people with limited abilities or to the elderly. On the other hand companies can benefit by accessing skilled work labor and incorporating retired professionals. Working terminal can also lead to a greater decentralization of the production system and satisfaction of the local customer needs.

The working terminal is designed to assist any person who falls under the respective categories, namely people with disabilities and elderly people, aiming to increase productivity and provide comfortable accommodation to the user. However, it is important to mention that the work terminal is suitable for any one due to its customizable nature. The work terminal creates a smart individual and adjustable environment giving birth to new opportunities. The time-waste due to traveling can be reduced to minimum and possibilities of flexible scheduling can increase dramatically. Large scale integration of such concept can lead to other important social advantages as well. In case of a broad implementation of this concept, it can be assumed that it will also have a positive effect on the transportation system and will reduce the pressure during the rush hours, because an increasing number of people would not need to travel to the office.

Secondly, one of the most important aspects of the working terminal concept is greater social and professional inclusion for retired employees, which means that they can continue adding value to the fields in which they acquired significant long-term experiences. This concept is a win-win situation for companies and retired employees. While enterprises could benefit from skilled and knowledgeable working labor, elderly people would continue to be integrated in a professional environment.

PRODUCTION LINE SCENARIO

The work terminal is designed such that it follows an ergonomic flow for production. The purpose of the design is to provide a work flow pattern. This work flow pattern makes it easier for the user to develop a product in the right sequence increasing the productivity of the user. The design also provides easy access all around the working space.

The production sequence follows a step wise procedure. It is like a mini factory and the desk platforms are divided into a sequence of different phases. Let us consider an example for production of customized ear phones. The work process would commence in the following phases (Fig. 2a&b):

1. Data Input: This is phase 1 where the customer first provides the design specifications through special software, then the customer visits the work terminal where his ear is

scanned using a 3D ear¹⁰, making a digital impression of the ear canal.

2. Design Phase: The data collected from the first phase is used to develop a cad model.
3. Production Phase: The cad model is used as an input for 3d printing of the required components and a mini cnc mill is used to print small pcb boards.
4. Assembly Phase: The developed and pre-ordered components are all assembled together.
5. Testing Phase: The assembled product is tested using respective testing equipment.
6. Delivery and Storage: The finally tested product is then stored in the mini warehouse until the customer comes to collect it.

ASPECTS OF THE WORK TERMINAL

The aspects of the work terminal are as follows:

- Ergonomic design and modularity
- Modular components
- Raising desk
- Automated modular shelves (mini warehouse)
- Robotic arm
- Massage embedded chair with a holonomic wheel base
- Fatigue monitoring system
- Intelligent environment
- User following light intensity
- Well-designed wiring placement
- Centralized manual control unit for overall system

ERGONOMIC DESIGN AND MODULARITY

Besides the circular shape of the desk for better ergonomics, flexibility in the nature of the work terminal can be achieved by providing modular desk panels. For this reason, during the design phase of the working terminal, the desk panels are designed in an independent way. Each desk division consists out of two main parts (Fig. 3), one fixed and one removable. The removable part will accommodate the right equipment for a particular task. If the task needs to be changed the equipment can be replaced directly with the desk part to avoid any needed un-installation process. Each division is fixed to rails of the main frame with a lifting mechanism to provide independent adjustable height (Fig. 4). It is up to the user to decide whether the complete version (Fig. 5) of the working terminal is required or a smaller version with less desk divisions, depending on his/her particular needs. A smaller version, however, is expandable and further desk divisions can be added.

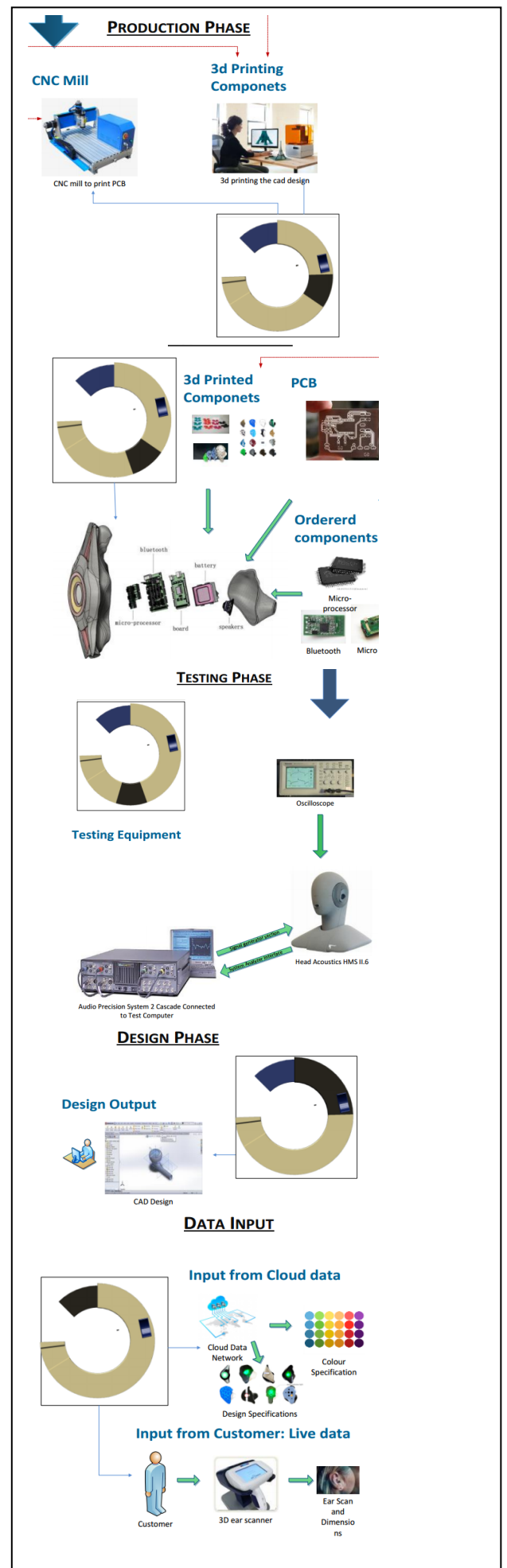


Fig. 2a Production Flow

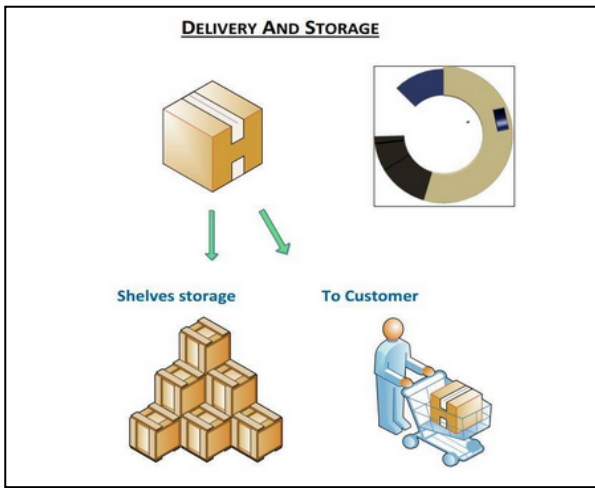


Fig. 12a Production Flow

AUTOMATED MODULAR SHELVES (MINI WAREHOUSE)

Many various storage systems with integrated automation exist, however none of them have been implemented in a home environment. For the proposed concept, a "Mini warehouse" system compliments the design. The designed "Mini Warehouse" consists of four main sections:

- The Shelf Set
- The Load-Unload Mechanism
- The Delivery Mechanism
- The Delivery Platform

With efficient control (voice and gesture control) and by cooperation with other systems (e.g. robotic arm) the user can be provided with a great deal of assistance.

The shelf set is also modular in nature like the desk panels; it may differ in number as per the users requirement. The user can expand the shelves further if he/she requires.

The shelf set consist of the main infill frame, the fixed shelf storage compartments and the light weight shelf boxes which are stored into the fixed shelves.

The shelf load-unload mechanism (Fig. 6) is fixed on the rails and moves across the shelf section to access any existing shelf and its contents (shelf box). Once it accesses the shelf, it moves on to the delivery mechanism and transfers the shelf on to the delivery mechanism (Fig. 7 & Fig. 8).

The shelf delivery mechanism in its place follows another rail line which moves along two different paths. One of path includes a turning point from a vertical to a horizontal axis. Therefore, the delivery mechanism has a circular shape and has another part which is integrated from the inside. When the delivery platforms reaches the turning point, the additional integrated platform will always rotate towards the opposite direction so that when the delivery platform moves from horizontal to vertical the integrated platform will compensate the rotation and always keep the delivered shelf in an upright position.



Fig. 3 Single desk component

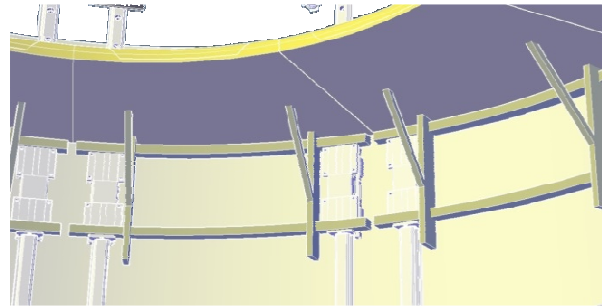


Fig. 4 Supportive structure of desk divisions

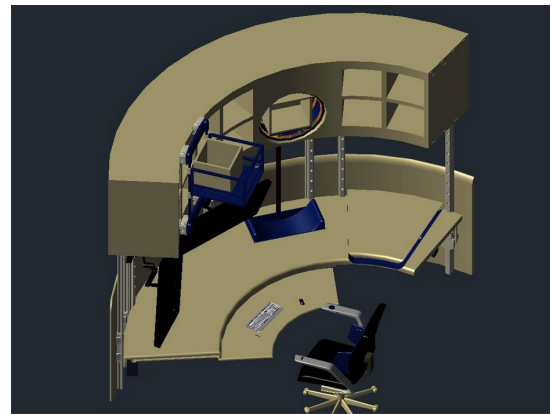


Fig. 5 Smaller version of the desk

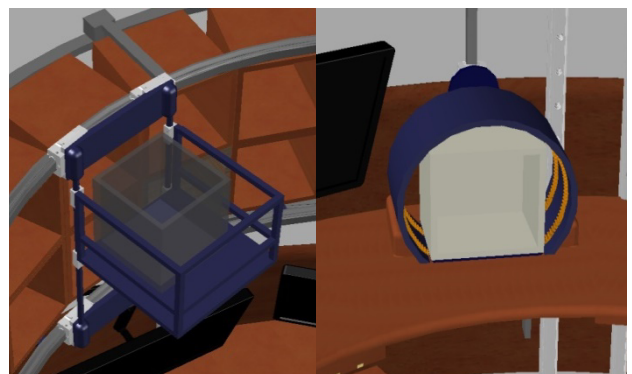


Fig. 6 Shelf Load-Unload mechanism

Fig. 7 Shelf Delivery mechanism

ROBOTIC ARM

The Robotic arm is proposed as an optional feature of the working terminal. Various ways of installation

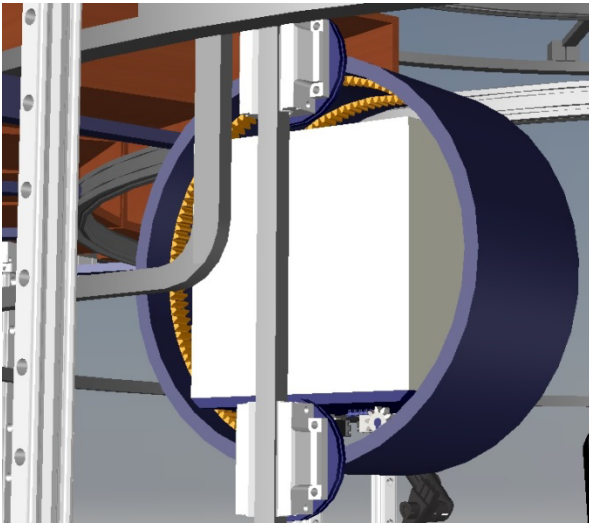


Fig. 8 Shelf delivery mechanism view from behind

have been considered. The most modular way is to install the robotic arm on the rail which is already being used by the delivery mechanism. In this case an additional rail is provided and attached to the main rail, providing the robotic arm a path to free the rail for the delivery platform when required (Fig 9). The mechanism to provide the change of path is based on the train rail principle (Fig. 10a&b).

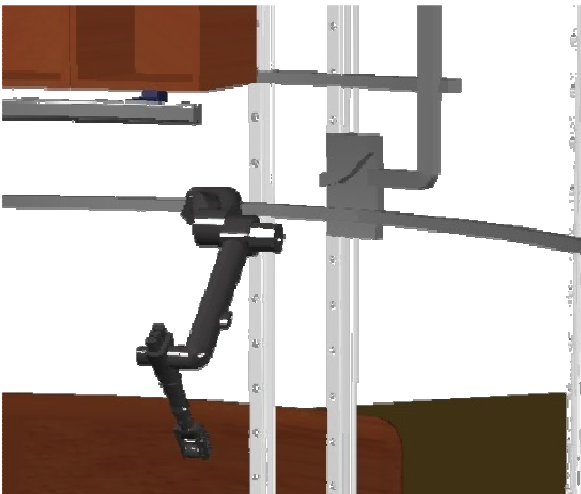


Fig. 9 Robotic arm

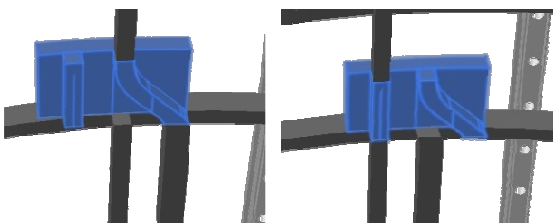


Fig. 10a Path changing mechanism

Fig. 10b Path changing mechanism

THE CHAIR AND THE INTEGRATED SYSTEMS

The chair is designed to accommodate to the comfort of the user and increase his/her productivity. Considering the design of a typical office chair (Fig.

11), this research combines modern technologies without changing its shape and dimensions. The employment of the dominant chair design allows to fulfill the requirements of a comparatively compact size and to keep basic chair functions (Fig.ure 12).



Fig. 11 Chair – Conceptual view



Fig. 12 Basic chair functions

The next important fact which is taken into consideration is the needs of the targeted groups, namely elderly people and people with disabilities. To respond to those requirements, the chair is equipped with the smart control method that provides freedom and maximum flexibility in movement. An office chair's base is already flexible and can move to almost any direction without significant restrictions, however if it needs to be controlled electronically to provide assistance to the person, it has a lot of technical issues which cannot be solved without significant modifications. For this reason the proposed concept has a holonomic wheel base controlled with touch pads. The control concept is represented in Fig. 13. On the sides of each arm bracket there is a touch button to enable the electric control of the chair (Fig. 11).

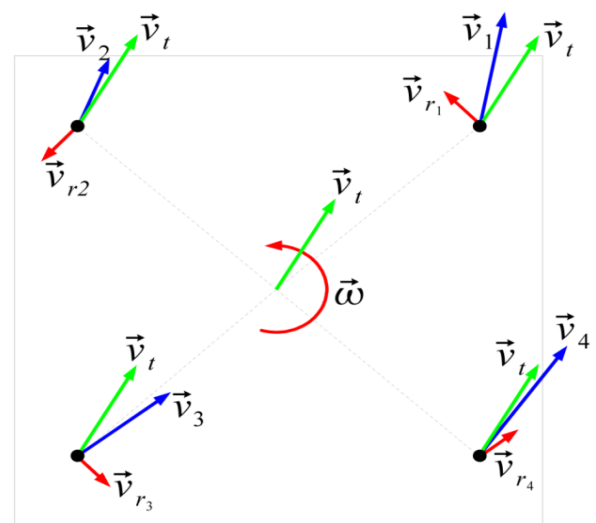


Fig. 13 Holonomic Drive representation

the vector for the speed and the direction of the

chair, while the one on the left represents the rotation direction. For better productivity and relaxing the chair has a massage feature embedded in its backrest. Another feature includes integrated pressure and vibration sensors embedded in the seat for monitoring the heart rate and the posture of the user.

FATIGUE MONITORING SYSTEM

Various researches have been conducted about integration of fatigue monitoring systems in vehicles for automotive industries¹¹. The fatigue monitoring system includes a camera, a seat of the chair integrated with pressure and vibration fiber optic sensors¹² and an optional addition of Kinect. Using these elements various physical features including the human posture, heart rate and respiratory rate can be monitored.

The fatigue level can be monitored by using a blinking counter¹³; the camera can calculate how often the person blinks and how the shape of the eyes changes while the person's fatigue level increases. The Kinect can cooperate with the camera and also monitor the posture of the user¹⁴.

The data collected from the sensors embedded in the chair as mentioned earlier with the cooperation of the camera and/or Kinect will be processed on the central computing unit being able to detect and minimize fatigue level by giving hints to the person. Using this technology the user can be guided on some stress releasing activities, for example the user will be notified to take a break or/and proceed to elementary physical activities such as moving, stretching etc. The same data can also be used to make historical analysis about the user's health statements and productivity, which can be shared with a physician if required.

INTELLIGENT ENVIRONMENT

The proposed working terminal combines various automation systems, sensors, monitoring activities and human-robot interaction. To combine all these efficiently an intelligent environment is a definite requirement. The data concerning all the systems (condition, current task, position, activity etc.) needs to be transmitted to one central computing unit, which would provide the master control by using various algorithms and an intuitive graphical user interphase. Through combination of the sensors and machine learning algorithms the environment will be able to adjust to the user accordingly to his/her activity (predicting his/her next movement or task, adjust the lighting, remind scheduled medicine taking etc.).

IMPLEMENTATION IN A MOCKUP MODEL

Based on the detailed 3D-Design a semi-functional mockup model of the work terminal was developed.

For better details an unusually large scale of 1/5 was chosen. It was decided to use mostly wooden material with combination of mdf sheets. Fig. 14 represents the results of our semi-functional mock up models which includes the chair and the working terminal.

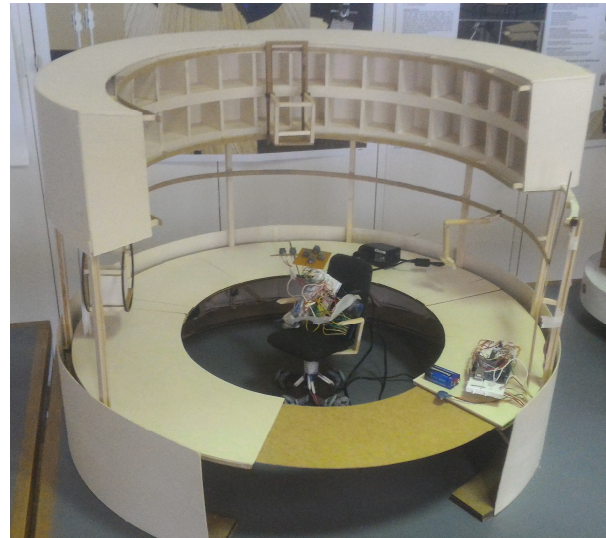


Fig. 14 Mock up model

THE WORKING TERMINAL MOCKUP

During the implementation process several simplifications were made in the mock up models. As shown in fig. 15, instead of two supportive rails only one has been developed and placed in the center of each desk component. The question whether the structure will hold the real load is not being researched on this stage of the project, but existing technologies show that it is indeed possible with a careful and well calculated design. Great examples are firms like Dexion and Schaefer that specialize in storage systems and automated pallet racks. The structures that they make for storage systems are made of stainless steel and other metals, they are compact in space and comparatively light, yet they carry tons of heavy load.



Fig. 15 Supportive rail simplification

All the modular desk components can slide on their supportive rail; a representative mechatronic implementation has been developed for one such component. To achieve successful mechatronic height adjustment a simple servo-motor has been used. Similarly each desk component can be adjusted accord-

ingly, however in the real concept a detailed feedback about the position of each desk component will be provided to a cloud platform, which has been mentioned previously in the section Intelligent Environment.

The rails used in the mockup are made out of wood. An “H” shape column has been used for the rail as shown in (Fig. 16).

The physical model of the robotic arm is hosted on the rail, the robotic arm shares the rail with the shelf delivery platform Fig. 17. Physical coexistence of these two could not be tested because the rail is simplified and the “Path changing mechanism”(Fig.10) has not been implemented in the mock up model.



Fig. 16 Mock up rail shape

User following light intensity has also been implemented using LED stripes; however the sensors have been simulated with buttons. This part of implementation makes clear that such integration is easily possible with any sort of furniture.



Fig. 17 physical model of the robotic arm

THE CHAIR MOCKUP

The most important part of the chair is the movement control and proof of concept of the holonomic base integration. There have been several studies for different variations of holonomic bases used for robotic applications¹⁵ or even for wheelchair applications¹⁶, but no studies have been made integrating such base into an office-chair for better mobility in a home environment. Fig. 13 represents all the necessary required movements in order to achieve or provide full freedom of control. As for our first mockup model (Fig. 18) Omni directional wheels were specially 3D printed to fit the size of the chair, 4 simple 6volt DC motors were used to power these wheels, which were simulated with buttons. However, for precise control step motors with rotary encoders would be required. The mockup was developed to perform and prove basic movements (Front-Back, Right-Left, clockwise-anticlockwise rotation).

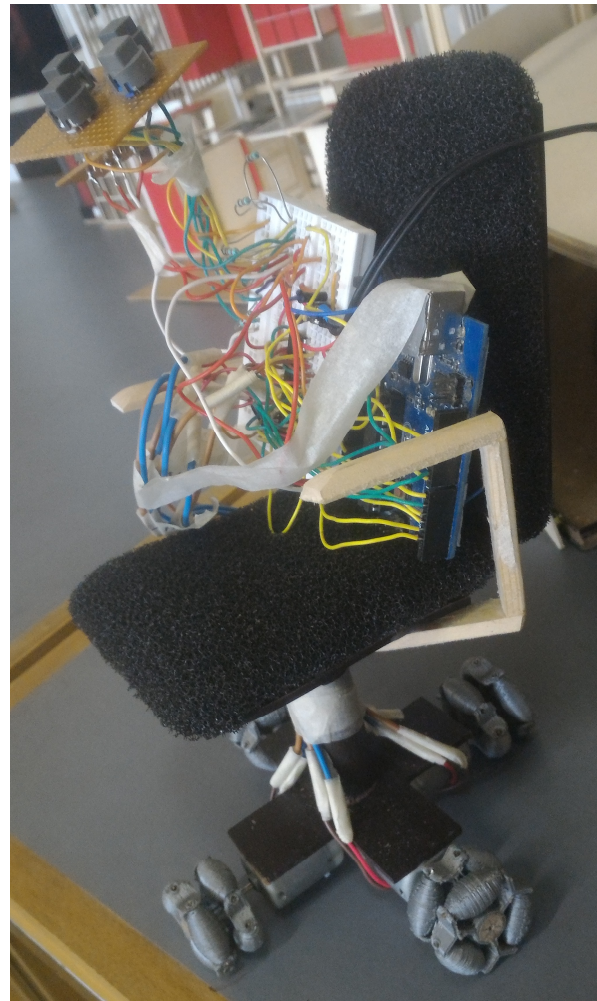


Fig. 18 Mock up model of the chair

RESULT

The research focus was based on the concept of the working terminal and its feasibility. The mock up leads to a conclusion that at this stage the rail should be designed in a way to be able to host a sliding mechanism from two opposite sides, it should be symmetrical, but the exact shape has to be decided based on the sliding mechanisms chosen.

The Load-Unload mechanism of the mockup is just a physical model, which keeps the dimensions that have been used during the design to prove that it can physically coexist within the working terminal with the other system. The same applies for the shelf delivery mechanism (Fig. 19).

Furthermore several wiring issues occurred which lead to serious complications in case of sliding objects, there are examples of electrically powered sliding mechanisms out of which the most common is the elevator, but in the proposed working terminal the path for the mechanisms is much more complicated than just a line. Therefore, the example of pallet racking systems is taken into consideration, specifically the “Pallet Shuttle System” from Dexion¹⁷, which uses a platform to move loaded pallets. The platform is not connected to any power supply with wires; instead it has a battery which is

charged at a docking station every time the system is not in use. This concept is to be implemented to the proposed terminal's mechanisms and to the platform which holds the robotic arm and simultaneously powers it.



Fig. 19 Shelve load-unload and delivery mechanisms

In case of the Chair Mockup, the poor quality and rough surface of the wheels caused a lot of friction. Therefore the wheels were unable to rotate smoothly. It was observed that due to high friction and different floor surfaces the displacement of each wheel varied, even though the same signal was sent to each wheel. These observations lead to the conclusion that implementation of step motors with encoders to provide feedback will not be enough. Another reference point needs to be created, it could be a precise accelerometer in a combination with a gyroscope e.g. the chip MCU6050¹⁸. Data from this chip can be compared with the feedback from the motors and a more efficient PID controller could be designed if not only the data from the motors is used but also from the gyroscope and the accelerometer. Another considerable factor is that when we add a holonomic base to a chair the weight distribution per wheel changes as per the person's sitting position. Compared to holonomic bases for robotic applications, our case requires more attention for particular issue.

CONCLUSION AND FUTURE WORKS

The current paper proposed a concept of the home work terminal, the terminal which would enable home production, increase decentralization of the production system and assist people with disabilities and elderly people. The main advantages of the module are greater social inclusion, mobilization of the resources in aging society and greater production efficiency. The concept is based on the main frame to which other modular objects are attached, the fact which provides greater flexibility.

It is suggested that the future research would look in detail on the concept of empowering objects using the rails holds, where the plug and play system allows avoiding complication of the necessity to provide a docking station for every object. Therefore, research could be made on a way which would pro-

vide the possibility to simply attach an object i.e. the sliding mechanism on the rail. The area of wireless power transfer¹⁹ has unlimited potential and can solve this issue by embedding this technology among the length of all the rails and realizing with that continuous energy transfer between each rail and the modules attached to it.

Another research possibility is with the fork lift robot which would assist in the modularity. The concept is that the robot can change the platforms along with the machines and replace it with another platform that changes the nature of the production line.

On the other side, one of the possible limitations of the working terminal could be accounted for design. The mock up model implementation showed that there are some important drawbacks in the design and aesthetics; the design outcome of a structure is restricted when it comes to providing modularity. It is assumed that design-research could contribute to more aesthetic, furniture-like, appearance of the terminal and thus add on to the value proposition of the module.

ACKNOWLEDGEMENTS

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BCUBE – Assistive Customizable Bathroom Module for Physically Impaired Individuals

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As a response to forecasted aging of societies, as well as to increasing costs for institutional admissions and healthcare home aids, new solutions have to be developed in order to support the elderly into "aging in place". Advanced technologies, including automation, object intelligence and service oriented technology await to be integrated into elderly's houses, in order to better support impaired seniors into performing the ADLs (Activities of Daily Living). However, the reluctance of elderly to welcome new technologies, the costly and time-consuming process of retrofitting traditional houses, as well as the presence on market of cheaper home modifications impedes the advanced technology into entering the market of Ambient Assisted Living for elderly. The current paper will focus on the bathroom environment, the location labeled as most hazardous, as well demanding for a wider range of complex tasks and activities, in a senior's house. BCUBE was thought as an alternative type of bathroom, made up of a platform, easily deployed in traditional housing, that can seamlessly support advanced technologies on market (eg, sensors, actuators, MEMS etc.), as well as bathroom furniture components allowing for automated functionalities to support different levels of seniors' disability. The result is a compact, modular and customizable cabin, unifying together all the complexity that otherwise will have to be distributed all around the house that supports certain bathroom disabilities of elderly.

Keywords: Ageing Society, Home Care, BADLs, Assistive Technology, Mass Customization

INTRODUCTION

Western Europe is currently going through a phase of demographic change, the so called "aging of society". Due to increased life expectancy on one hand, as well as baby boomers generation reaching their retirement age on the other hand, almost one fifth of Germany's current population (21%) is at least 65 years old. Following the same trend, by 2060, every third German person will be of retirement age¹. Most of the seniors still, or would prefer to, live in their houses as they get older. Yet, due to various age related physical, sensory or cognitive impairments, nowadays Germany has over 2.1 million seniors in need of care². Apart from personal desire, evidence shows that "aging in place", when properly assisted and secured, helps to prevent or reduce the severity of age-related impairments³.

According to several authors^{4,5}, the older adults encounter difficulties into performing ADLs (Activities of Daily Living) mostly in the bathroom, which is identified as the most unsafe space in the seniors' home environment⁵. Table 1 shows the BADLs (Bathroom Activities of Daily Living), which are associated with age-related physical disabilities⁶. The difficulty into performing one or several BADLs is a strong indicator of an eventual long-term nursing home admission⁷, increased hospital usage, need for a home aide service, as well as a primary predictor of morbidity, and ultimately – mortality⁸, mainly due to falls and near-falls, which represent the fifth leading cause of death among the older individuals⁹. Circa

15% of falling episodes among the elderly happen in the bathroom, which makes it a common location for casualties⁴. Previous studies¹⁰ concluded that the reasons behind a fall are usually a combination of three domains of factors: personal (age-related impairments), environmental hazards (eg, slippery floor), and behavioral factors (ADL that are regarded as dangerous for seniors). The personal risk factors have been subject of much assessment involving older people¹¹, and the most predicting ones were those related to lower extremity impairments, as shown in the Fig. 1.

Risk Factor	Mean Relative Risk*
Muscle weakness	4.4
History of falls	3.0
Gait deficit	2.9
Balance deficit	2.9
Use of assistive devices	2.6
Visual deficit	2.5
Arthritis	2.4
Impaired activities of daily living	2.3
Depression	2.2
Cognitive impairment	1.8
Age > 80 years	1.7

Fig.1 The most common personal risk factors predicting falls, identified in 16 different studies¹¹

As a response to environmental hazards, as well as a means for developing safe behaviors, rehabilitation specialists have opted for home modifications, meant

Table 1. BADLs associated with disability

Utility	Activity
Bathtub / Shower	Undressing / dressing Helping get in / out of the bathtub / shower Rinsing Soaping Body drying Body creaming Body inspection
WC	Helping sit down on / stand up from the toilet Washing the body parts Toilet disinfection
Sink	Hand washing Oral hygiene Hair care Face care
Miscellaneous	Access to the bathroom / movement inside the bathroom Cleaning of the bathroom Safety control Handling emergency situations

to maximize safety, independence and the ease of use. However, following the new developments among assistive technologies, the home modifications can be brought to a new level of automation, intelligence and network supported assistance, which would enhance the functionality of traditional modifications and would provide a safe environment for elderly to age in place. Yet, the conventional built environment and furniture does not always allow for an easy "upgrade" to an advanced automated and intelligent environment¹², as well as elderly are not always eager to accept an evident change of settings within their homes. Thus, the options for an almost "invisible", easy to mount, and fast intervention is to be discussed. Moreover, due to the complexity of each individual's situation and multi-morbidity, it is very hard to develop a standardized system that would respond to every current or further impairment, as well as to ongoing change within the disability state of an older individual. Thereafter, an "inclusive design" should be considered. For housing, the inclusive design is a new trend pointing at a predictive design, able to adapt, or permit for further adds-on, in order to meet the future, unpredictable at times, needs¹³. Finally, along with the development on market of service robotics, special attention should be paid to integration of robotics within building components and furniture¹², as a part of AAL

(Ambient Assisted Living), especially if speaking about the partial or total replacement of a home aid input, which would spare the elderly, as well as their care giver, the financial and emotional burden.

The purpose of the given paper is to: (I) develop a prototype of a platform, specifically designed for the bathroom environment, aimed at providing a seamless environment, as well as an adaptable plug and play system, for existing on market assistive technologies and further developments; (II) propose a basic kit of automated bathroom furniture, supported by the platform, developed for seniors suffering from mobility dysfunctions - the most imminent indicator of possible injuries or fatality (Fig. 1); (III) discuss a possible business strategy, aimed at facilitating the wide spread and procurement of the given system.

The following sections of the paper will present: (I) a review of the state of art of bathroom assistive technologies for older adults; (II) BCUBE - a possible solution to the issues previously discussed and a rough implementation of one of the BCUBE's proposed functionalities; (III) the options for the mass customization of the BCUBE; (IV) a business strategy aimed at facilitating the wide spread and procurement of the BCUBE; (V) a discussion of results; (VI) the conclusion and the future research.

RELATED WORKS

As a response to age-related impairments, assistive technologies are usually employed to restore independency and safety. The umbrella term "assistive technology" covers a broad range of devices from the very simple, conventional, low-cost ones to the most advanced monitoring and communication technologies. One study¹⁴ classified the existing devices into four distinct categories: Telecare (eg, alarms, movement sensors etc. to provide personal safety), Telehealth (remote disease monitoring), Equipment to facilitate physical rehabilitation (eg, interactive rehabilitation), Environmental design (eg, grab rails, raised toilet seat etc.). For a personalized environment, able to meet different requirements and provide safety and independence on a multiple level, a carefully customized combination of the up-mentioned categories is required, mainly due to the presence of very specific multi-morbidity for every older individual¹⁴. When talking specifically about the bathroom environment, the elderly are generally opting for conventional assistive devices and home modifications, mainly due to lower costs, easier installment and more available information. Common home modifications¹⁵ include (I) adding supplement equipment to existing bathroom settings (eg, nonskid mat or abrasive stripes, grab bars, handled shower spray, shower seat, transfer bench, raised toilet seat^{8,16}); (II) rearranging items (eg, moving furniture); (III) changes in the building structure (less common, eg, adding a first floor bathroom, widening the bath-

room etc.). According to Naik (2005)⁸, conventional bathroom adaptations facilitated reduction in health care expenses, as well as lowered the need for home aide services and institutional admission. However, different studies report varying degrees of usage of the already installed devices - from 46% to 87%¹⁷. The reasons behind the underutilization of assisting devices are discussed in several studies. One of the most common reason is that of an eventual decline or improvement in the disability state of the individual¹⁸, which does not go well with the rigid mechanism of the conventional bathroom equipment. Another reason is that of the devices being unsuitable for the patient's disability in the first place, due to a limited choice or degree of customization, or due to limited available information¹⁷. Other identified reasons where those related to feelings of embarrassment to use an assistive device and lack of instructions to use them correctly¹⁷. Some of the assisting equipment may be a danger itself, if not used or positioned correctly; for instance, the grab bars might present themselves an environmental hazard in case of a fall¹⁹.

Following the current trends, telecare and telehealth are gaining popularity, especially among younger generations who want to support their elderly parents. However, there is still not very clear evidence about the acceptance of the new technology among the nowadays older generation¹⁵. A telecare study recognized the elderly being worried about being remotely supervised²⁰, especially if talking about the bathroom environment, where privacy has a significant role. Moreover, it is highly possible that the current elderly generation is less familiar with available complex technology and therefore less likely to accept it in their daily life. According to Brooke (2004)²¹, robotic systems should be integrated into assistive devices for elderly. For instance, a Japanese company developed a so called washing machine for humans, where the individual is soaped, rinsed and dried, without any need of the individual's or a care giver intervention. The main driving force for Japanese developments are those related to costly local health care aides, as well as a significant expected increase in elderly population. However, the given robotic systems did not acquire an extended market for several reasons: high price, reluctance of elderly to trust robotics and hardship in maintaining (Nagamachi, 2014)²². The lack of purchase motivation is mainly due to the fact that elderly are often frightened by the robotic motion and activity, which significantly decreases their willingness to accept them (Nagamachi, 2014). On another note, the privacy, independence and security the given machines offer are a big reason why an elderly would prefer to use it. According to Brooke (2004), elderly who dared to test the "washing machine" gave a positive feedback and had a good experience. Nagamachi

(2014) suggests that a better older human / machine interaction could be obtained through greater attention to ergonomics and settings that are familiar to elderly.

Thereafter, more attention should be paid to a seamless integration of the complex robotic systems in the familiar, existing, conventional assistive bathroom equipment and furniture, as well as to provide greater flexibility and mass customization to the overall system, through the means of a unified platform that would allow for easy plug and play and in time adaptability of the robotic equipment and furniture. A similar concept was developed, as a part of an R&D project¹², where a service unit was designed as a seamless robotic system, to embed MEMS (microelectromechanical systems), sensors, actuators etc., responsible for functionalities needed for the smart home care. The service unit was to be easily deployed in existing houses, "upgrading" the conventional environment to a smart home. However, to the best of our knowledge, the service unit had a rather general approach, and was not further specifically adapted to the bathroom settings.

CONCEPT AND IMPLEMENTATION

Based on previous considerations and developments, the given paper presents an approach to "upgrading" an elderly conventional bathroom environment to a higher level of AAL, by means of a unified platform and subsequent bathroom furniture and equipment easily attachable to it. The bathroom furniture was carefully designed in order to externally resemble conventional bathroom settings as much as possible.

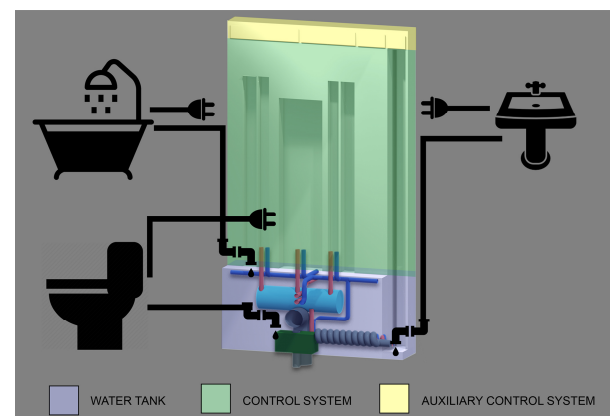


Fig. 2 The functional core, made of three parts

The Functional Core

The main component, the so called "Core" (Fig. 2) is a functional wall (2400 mm x 1180 mm) designed to be easily deployed in a conventional bathroom, or anywhere else in the house. The Core is made up of three parts: (I) the lowermost part is an integrated water saving system tank, that was specifically designed for facilitating an easy plug and play of the

sewage system of the bathroom furniture; the water tank has one connection to the grid water only and one connection to the drainage pipe; (II) the middle part is a platform meant to unify together all the micro controller systems of the bathroom furniture, as well as provides the structural robustness for supporting the physical add-ons; (III) the upper most part is reserved for telecare and telehealth technology. A floor for optimized drainage is attached to the wall component.

The following components, attachable to the functional Core, are integrated systems of various assistive functionalities, that, according to different amount of automation, account to different levels of physical disability, in the way that components themselves can be customized according to each patient's needs, at any time. Also, the components themselves might be attached all at once, or one by one. The easy control of the bathroom furniture was assured by means of pre-programming settings (eg, shower cycle, sink's positions etc.) and let the elderly only control the settings he is highly familiar with (eg, water pressure, water temperature etc.). An easy mountable cabin enclosure is available in case the bathroom will be relocated in any other part of the house (Fig. 10).

The WC Component

The WC Component has an inclusive design, to facilitate different levels of functionalities. The possible add-on functions span from low to high level of automation, according to the degree of physical impairment of the elderly: robotic toilet seat for assisting the process of standing up / seating down; automatic water flush; automatic wash of the body parts; automatic disinfection, etc. The functions will come up as boxes that can be attached or removed to / from the main skeleton - the toilet, according to disability evolution of the patient (Fig. 3).



Fig. 3 The WC component, along with its possible functionalities

The Shower Component

The shower component is made up of a vertical and side water sprays, for a maximum coverage of the

human body. The sprayers will perform the soaping and rinsing task, while the integrated body dryer will substitute the towels (Fig. 4). The whole cycle can be pre-programmed, choosing the temperature, the water pressure and the timing, so that the elderly can start the process with the same ease as starting a conventional washing machine. The whole cycle of "bathing" will happen gradually, while the user sits in the same position and can carelessly enjoy the process. Just like in the case of WC components, the functionalities can be added or removed.



Fig. 4 The Shower component, along with its possible functionalities

The Sink Component

The robotic sink is an alternative proposal that is able to perform vertical, horizontal and rotational movements, in order to better adapt to the user needs, as well as offer a wider range of functionality according to position. Fig. 5 presents some possible positions, where the sink can serve for individual use, as well as facilitates the intervention of a care giver when needed. The desired position can be easily pre-programmed via a Bluetooth device, while associated to a certain activity, in order to facilitate the easy control: the final user will have to press the button associated with the activity he / she wants to perform, and the sink will take its position. The given functionality was tested through the means of a scaled physical model, as presented in the next paragraph.

Implementation

As mentioned above, the sink component can be easily controlled by a Bluetooth device. An actual demonstration of the given concept was performed through the means of a rough scaled physical model. For the lifting mechanism, a 360-degree servo motor FS5103R, a rack and a gear were used, in order to obtain the vertical movement of the scaled physical model of the sink. For the sake of simple control, an Android user-friendly interface was designed through the means of App Inventor2. The interface was randomly set to three positions (up, down and middle). The Bluetooth receiver connected to the servo motor allowed for easy controlling of the vertical movement when a button was pressed. The motor was actuated

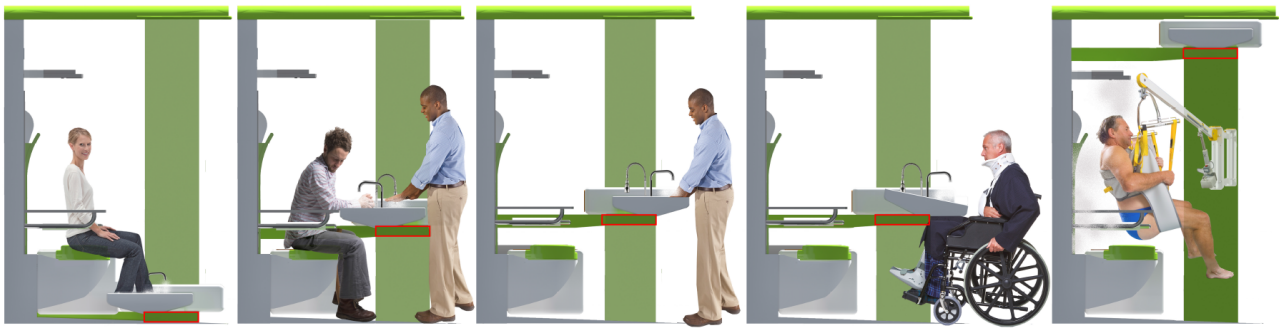


Fig. 5 The different possible positions of the sink and functionalities associated with them

via an Arduino board. For safety reasons, an IR sensor was placed underneath the sink for collision avoidance. In case of an obstacle the lifting mechanism of the sink will immediately stop and a LED light would start flashing. It will start again when the obstacle is out of the pre-set range.

MASS CUSTOMIZATION

The main focus of the up-mentioned design proposal was the adaptability of the bathroom environment not only to different scenarios of individuals with physical disability, but also to eventual negative or positive further evolution of the disability of the same individual. For that reason two levels of customization were proposed. First level is the Core and the possibility to choose the required / desired bathroom furniture and equipment, in order to obtain a customized layout. Second level is the bathroom furniture that acts as the skeleton for possible functionalities (eg, body drier, automatic toilet disinfection, side soaping etc.) that would stand for, or assist, the BADLs associated with disability (Table 1), in this way decreasing or substituting the need for a care giver input. Some functionalities were already thought of and described above, while others can be further found and developed (Fig. 7).

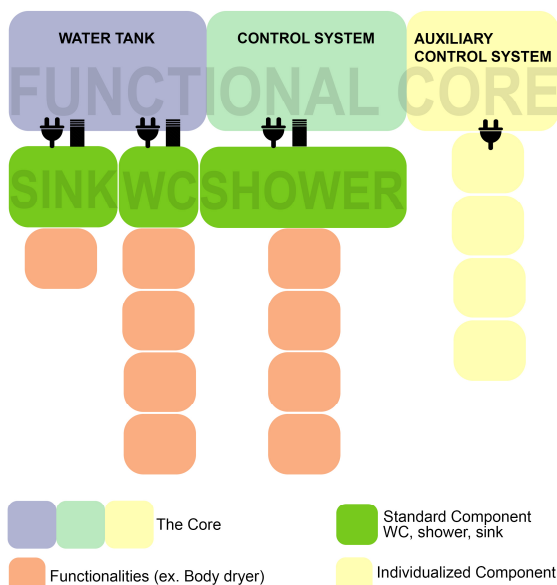


Fig. 7 The options for the mass customization

BUSINESS STRATEGY

Due to the fact that the BCUBE could reach costs beyond the individuals' / companies possibilities, a need to look for potential external funding for the future customers was imperative.

Apart from facilitating an easy plug and play system for pipes, the integrated water saving system tank was developed for opening new possibilities on the target market as well. The given system is an upgraded version of the one developed by an Australian company²³ and, according to them, the system is capable of saving up to 70% of water and 60% of energy, annually. The system captures the grey water coming from the usage of the sink or shower and forwards it to a recycling system: instead of the water going down the drain it goes through a special filter²³ that permits the real time water recycling. Due to the fact that the recycled water is rather warm, less energy needs to be spent in order to re-heat it. Once the shower is over, the water goes automatically to the toilet tank to be drained, so the next person to shower / use the sink will not use the recycled water from the previous one. Also, the functional core has the role of monitoring and controlling the water / energy use. Due to pre-programmed showers, automatic soap sprayer, real time water recycling and usage of grey water for the toilet wash, the water consumption is much better controlled and therefore reduced. Also, the functional core will keep track of water / energy usage and would keep the user posted about the situation.

Given the reduction into water and energy consumption of the bathroom module, a similar project could be of relevance: Solarcity²⁴, the biggest solar panels supplier in the USA, was partly founded by the US government due to their energy saving policies. Therefore, the individual consumers would receive government funding (30% of the cost of the product) for acquiring the solar panels, and therefore, for entering the national program of renewable energy. Same way, the possible customers could be encouraged to acquire the BCUBE, by persuading the government to fund them, according to their level of impairment or disability, as a part of the national program of water and energy saving. Also, instead of

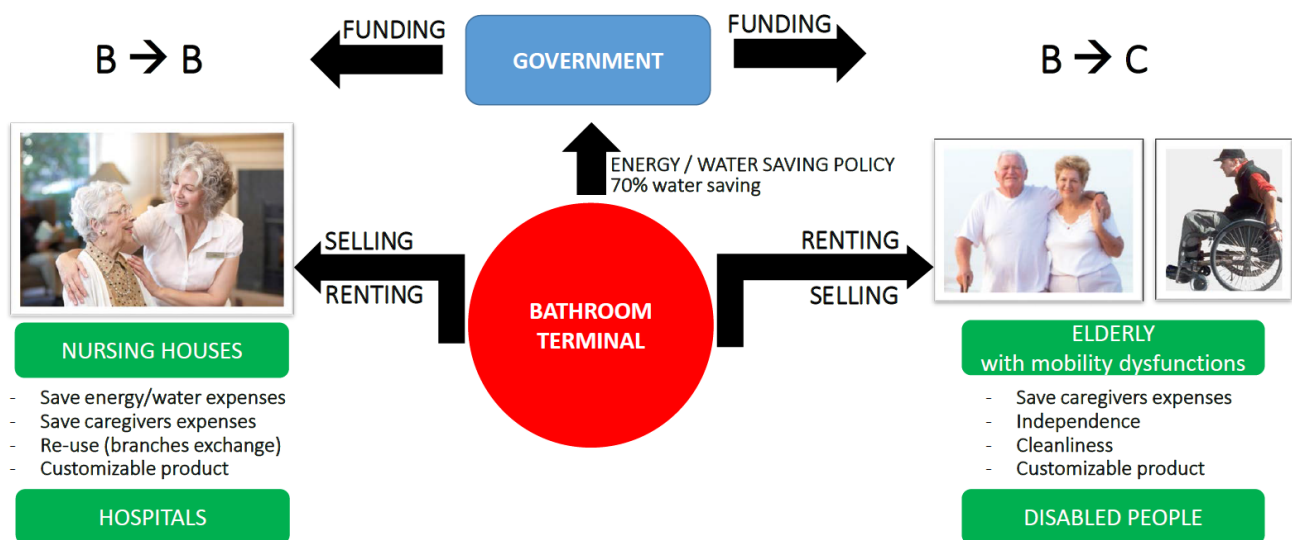


Fig. 8 The business strategy illustrated

selling the BCUBE, the possibility of renting it should be considered, and again, to persuade the government to provide a special subvention, which will represent a certain percentage of the monthly rent. At the end of the life span of a BCUBE, the functional core could be refurbished and re-used for the next customer. Apart from receiving funding to acquire the bathroom module, the customer, apart from saving funds on water and energy consumption, will save upon the expenses coming with hiring the caregiving personal. That would account for a significant money saving, if we talk about nursing houses or hospitals (Fig. 8).

DISCUSSION

Based on previous findings, elderly people are more likely to have conventional bathroom fittings and equipment standing for their disabilities. A well-positioned aid or adaptation can be very beneficial to disabled elderly people. However, faulty aids are of little use or might be plain dangerous. Moreover, most of the aids are of a standardized nature, as well as are not responsive to eventual changes in initial disability. Therefore, in time, most of the elderly become either dependent on constant care or are constrained to move to specialized nursing institutions. Automation, intelligence and network supported assistance is able to significantly enhance the role of home assisting equipment, as well as better adapt to individual cases. Yet, it is not very clear the level of acceptance of the given technologies by the final users - the elderly, seldom not familiar with current technological trends. Also, the existing houses are not always easy to reconfigure or "upgrade". Thus, a compromise is needed. The BCUBE tried to offer a solution through the means of a unified platform to "collect" and "hide" all the technical part, as well as allowing for different system configurations. Moreover, several levels of automation permit

to upgrade the system when more support is needed. The bathroom furniture was carefully designed in order to externally resemble conventional bathroom settings as much as possible, or any other settings already familiar to elderly (eg, pre-programmed shower acting as washing machine).

The outcome was a compact bathroom cabin (Fig. 9), which minimizes the individual's input into performing de BADLs. According to one study²⁵, active, vigorous elderly are more prone to injuries or falls than the frail, static ones, due to higher exposure to risks. Though the active life style for the elderly should be promoted, the bathroom environment, as the most hazardous location in the house, should minimize the activities, at least the hazardous ones.

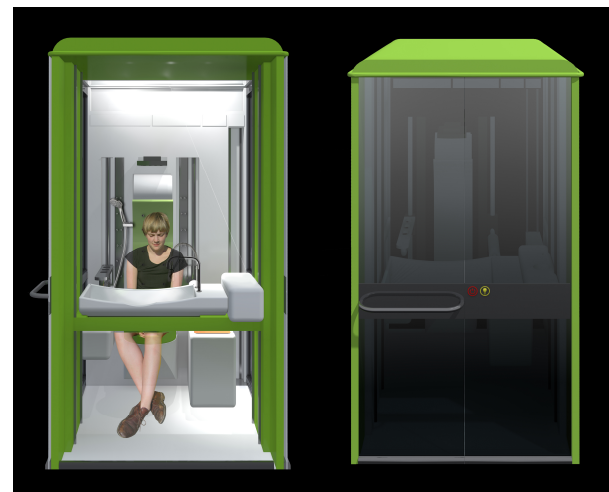


Fig. 9 The BCUBE

There is not a sharp value regarding the cost of the system, or the possible expenses reduction on an individual or national level, due to the usage of the BCUBE. However, some assumptions could be made. Possible reduction of expenses could be encountered in following domains: (I) expenses related

to institutional admissions, hospitals or nursing houses, due to the fact that the BCUBE has the potential of keeping the elderly at home for a longer time and / or preventing injuries; (II) expenses related to hired qualified homecare aids, as the BCUBE was aimed at partly replacing the eventual input of a caregiver through the means of automation; (III) expenses related to qualified personnel assisting elderly in nursing houses, due to the fact that assistance into performing BADLs is one of the hardest both on a physical, as well as emotional level; (IV) expenses related to water and energy consumption, due to the presence of a prototype of a water saving system tank, as well as due to a higher control over the usage of water (eg, pre-programed showers etc.).

CONCLUSION AND FURTHER RESEARCH

The BCUBE (Fig. 10) is a response to forecasted aging of societies, as well as to increasing costs for institutional admissions and healthcare home aids on one side, and as a means of integrating advanced technologies, including automation, object intelligence and service oriented technology within the home environment, on the other side. Moreover, the BCUBE, due to its inclusive design, was meant to be adaptable and responsive to different typology of disabilities, as well as "evolve" in time, if needed, to new conditions. The working environment for the BCUBE is the bathroom, one of the most hazardous locations of the seniors' houses. The result is a compact, modular and customizable cabin, unifying together all the complexity that otherwise will have to be distributed all around the house that supports certain bathroom disabilities of elderly. The overall system is made up of a platform, easily deployed in traditional housing, that can seamlessly support advanced technologies on market (eg, sensors, actuators, MEMS etc.), as well as bathroom furniture components allowing for automated functionalities to support different levels of seniors' disability.



Fig. 10 The exploded BCUBE: the functional core, the wc, shower and sink components, the enclosure

The final users' acceptance of the system is not yet very clear given the lack of any experimental work so far. The next proceedings would be further detailing of each component, physical prototyping and laboratory testing along with the final users, the elderly. Additional efforts should be made into better understanding the possible configurations of the system and methods of easy assembly (the way the main platform interacts with components, and the components with their add-on functionalities).

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A Novel Knee Position Acquisition and Face Recognition System Using Kinect v2 at Entrance for Fatigue Detection and Automated Door Opening

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Extending the healthy life expectancy is certainly important in the aging society. Of course it is important for every single-person household to regularly ensure their safety, but especially for elderly people the importance is higher at the point of healthy life expectancy, because they have a higher risk of accidents aggravation. Therefore the authors here propose a monitoring system for single-person households, particularly for elderly people, based on the MS Kinect v2. The entrance area of the home environment is here considered, where the monitoring system is activated upon while the user approach, in order to first detect and calculate the user's fatigue levels, as well as to identify the user by facial recognition, in order to actuate a door opening mechanism. The proposed system for entrance is a part of the whole monitoring system. The system consists of mainly two sub-systems; the first sub-system acquires the knee position while the user is walking up the stairs, the second sub-system conducts the face recognition for door opening. The proposed system has been successfully tested, and it could comprise an unobtrusive health status validation and automated door opening solution for elderly people.

Keywords: *Kinect v2, Face recognition, Fatigue detection, Microcontroller*

INTRODUCTION

These days the number of single-person households is increasing and it is predicted to be continued in the following years. In developed European and Asian countries single-person household percentages range to more than 33% ¹. One of the concerning things is that the single-person households have a higher risk of exacerbation of the accidents which happen in living spaces than the others. It is because in the case of the single-person households' life, normally there is no one else in their living spaces, so they cannot retrieve any assistance or care in case of an accident.

This is a serious concern, especially for elderly people. Elderly people are affected heavily because they have less ability of recovering. For example, if they fall down, many of them might not be able to walk and this fact makes them weaker. Therefore, an unobtrusive monitoring system could increase their safety.

To decrease the risk of accidents in living space for single-person households, the detection of the resident's physical and mental information in real-time is required, in order to be able to recognize risk situations. Considering the time flow of the monitoring system in the living space, the sensing is activated when the resident enters the house. Therefore, it is more effective to position the sensing system at the entrance part so that we can retrieve as early as possible the resident's initial condition.

The authors eventually aim to predict the resident's physical and mental fatigue. As the first step of it, in this research, we suggested the combined system which consists of the knee position acquisition of stair walking and face recognition based door opening. The knee position acquisition is expected to be extended to get the feet joint parameters for physical fatigue evaluation. And face recognition is expected to be a tool for aspect prediction for mental fatigue evaluation. In this study, we used the Kinect v2 which provides RGB-color, IR-depth and IR images with 1920x1080, 512x424 and 512x424 spatial pixel resolution respectively, and can detect the human body and track 25 joints without putting any markers². The proposed system has been implemented and realized in the experimental ambient assisted living laboratory of the authors at the Technical University of Munich.

BACKGROUND

Previous research done on smart homes embedded with sensors and actuators inside walls, floors or ceilings, etc., which retrieve information about the environment accumulate into a sort of live log, to optimally control smart devices, and to make residents comfortable^{3,4}. However, all these suggestions introduce limitations due the incurred installation processes required to embed all the sensors and actuators in order to transform low tech homes into smart environments. In some situations large scale reconstruction is required or even to move to a brand new smart home construction. Moreover, even if we

can live in such smart house once, we have to change the sensors and devices often, because nowadays the technology for these devices is developing rapidly, on the contrary to the predicted lifecycle period of a building.

Thus, instead of focusing on a smart wall, or smart floor, or smart ceiling approach, the authors chose the so-called “Terminal” approach⁵.

“Terminal” is a modular furniture containing all the required functions and services for a specific room within the home environment. It can be said a kind of furniture with several sensors in simple words, so that it is easy to install into existing buildings. This concept saves us from changing whole house to fit the new sensors and devices. It is designed and manufactured by combining standard products to save the cost of production. Moreover due to the fact that it is “modular”, it can straightforwardly be adapted to any kind of house. Every house has its unique features and arrangement. Additionally every user might require a different level of intelligence (considering the terminal sensors and actuators), so modularity here allows for user customization.

An example of such terminal can be seen in Figure 1, which was developed under the research project L.I.S.A., investigating the possibilities to embed mechatronic, assistive functions and services into compact wall “terminal” elements thereby enabling autonomous and independent living upon performing Activities of Daily Living (ADLs) by means of generated structured environments and robotic micro-rooms (RmRs)⁵. The proposed system in this paper could comprise an add-on for the terminal shown in Figure 1, since its output can be fed to the terminal onboard screens, to display the resulting user fatigue condition at the time, and provide with necessary advices. Also, it is possible to control the lighting and air conditioning devices on the L.I.S.A. wall based on the results.

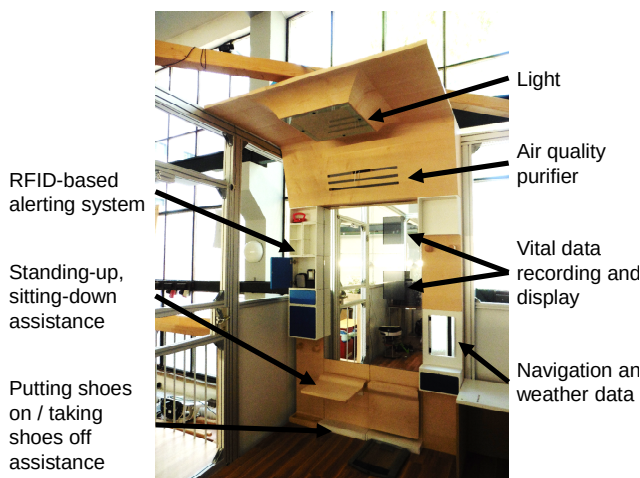


Fig.1. The entrance “Terminal”, L.I.S.A.⁵

This study was held as an implementation in experimental house at the Technical University of Munich. This house is built in Prof. Bock’s laboratory, and it has entrance space, living room, bed room and bath room. Except the bathroom, there is no wall. There are eight steps toward the entrance door, and the entrance door is simply composed of steel frames, as it can be seen in Figure 2. The Kinect v2 by Microsoft (Figure 3) was used in this study. To acquire RGB, depth, and also IR consecutive images as an animated film, in order to create 3D models by combining these data. Moreover the Kinect v2 has a skeleton tracking function, face tracking function, and microphone arrays. In this study, skeleton tracking and depth data for knee position acquisition, and face tracking and IR images for face recognition were respectively used as shown in Figure 4.



Fig.2. Experimental ambient assisted living laboratory

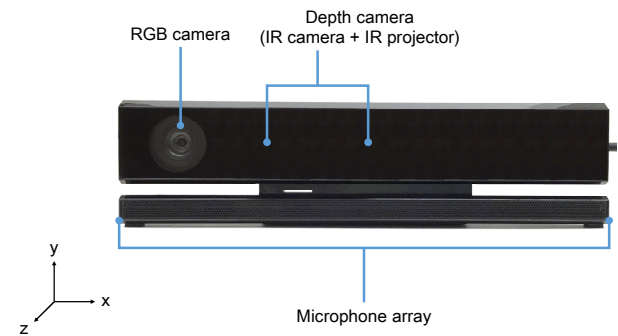


Fig.3. MS Kinect v2

PROPOSED KNEE POSITION ACQUISITION ALGORITHM

The knee position of stair walking acquisition system was used in order to estimate the resident's fatigue level upon arriving home. It is meaningful to be aware of the resident's condition upon arriving home. If they are really tired then the system can warn and notify them upon their condition in order to prevent potential accidents.

Kinect v2 can detect up to 6 people's bodies. It can not only detect human body, but also mark the 25 different joint points. The available range of this function is limited in 4.5m from Kinect, but the entrance

approach of experimental house was within the range, so the efficiency of the system was not questioned.

Firstly, the knee position of stair walking was retrieved by directly using the skeleton tracking function. The visualized joint position marks are shown in Figure 5. According to the original knee position, it is clear that it does not correspond to the actual knee position. Thus, the knee position correction was proposed based on following two facts after considering stair walking.

- Fact 1: The true knee position is always between the knee position and the ankle position which are given by Kinect v2.
- Fact 2: The true knee position is always the forefront of forward movement in the part of the foot.

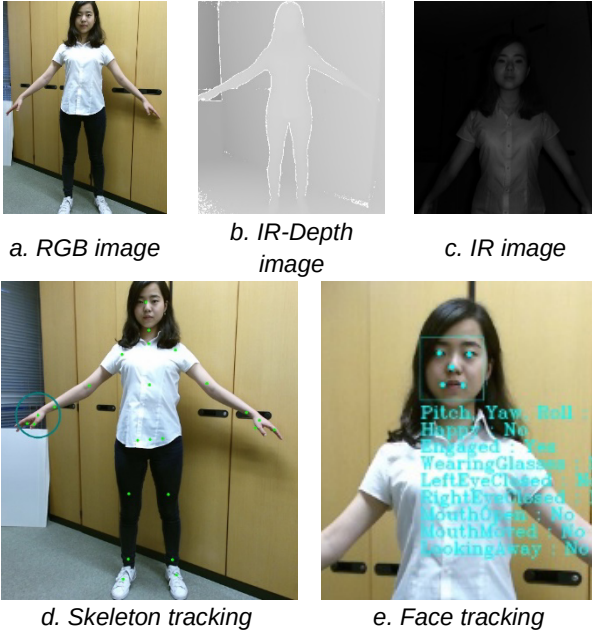
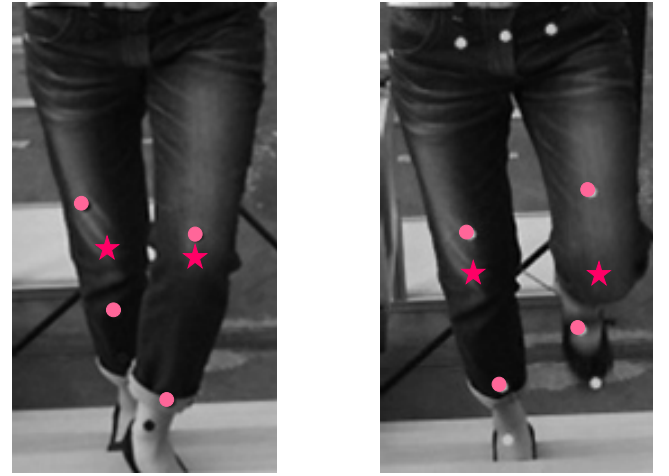


Fig.4. The main function of Kinect v2



Fig.5. The original joint position of Kinect v2



● Knee and ankle position of Kinect v2
★ True knee position

Fig.6. Fact 1: The true knee position is always between the original position of knee and ankle

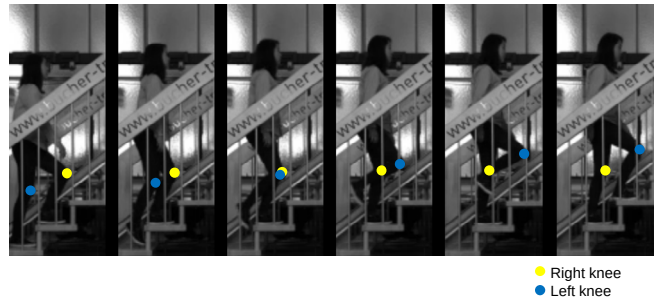


Fig.7. Fact 2: The true knee position is always the forefront of forward movement in the part of the foot

Then the knee position correction algorithm was implemented which is based on the knee and ankle position provided by the Kinect. Firstly, the 3-D value of the knee and ankle position is obtained. Then the straight line from the knee to ankle position is calculated according to equations (1), (2) and (3). At this time, only y-z plane is considered.

$$y = mz + n \quad (1)$$

$$m = \frac{y_{Knee} - y_{Ankle}}{z_{Knee} - z_{Ankle}} \quad (2)$$

$$n = y_{Knee} - \frac{(y_{Knee} - y_{Ankle})z_{Knee}}{z_{Knee} - z_{Ankle}} \quad (3)$$

After that the points along the line on the x-y plane are examined one by one. Then the distance between the depth (z value) of each point and the straight line which connects knee and ankle position in the y-z plane is calculated. The equation of the distance between the line and each position is expressed in equation (4):

$$d = \frac{|y_i - mz_i - n|}{\sqrt{1 + m^2}} \quad (4)$$

Finally, the point which has the maximum distance from the straight line can be detected as the true knee position (Figure 8).

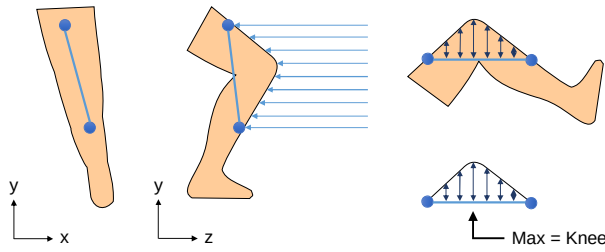


Fig.8. The algorithm of knee position detection

Applying this method, the accuracy of knee position was far revised. However, it is not always accurate because it is not sure that the Kinect will always get the knee and ankle position. Thus the algorithm consists of a 3-step correction in order to predict the true knee position more accurately. The first step is already explained above, depending on the knee and ankle position by Kinect v2.

The second step was developed for the case the calculated value was incorrect. Incorrect value can be considered a value which is extremely small, extremely large, or out of range. All those values are rejected by a proposed filter. In particular, the value will be recognized as an incorrect value when the z value difference of the calculated knee and spine base is more than 1000mm. Sometimes it was observed that the value of the specific position could not be obtained. Especially this kind of error is occurring when hands and feet are being detected reducing the accuracy of the algorithm. On the other hand, the most stable joint position is the spine base. Therefore, the difference with spine base was used in the proposed implementation. The true knee position will be the smallest value selected in the area of the rectangle which consist of the knee and ankle x and y position (Figure 9).

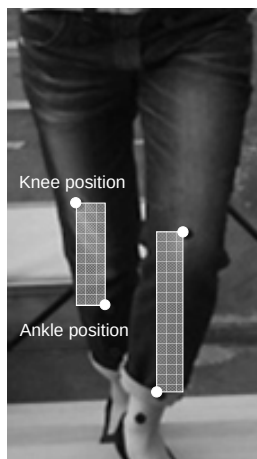


Fig.9. Range of knee detection for 2nd correction

Finally the third step is proposed in the case no or incorrect values of knee and ankle positions are

given by Kinect. Same as the second step, the value will be recognized as an incorrect value when the z value difference of the knee or ankle and spine base are more than 1000mm. The program is written to find the true knee position by using spine base, spine left, spine right and neck to define the range of the rectangle. And find the minimum depth value inside of the range. In particular, the definition of the range of rectangle is shown in Figure 10. The y distance is defined as half of the y distance between the neck and the spine base. And the x distance is defined as the x distance between spine base and spine left or right centering on spine left or right.

The overall proposed 3-step knee position detection algorithm flowchart is shown in Figure 11.

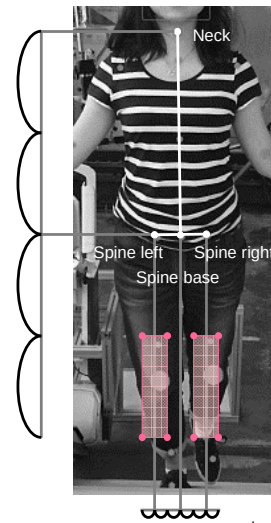


Fig.10. Range of knee detection of 3rd correction

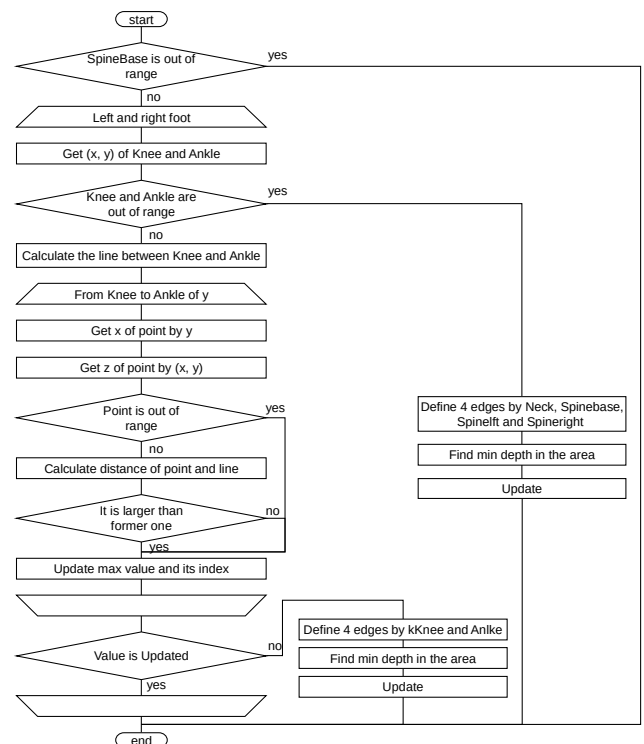


Fig.11. Proposed knee position detection algorithm flow chart with 3-step correction

PROPOSED FACE RECOGNITION METHOD

The face recognition based door opening system was placed on the entrance door of the experimental house. Thus, it will be held after the knee position acquisition. Normally depth data should be used for sensing because of the privacy protection in living space, which is a very personal place and hard to accept putting cameras inside. However, this face recognition system is supposed to be used in front of the entrance, which means outside of the house just like an intercom, so that there is no need to consider about resident's privacy because outside of the house is no longer public space. Therefore RGB, IR-depth or IR images can be used in this sense. In the proposed implementation only RGB and IR images were used for the face recognition function. Firstly, RGB images were used, but in the feature extraction phase, due to the fact that the features in the images depend on the lighting condition, the accuracy was unstable (Figure 12). Therefore, IR images were used instead. The proposed face recognition flow consists of four phases: 1) Face detection, 2) Feature extraction, 3) Read of database, and 4) Identification of the person.

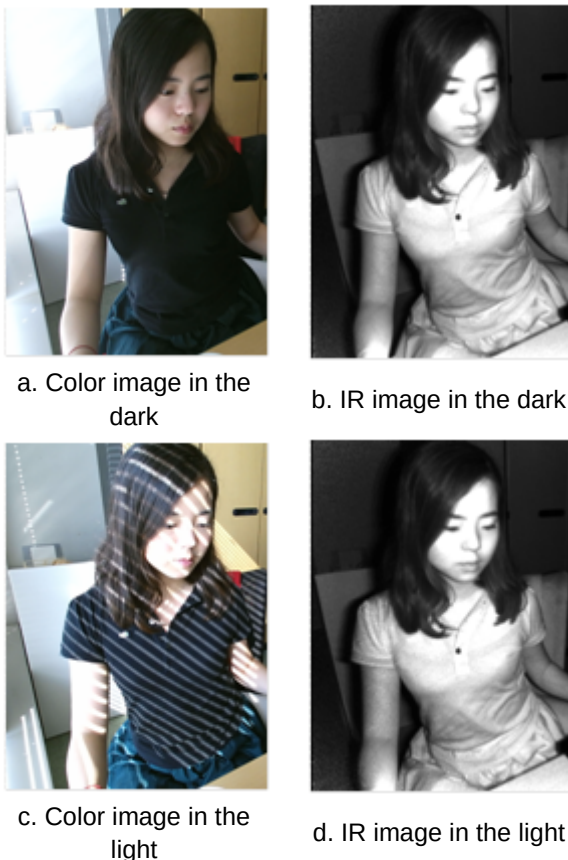


Fig.12. RGB images are affected by the light condition whereas IR images are not

Face detection

As we mentioned before, Kinect v2 has the face tracking function which actually works based on the

skeleton tracking function, i.e. it can detect the face automatically. Therefore, this function was directly applied.

Feature extraction

Here the Local Binary Pattern Histogram^{6, 7} was used as the feature extraction method of the face recognition.

Local Binary Pattern Histogram is one of the local feature descriptor and is widely used for face recognition⁸. Also, it is evaluated as a balanced feature extraction method at the point of accuracy and processing speed⁹. Therefore, we used LBPHFaceRecognizer provided by OpenCV.

Read of the database

Several JPG images were obtained of various subjects for the generation of the database and an Excel file was created listing the image file names. The size of the database was also concerned. The larger the number of images in the database, the higher the performance of the face detection algorithm, but the processing speed is slower, and vice versa. Eventually we collected three subject's images in the database.

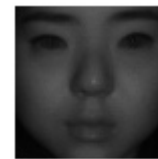


Fig.13. Example of JPG images in the database

Identification of the person

If the input image identified specific person who were saved in database previously, it means face recognition is done. The threshold of the classification after a series of experiments was empirically set to 50.0. If the distance from the feature value of the input image to any prototypes is larger than the threshold, the input data is rejected and the person is recognized as a "Stranger".

PROPOSED DOOR OPENING SYSTEM

Using an Arduino Uno microcontroller board interfaced with the door opening mechanism (Figure 14) as well as with the Kinect, following a successful face recognition result, the result could be used to enable a signal on the microcontroller's output to actuate the door opening mechanism. When the user's face is recognized as the resident, a logical '1' is enabled on a specific pin on the Arduino GPIO, which is used as a signal to drive the door opening mechanism. Also a green LED is lit for visual response. On the other hand, when the user's face is not recognized as any of the residents stored in the database, meaning the user is recognized as a stranger, a logical '0' is enabled on the GPIO pin. Additionally a Red LED is lit accordingly for visual purposes. With a logic '0' the door opening mechanism remains idle, i.e. the door remains closed. The

door operating system is programmed to close the door several seconds after the door opening.

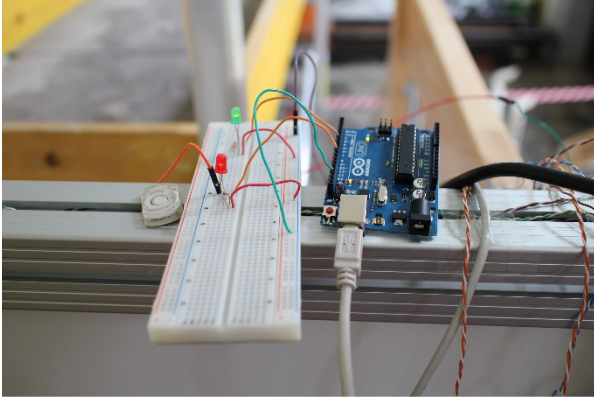


Fig.14. ARDUINO connection diagram

DEMONSTRATION

We conducted a demonstration in the experimental laboratory setting. The demonstration setup is shown in Figure 15. Kinect v2 was installed 1653mm higher than the top floor of stairs, and the field of view angle was set 34.3 degrees.

Both subsystems, knee position acquisition in stair walking and face recognition based door opening, were written in C++. A real scenario of the combined system was demonstrated at the experimental flat as follows:

- When Kinect detects a subject, the knee position acquisition of stair walking starts. The calculated data is accumulated temporarily.
- When the subject arrives at the door step (i.e. terminates walking), the knee position acquisition is interrupted and the face recognition algorithm initiates.
- If the subject is recognized as a resident whose face have been saved in the database in advance, the door opens automatically.

The trigger to switch from stair walking acquisition to face recognition is the distance between subject and Kinect v2. The distance is defined as the depth value of spine base position which is given by Kinect v2 and it was 1150mm.

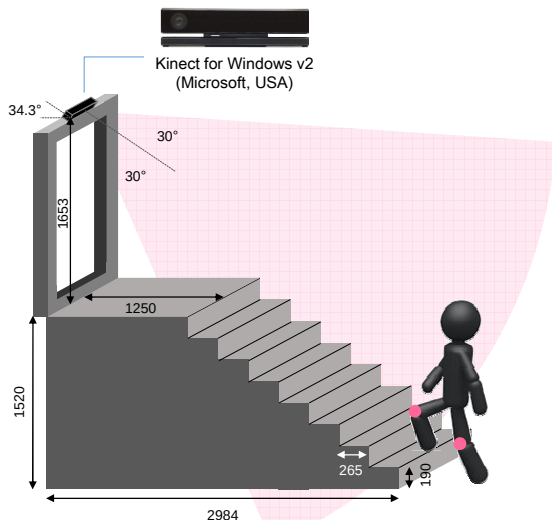
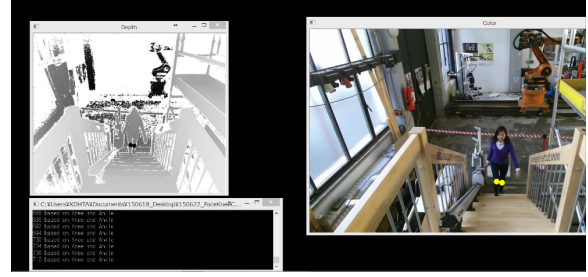
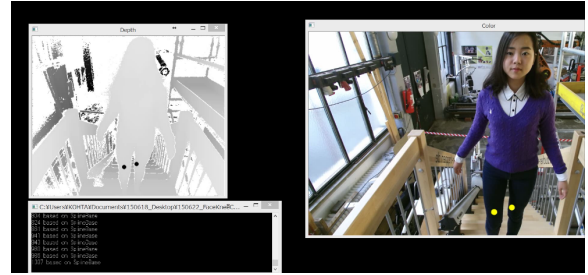


Fig.15. Demonstration setup



a. A subject is detected and knee position acquisition starts



b. Knee position acquisition finished



c. Face recognition starts



d. The subject is recognized as a resident, and the door will open

Fig.16. Execution screen of demonstration

CONCLUSION

In this paper, a system that offers knee position acquisition of stair walking and face recognition based automatic door opening is proposed. This combined system aims to predict both the mental and the physical fatigue of the resident upon returning home.

In the knee position acquisition phase, the authors proposed a novel algorithm of knee position estimation with 3-step correction. According to the acquired obtained result, the accuracy was undoubtedly increased.

Considering the face recognition phase, images of three different individuals were collected for the generation of the database. Here the number of images as well as the number of individuals was considered

for the trade-off between performance and processing speed. The system was installed and tested under realistic 1:1 scale in order to prove its possibility for realization. The position of the Kinect sensor in the experimental setup was extensively tested. Currently the authors are conducting accuracy verification experiments for both subsystems. As a future plan, the face recognition phase can be expanded to detect the mental fatigue level according to the facial expression. It is expected that the Kinect v2 detailed face tracking function can be exploited towards this goal.

About the knee position acquisition phase, the authors expect to predict the fatigue level by comparing the acquired data and accumulated data in the database, and then issue warnings and advices to the user depending on the fatigue level. Additionally the face recognition can be used not only to actuate the door opening mechanism, but also to access to the resident's personal database including gait data for this study. In this way the profile of the user can be retrieved in order to automatically regulate potential smart home devices such as lighting, air conditioner, aroma diffuser, music player, etc. according to the condition of the user, retrieved via the fatigue level etc. The authors also intent to interface the proposed system with the L.I.S.A. Terminal system to be able to seamlessly actuate its embedded devices depending on the user status.

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A Fatigue Detection System implemented in an Office Deployable Gateway based on Eye Movement

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This article is proposing a fatigue detection system on the basis of eye movement, implemented into a movable cover chair. The proposed system measures eye closure time and blinking rate to detect fatigue. These indicators are detected by applying image processing to IR images, using the MS Kinect sensor v2. Preparatory experiments were conducted to determine the position of the Kinect sensor inside the chair to detect eye information. The experimental results showed that eye movement can be measured accurately under the condition that the Kinect sensor was set at the eye level opposite from the user. Based on the result, the implementation of the proposed system into the chair was carried out, installing the Kinect and a personal computer at appropriate positions. Finally, this system was tested in a real environment with test persons sitting inside the chair. After the eye movement is measured and analysed, the fatigue is indicated in the computer screen. As a result, it was shown that this system could be feasible for the realistic use. Overall, this study constitutes a first step toward a more robust and accurate fatigue detection system based on multiple bio-information including respiration rate or heart rate, which could be implemented into this chair.

Keywords: *Fatigue, Eye detection, Kinect v2, Getaway*

INTRODUCTION

Detection and removal of fatigue is important for health and high work performance^{1,2}. Concerning releasing fatigue, LIQUIFER Systems Group has developed “Deployable Getaway for the office”, which is a chair with a mobile, ergonomic and transformable ‘cocoon-like’ structure that employees may utilize during the work day for the purpose of rejuvenation³. As a next step, a fatigue detection system to the chair was proposed for implementation. It is expected that combining a fatigue detection system to the “Deployable Getaway for the office” could provide healthier living for both office and home, especially for the elderly. Accordingly, this paper proposes a fatigue detection system implementation into the chair.

Previous studies on fatigue detection have proven that eye movement, especially eye closure time and blinking rate, could be used as index for the driver fatigue detection system⁴⁻⁶. Therefore, in this paper, eye closure time and blinking rate were considered as index.

Earlier studies proposed eye movement measurement systems using wearable cameras, which have high accuracy, though their usage might cause burden^{7,8}. In order to reduce the burden of a subject, other studies have focused on image processing methods to measure eye movement⁹. However, one issue is raised when applying such methods to our fatigue detection system: Image processing is easily affected by lighting condition. As it is dark inside the chair, it is necessary to deal with this issue. Thus,

image processing was applied to IR images, instead of RGB color images.

Preparatory experiments were conducted to determine the proper device and its position inside the chair to efficiently detect eye information. Based on the results, the Kinect v2 and a PC were installed to carry out implementation of proposal system into the chair. Finally, the performance of the proposed system has been tested to prove its performance.

PROPOSED FATIGUE DETECTION SYSTEM

The outline of the proposed fatigue detection system is shown in Fig. 1. First, the Kinect takes images of the user and detects the eye. If the eye is detected, the eye area is stored and a storage routine of images for 5 seconds is initiated. After enough images are stored, the eye is extracted from the stored images according to the obtained eye area. Then, the eye closure time and eye blinking rate are calculated using the extracted eye images. On the basis of this information, fatigue is detected and the result is shown on the display of the PC.

In this system, the Kinect V2 is used as a sensor. Kinect V2, shown in Fig. 2, mounts image sensor, distance sensor and microphone. Table 1 shows the specification of Kinect V2. As it could detect joints, another application is expected to be added to this proposed system in the future.

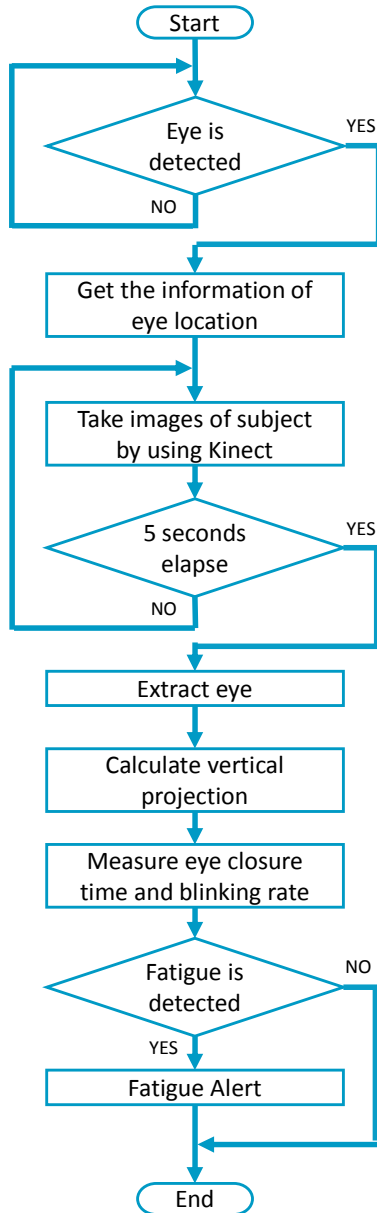


Fig. 1. Outline of proposed fatigue detection system

Table 1 Specification of Kinect V2

RGB image resolution	1920 × 1080 pixel
Depth image resolution	512 × 424 pixel
Measurable distance	0.5 ~ 4.5 m
Infrared viewing angle	Horizontal: 70° Vertical: 60°
Frame rate	30 fps
Skelton joints	25

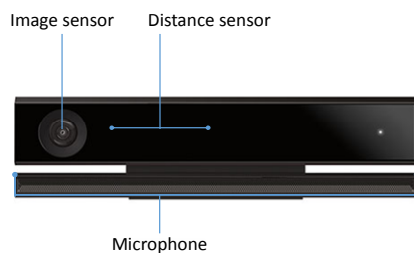


Fig. 2. Kinect V2

Eye segmentation

There are 2 methods for eye segmentation using Kinect V2. One method is done by the Microsoft Face Tracking Software Development Kit for Kinect for Windows (Kinect SDK). It could track human face including face expression and position of eye, nose and mouse. The other method is done using the Open CV library. It could perform object detection based on Haar-like features¹⁰⁻¹², by loading proper xml file as proper object detector (face detector or eye detector), the desired object included in image is detected. Accordingly, the face is detected by frontal face detector. Then, the eye is detected by eye detector from extracted face area so that it could enhance the accuracy of the overall detection algorithm. Experiments made a performance comparison between eye segmentation of Kinect SDK and that of Open CV. As a result, it was shown that the Kinect SDK method requires more than 1m distance between Kinect and a subject to obtain upper body's joints information, which is required for detection of face. On the contrary, in terms of Open CV method, eye could be detected even with a distance less than 1m. Moreover, it was observed that the smaller the distance was, the higher the accuracy. Considering the available limited space inside chair, it was decided that the Open CV library should be used for the proposed eye segmentation approach.

For robust eye tracking, the eye area is estimated based on the relationship between eye and face; when the eye is detected for the first time, the relationship between eye and face is stored as r_x and r_y as follows. The variables used in equations (1) and (2) are shown in Fig. 3. Number included in variables means frame number.

$$r_x = \frac{eye.x(1)}{face.width(1)} \quad (1)$$

$$r_y = \frac{eye.y(1)}{face.height(1)} \quad (2)$$

In terms of $eye.height$ and $eye.width$, they are defined as the certain values, assuming that a subject doesn't move forward and backward.

By using this relation, eye area can be calculated as follows even when only face area was detected.

$$eye.x(n) = r_x \cdot face.width(n) \quad (3)$$

$$eye.y(n) = r_y \cdot face.height(n) \quad (4)$$

As face detection could be performed with high probability (face detection succeeds more than 90 out of 100 frames), eye area could be calculated in almost every frame. Fig. 4 illustrates the proposed eye detection. It was observed that the eye is tracked and extracted properly even when the subject moves.

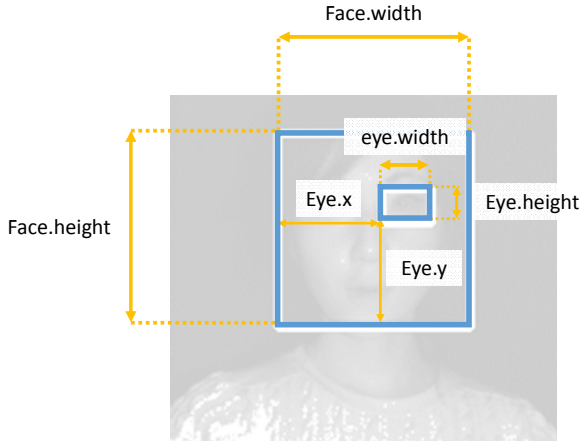
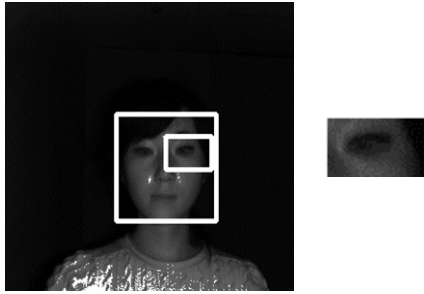


Fig. 3. Relationship between eye and face

Eye is detected



Eye is not detected (face is detected)

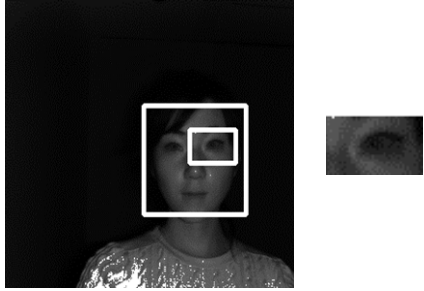


Fig. 4. Eye tracking method

Classification of open eye and close eye

In order to classify open eye and close eye, vertical projection curve was introduced. Upper right graph in Fig. 5 shows vertical projection curve of open eye, while lower right graph shows vertical projection curve of close eye. As shown in Fig. 6, the curve of close eye image is very flat, compared with the curve of open eye image. This will lead to a good judgement whether eye is open or closed.

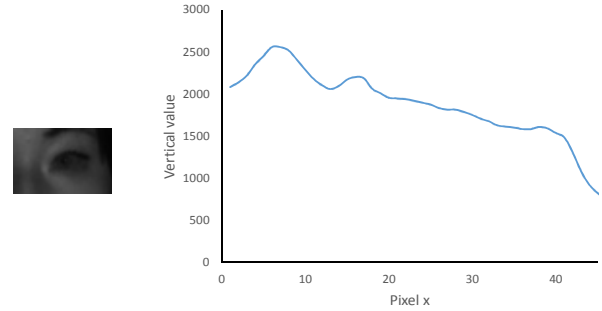
In order to decide the best way for determination, 5 *Change Factors*, variable to determine whether eye is open or closed, are introduced and compared with each other. The classification methods based on various *Change Factors*, represented as *CF*, are discussed briefly as follows.

Minimum value of vertical projection

In this method, *CF* is defined as the minimum value of vertical projection curve; the eye is judged open when *CF* is larger than the certain threshold, repre-

sented as *Thr*, while the eye is judged close when *CF* is smaller than *Thr*.

Open eye



Close eye

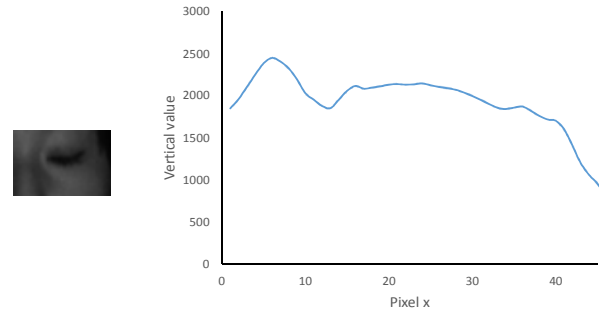


Fig. 5. Vertical projection

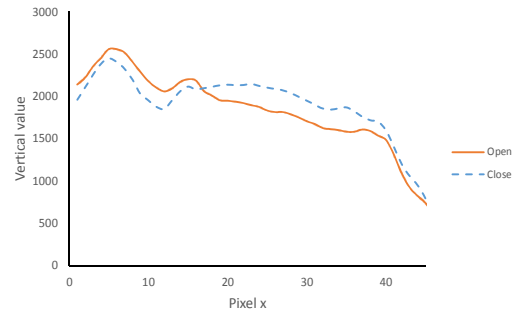


Fig. 6. Vertical Projection of open eye and close eye

Subtraction of minimum value of vertical projection

In this method, *CF* is defined as the subtraction of minimum value of vertical projection curve obtained from successive frames; it is judged the eye gets open when *CF* gets larger than threshold, represented as Thr_{open} , while it is judged the eye gets close when *CF* gets smaller than threshold, Thr_{close} . When *CF* is between Thr_{open} and Thr_{close} , it is judged that the eye is not changed its state.

Normalized subtraction

In the 3rd method, before calculating *CF*, normalization was applied to the vertical projection value. Then, *CF* is calculated as min or max value (with larger absolute value) of subtraction of vertical projection curve obtained from successive frames. The deci-

sion approach is the same as that of 2nd method; i.e. it is judged the eye gets open when CF gets larger than Thr_{open} while it is judged the eye gets close when CF gets smaller than Thr_{close} . When CF is between Thr_{open} and Thr_{close} , it is judged that the eye is not changed its state.

Subtraction 1st frame from the other frame

For the 3rd method discussed above, CF was defined as min or max value of subtraction of vertical project curve of successive 2 frames. In order to enhance robustness, in this method, CF is defined as max value obtained through subtraction of n frame's vertical project curve from 1st frame's vertical project curve. The way of judgement is the same as that of 1st method; the eye is judged open when CF is larger than Thr while the eye is judged close when CF is smaller than Thr .

Extraction of eye

As illustrated in Fig. 6, the vertical value of the original image is small at both ends. This is because nose and edge of face are included at both ends, which could lead to a large subtraction value with slight movement. The authors solved this problem by rejecting the area that could cause subtraction errors. Fig. 7 illustrates the vertical projections of the extracted open eye and closed eye. As shown in Fig. 8, the difference between open eye and closed eye is depicted more clearly.

Using obtained extracted eye images, CF was calculated as follows. First of all, vertical projection curve of 1st frame, represented as $V(1)$, and that of n th frame, represented as $V(n)$, are normalized with its max value:

$$f_{1dim}(1) = \frac{V(1)}{\max(V(1))} \cdot 100 \quad (6)$$

$$f_{1dim}(n) = \frac{V(n)}{\max(V(n))} \cdot 100 \quad (7)$$

Change Factor of n frame, represented as $CF(n)$, is calculated as max value of subtraction between these values:

$$CF(n) = \max(f_{1dim}(1) - f_{1dim}(n)) \quad (8)$$

In order to determine the threshold, Change Factor when eye is open (CF_{open}) and Change Factor when eye is close (CF_{close}) are calculated respectively below:

$$CF_{close}(n) = \max(f_{1dim}(1) - f_{1dim}(n_{close})) \quad (9)$$

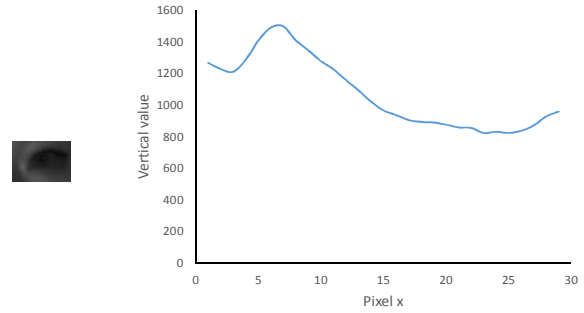
$$CF_{open}(n) = \max(f_{1dim}(1) - f_{1dim}(n_{open})) \quad (10)$$

Based on these values, $Threshold(=f_{thr})$ to determine whether eye is open or closed is calculated as follows:

$$f_{thr} = \frac{1}{2} \left(\frac{\sum CF_{close}}{n_{close}} + \frac{\sum CF_{open}}{n_{open}} \right) = 20 \quad (5)$$

Using this value, the eye is judged open when Change Factor($=f_{ch}$) is larger than $f_{thr}(=20)$ while the eye is judged closed when f_{ch} is smaller than f_{thr} . Fig. 9 illustrates classification result with this method, which shows that this method has high accuracy.

Open eye



Close eye

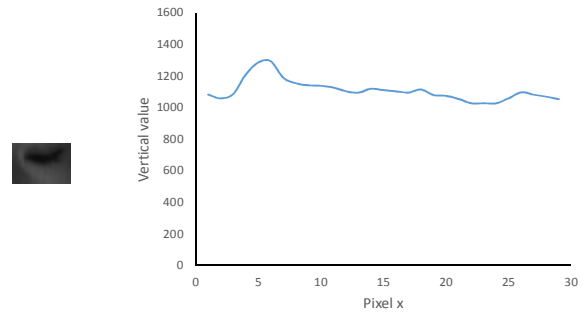


Fig. 7. Vertical projection of extracted eye image

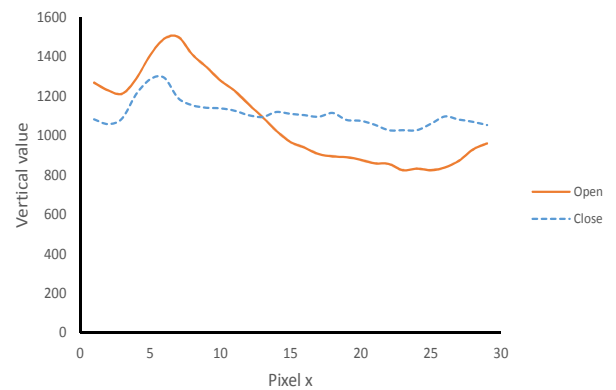


Fig. 8. Vertical projection of extracted eye

In order to compare these 5 methods, these methods are applied to data-set consists of 100 images with 1 blinking. Results are listed in Table 2. These results suggest that 5th method, extraction of eye method, is robust and useful.

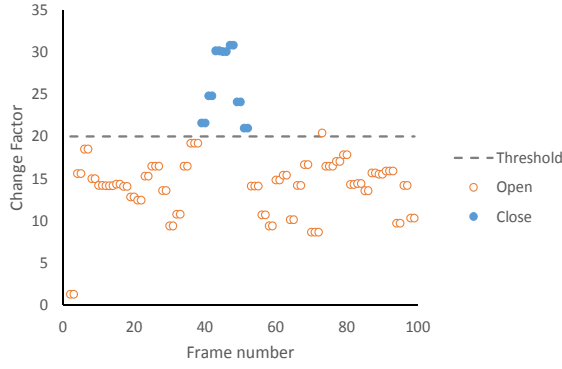


Fig. 9. Threshold to classify open and close eye

Table 2. Comparison of 5 methods

Method	Error rate [%]
Minimum value	36
Subtraction of minimum	45
Normalized subtraction	14
Proper subtraction	11
Extraction of eye	1

Fatigue detection

By using the method discussed above, the eye movement was measured. Fig. 10 illustrates a graph depicting whether the eye is closed or open. Based on this obtained information, blinking rate and eye closure time are calculated to detect fatigue. Fatigue detection used in this system is based on¹³; when eye closure time is more than 0.2 sec and eye blinking rate is more than 20 per min, fatigue is detected.

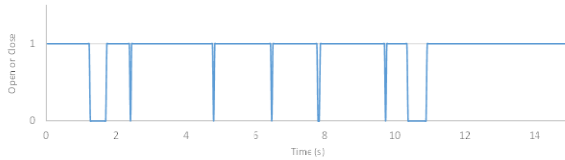


Fig. 10. Eye information (open or closed)

PREPARATORY EXPERIMENTS

Consideration of device

In order to run fatigue detection system, a device to acquire images even in dark scenes is required. Indeed, it could be theoretically possible to install lighting inside the chair and use RGB camera instead. However, considering time and difficulties that might take, it is plausible to introduce an IR camera that could still function in low light conditions. The Kinect V2 comprised an adequate candidate for the proposed implementation considering its performance. However, the slightly increased cost compared to the Kinect V1, forced the authors to verify whether Kinect V1, which has lower performance and lower cost, could also efficiently perform in the proposed system.

Kinect V1, shown in Fig. 11, mounts image sensor, distance sensor and microphone. Specifications of KinectV1 are listed in Table 3.

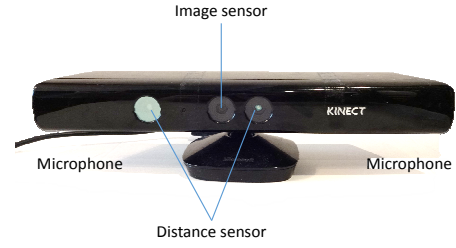


Fig. 11. Kinect V1

Table 3. Specification of Kinect V1

RGB image resolution	640 × 480 pixel
Depth image resolution	640 × 480 pixel
Measurable distance	0.8 ~ 10 m
Infrared viewing angle	Horizontal: 57° Vertical: 43°
Frame rate	30 fps
Skeleton joints	20

Experiments were carried out on the feasibility of the proposed system using the Kinect V1. First of all, the image of a subject is taken with Kinect V1. As shown in Fig. 12, noise included in the obtained image is too heavy to detect eye. Thus, 2 image processing methods are applied to reduce the heavy noise; “averaging” and “erosion and dilation”. Then, the eye extraction method is applied to the obtained images. First, averaging method is applied to the obtained image. As shown in Fig. 13, 3 images are created by averaging the pixel values over 25, 100 and 1000 frames respectively. However, the subject’s eye couldn’t be detected from these images.

Secondly, 1 dilation and 1 erosion method is applied to the obtained image. Dilation could connect divided area by making some areas larger with the certain shaped pixel. Erosion could make thinner some lines and get rid of minor noise by making some areas smaller with the certain shaped pixel. In the experiments, cross and ellipse were considered as the shape of structuring element. Resulting images are shown in Figures 14 and 15. Fig. 14 shows processed images using a cross shaped structuring element with different size while Fig. 15 shows processed images using ellipse shaped structuring element with different size. Then, eye extraction method is applied to all obtained images. However, it was found that eye couldn’t be detected from all processed images.

In conclusion, it was shown that image processing couldn’t reduce enough noise of image obtained by Kinect V1. Thus, these results suggested that Kinect V2 should be used for proposal system.



Fig. 12. Original Image obtained by Kinect V1

Frame number	Image
25	
100	
1000	

Fig. 13. Averaging with different number frames

Size	Dilation Image	Erosion Image
3×3		
5×5		

Fig. 14. Dilation and erosion (Cross)

Size	Dilation Image	Erosion Image
3×3		

5×5		
6×6		
7×7		

Fig. 15. Dilation and erosion (Ellipse)

Consideration of distance

To verify distance limitation, the experiments were conducted with several distances between the Kinect V2 and the subject; 0.5m, 0.8m and 1.0m. Results listed in Table 4 showed that eye was detected when Kinect V2 was set within 0.8m from the subject.

Table 4. Distance for eye detection

	0.5m	0.8m	1.0m
Face detection	✓	✓	✓
Eye detection	✓	✓	—

IMPLEMENTATION

Device

For the implementation of the proposal system, devices such as the Kinect V2 and a mini PC are installed into the chair. Specification of the mini PC are summarized in Table 5. Regarding the chair, LIQUIFER SYSTEMS GROUP has been taking on the “Deployable getaway” project, which refers to design of the space that provides space-efficient storage and a flexible set-up for more privacy. For example, “Deployable Getaway for the international space station” and “Deployable getaway for the office” have been developed¹⁴. For our implementation, the latter was focused. As shown in Fig. 16, it is a chair with mobile, ergonomic and transformable ‘cocoon-like’ structure that employees may utilize during the work day for the purpose of rejuvenation¹. It is supposed to be used in busy office environments as a workstation or a retreat from work and the office bustle. It could be used also in home to retreat from fatigue of the elderly. As shown in Fig. 17, closing the cover creates small and dark space before a subject where eye information is detected.

Table 5. Specification of PC

Windows edition	Windows 8.1Enterprise
Processor	Intel® Core(TM) i7-4770T CPU@2.50GHz
Installed memory (RAM)	8.00 GB
System type	64-bit Operating System, x64-based processor



Fig. 16. 'cocoon-like' structure

Cover is open



Cover is close



Fig. 17. Chair when cover is open and close

Installation

Before installation, experiments were conducted to determine proper position of the Kinect regarding the efficient detection of the user eye. As illustrated in Fig. 18, 3 positions (under PC, side PC and on PC) were considered. Experimental results showed that eye movement could be measured properly when the Kinect is installed on the PC monitor, at eye level relative to the user. Regarding distance limitation, preparatory experiment, discussed above, has shown that it is necessary that Kinect should be set within 0.8m from a subject for eye detection.

According to information obtained from these experiments, Kinect V2 and PC were installed properly. The chair with Kinect V2 and PC is shown in Fig. 19

Position of Kinect	Image
Under PC	
Side PC	
On PC	

Fig. 18. Position of Kinect for experiments



Fig. 19. Chair with Kinect and PC

Demonstration

The performance of the proposed system has been demonstrated to prove the feasibility. First, eye movement (eye closure time and blinking rate) is measured. When fatigue is detected based on obtained eye information, the result is shown on the monitor. Then, the algorithm moves back to the eye information measurement phase. Through this demonstration, it was observed that it could take time as measurement of eye movement and analysis of obtained information conducted alternatively. Thus, it is required to carry out measurement and analysis at the same time to save time.

CONCLUSION

In this paper, a system that detects fatigue based on eye information was developed and implemented in a chair which is supposed to be used as a 'isolating gateway' in busy office environments. The proposed system measures eye closure time and blinking rate to detect fatigue. These indicators are detected by applying image processing to IR images. Preparatory experiments were conducted to determine proper device and appropriate position of Kinect where it could detect eye movement of a subject inside chair. Experimental results showed that it was appropriate to set Kinect V2 on PC at eye level about 0.8m away from a subject. On the basis of this result, the Kinect and the PC were installed at the appropriate position to carry out implementation of proposed system to the chair. Finally, this system was demonstrated in a real environment, with real test persons. After eye movement is measured to judge whether the subject shows signs of fatigue, the result was displayed on a monitor in front of the subject.

Overall, this study constitutes a first step towards a more robust and accurate fatigue detection system based on multiple bio-information including respiration rate or heart rate. The improved fatigue detection system would be implemented into the chair. It is expected that combination of fatigue detection system and a fatigue relief chair could provide healthier life for both office and home.

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