An Adaptable AR User Interface to Face the Challenge of Ageing Workers in Manufacturing

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Abstract. In the last years introducing measures to face age discrimination and increasing work safety in production environments have become crucial goals. The present research proposes an innovative user interface exploiting Augmented Reality techniques to support frail people, mainly elderly, in everyday work on complex automated machines. It adapts its functionalities according to the user skill, tasks, age, and cognitive and physical abilities thanks to a set of knowledge-based configuration rules. A case study is described to illustrate the methodology to manage the complexity of configuration rules and the resulting developed platform.

Keywords: Human-computer interaction · Accessibility · User-centred design · Adaptation · Augmented reality

1 Introduction

Numerous studies claim that in 2050 more then one-third of the European population will be over the age of 65 and around half of workers will be aged over 50. The participation rates of older workers in production and operative roles will have an impact on economic growth and manufacturing efficiency because the mild deficiencies they are usually affected (e.g. reduction in sight, mobility, force, concentration, memory) can significantly decrease their performance and increase the risk of injury [1]. As a consequence improving the job quality, introducing measures to face age discrimination, increasing ergonomics and work safety have become crucial goals. Moreover, today processes in manufacturing become more and more automated and machines more and more complex to achieve short cycles and customized goods. Most of them embed computer-based and web interfaces. Despite the advantages, user interfaces (UIs) could represent a barrier for computer laymen and elderly people, acting as inhibitors to usage rather than facilitators as they are generally not appropriate, unfamiliar and acceptable for elderly [2].

In this context, the present research aims at developing an assisted production environment to support frail people working on complex machines by using an innovative human-computer interface that adapts its functionalities according to the user skill, tasks, age, cognitive and physical abilities. The implementation of set of

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knowledge-based configuration rules guarantees adaptation and easy information access. The interface is context-sensitive thanks to the implementation of Augmented Reality (AR) techniques to display the right digital information according to the workspace and the machine the user is in front of and to the tasks he/she has to perform.

The design of the Adaptable User Interface (AUI) follows a user-centred design approach, that starts from the identification of target users and the classification of their frailties, then analyses the context of use and the external events affecting human-computer interaction, correlates the identified user frailties with the UI elements to properly configure their features. Multiple interlinked 3D matrices are used to manage the complexity of the configuration variables. The overall system architecture is then defined and implemented. A preliminary system prototype is developed. Preliminary tests to demonstrate the AUI usability are carried out on a particular case study represented by tasks to control a wood working machine and perform ordinary maintenance on it.

2 Related Work

Nowadays usability and ergonomics issues have become crucial for manufacturing due to the increasing age of technical operators as a consequence of the aging trend of the global population [3, 4]. Contemporarily machines are becoming more digitalised and technologically advanced requiring high mental abilities that inevitably decrease with age [5]. In technological-oriented sectors the deterioration of health and functional status can strongly affect the job performance [6]. For instance, reduction in sight and memory can highly affect the user performance when high reactivity is required and the hard working conditions obstacle the use of glasses or the closing up to the target items. On the basis of literature review, four classes of frailties can be identified for elderly: visual, auditory, motor and cognitive. For each class, some accessibility problems can be defined and some solutions offered by traditional systems can be found in literature [6]. However, when machines are complex and require a very high-skilled interaction, the proposed solutions seem not be easily integrated in such machines and not appropriate for the elderly. In this context, the introduction of assistive technologies based on adaptable and adaptive user interfaces can positively benefit Human-Machine Interaction (HMI).

Adaptive User Interfaces (AUI) are defined as “systems that adapt what they displays and available actions to the user’s current goals and abilities by monitoring the user status, the system state and the current situation” [7]. They allow improving HMI mainly by offering a set of functions supporting the user in its own tasks in respect of usability design principles [8]. Practically, AUIs generally facilitate the user performance, minimize the need to request of assistance, help users in dealing with complex machines and avoid cognitive overload problems by conveying the right information to the user, both in case of able-bodied and impaired people. In the context of HMI, being adaptive means that the system is able to automatically adapt its features to the user in a transparent way [9]. In all cases the basic and distinctive characteristic of an AUI is its capability to dynamically tailor itself to the abilities, skills, requirements and preferences of the users, to the different contexts of use, as well as to the changing characteristics of users, as they interact with the system [10]. In order to be adaptive, the interface has to support the various "special" input and output data and dynamically reconfigure its main elements: (1) layout (colors, fonts, graphical compositions in general); (2) contents (information and data provided and managed at different levels of detail); and (3) feedback (interaction way to provide alerts and notifications). A good classification of AUI patterns and a deep analysis of adaptation mechanisms is provided by Nilsson [11].

A tool to make AUI context-sensitive is represented by Augmented Reality (AR), whose advantage is to overlays computer-generated information (e.g. textual data, 3D models, simulations, etc.) on the real world environment, enhancing the person's performance in and his/her perception of the world [12]. The displayed information and overlaid image are context-sensitive, which means that they depend on the objects recorded and recognized by a camera embedded into a portable and wearable device (e.g. web camera, Smartphone, Head-Mounted Display). Chi et al. [13] classified the AR enabling technologies in cloud computing environment for data management, localization technologies to identify the postures of subjects, portable devices and ubiquitous applications and finally natural user interface for the manipulation of digital contents avoiding communication via indirect input devices. One of the strongest and most promising application domains is actually manufacturing. AR can actually assist and enhance both manufacturing and product development, leading to shorter lead-time, reduced cost and improved quality. AR-aided manufacturing can be classified according to the activities connected with the production of an artefact (i.e. factory layout planning, robot control and programming, machine tools, measuring, testing and diagnose of parts, product assembly/disassembly, manipulation, transport and store devices, machine maintenance) [14]. Nee et al. [15] proposed an extensive overview of AR applications in manufacturing. The main critical aspects in AR-aided manufacturing concern both the technology and the application. Despite recent advances in technology, most of AR systems are laboratory-based implementations. Crucial technological challenges regard real-time tracking and computation, synchronization and related latency between real and virtual worlds, realisms of displayed objects, the performance of mobile devices and the usability of current HMD [15].

3 The Adaptable User Interface: From Design to Prototyping

3.1 The Interaction Design Approach

The proposed approach derives from the findings of Lee et al. [16] that successfully used a Quality Functional Deployment (QFD) correlation method to map the UI design components with the user needs of able-bodied persons. However, in the present research the correlation has an additional degree of complexity due to the elderly frailties to be taken into account and to the operational context that is represented by production machines. To solve this problem correlation is set into a 3D space made of the three main elements characterizing Human-Machine Interaction. These elements are the User, the Interface and the Environment. They lie respectively on x-y-z axes (Fig. 1). Each dimension is then the result of further correlations among elements defining them. For instance, the User dimension is achieved by relating the user frailties with the individual profile determined by his/her skill, education and age. The Environment dimension is defined by the context of work and the tasks to be performed.

The combination of the three dimensions results into a set of configuration rules able to adapt the interface features in a dynamic and interactively way. Rules derive from the correlation among user characteristics (e.g. age, frailties, skills, education), context of use (e.g. machine control, maintenance, assembly, training) and machine environment (e.g. tasks, position, external events). They are logical relations able to dynamically set the interface item characteristics and their degree of freedom considering the interaction style, graphics, dynamics and semantics (e.g. colour, icon and text size, shape, relative position, audio feedback). In this way when the operator posture and its position are recognized by the AR localization technologies, the system is able to link the tasks to be executed and as a consequence the contents to be displayed and then to infer which items of the interface will be used and reconfigured to be appropriate for use.

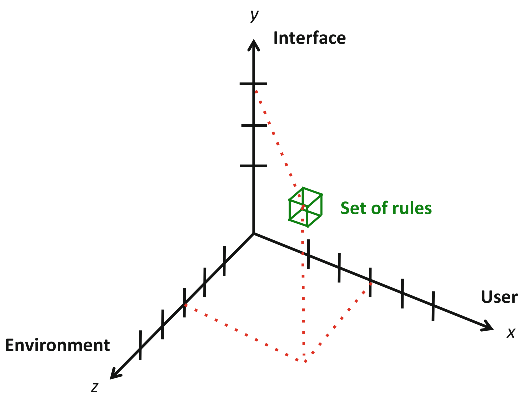

Fig. 1. User-interface-environment space for AUI

As mentioned before, a set of matrices are used to decompose the problem into different steps, each of which manages a set of data that are related each other by means of a specific correlation matrix as summarized in Fig. 2.

The first step regards the definition of the User characteristics dimension (i.e. x-axis). For that purpose it is necessary the fulfillment of Matrix 2, correlating the user profile, set in Matrix 1, and his/her frailties. A user profile is determined by his/her skill, education and age. Each kind of information is categorized into a 5-point scale, where 1 is the lowest level and 5 is the highest level, according to the Likert scale method [17]. The categories proposed in this study are described in Table 1.

The next step is the correlation between the user profile and his/her frailties (i.e. Matrix 2). Frailty classification is based on the model proposed by Clegg et al. [6] that consists of four classes: visual, auditory, motor and cognitive. The frailty classes and categories considered for this study are shown in Table 2.

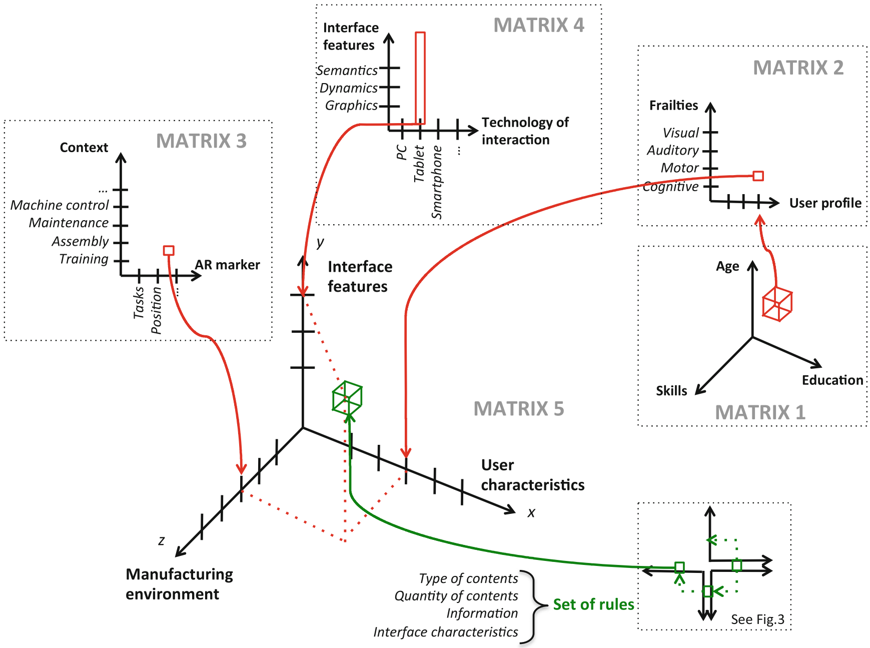

Fig. 2. Research approach for AUI in manufacturing

Table 1. User characteristics categorization

User characteristic	Categories				
	1	2	3	4	5
Skill	Difficulties in using digital / web interfaces ad interacting with technology	Basic use of digital / web interfaces (only)	Medium use of digital / web interfaces (with low knowledge)	Good knowledge and use of digital /web interfaces	High familiarity with technological devices and digital /web interfaces
Education	Elementary school	High school /college	Master / degree	Technical master / degree	Master /PhD in technical disciplines
Age	Over 70	65–70	55–65	40–55	18–40

The second step regards the definition of the Environment elements (i.e. z-axis). The environment is determined by the context of application (e.g. layout planning, maintenance operations, machine control, assembly) and the specific location of the operator in the factory, in front of the machine and its parts, within specific areas of the plants, etc. Both data are useful to the definition of the tasks the operator has to carry out and the information he/she needs for task execution. The localization technologies used in AR applications can be used to identify the user position in the factory. An example of localization technologies that can be exploited for the research purpose uses optical tracking and AR makers. AR markers are two-dimensional symbols that can be placed on key surfaces in the factory (e.g. on the wall, on an assembly bench, on the floor, etc.). They allow a camera generally mounted on a certain operator's equipment (e.g. protection glasses) or embedded in the tablet or Smartphone an operator has, to determine position and rotation relative to a surface. These data are then used both to define the user location and at the same time to superimpose 3D models or digital information at the AR marker. The fulfillment of Matrix 3 with the above-mentioned elements allows the determination of the z-axis. The last step regards the definition of the Interface components (y-axis).

Table 2. Frailty classification

Frailty Classes /Categories			
Visual	Auditory	Motor	Cognitive
Long-sightedness	Minor hearing loss (26-40 dB)	Minor reduced mobility of legs	Anxiety disorders
Short-sightedness	Medium hearing loss (41–55 dB)	Medium-High reduced mobility of legs	Memory problems
Far-sightedness & Astigmatism	Medium-High hearing loss (56–70 dB)	Minor reduced weight lift (<25 kg)	Difficulties in concentrating and processing large amounts of information
Contrast Sensitivity	High hearing loss (71–90 dB)	Medium reduced weight lift (<15 kg)	
Color-blindness	Sever hearing loss (>90 dB)	Highly reduced weight lift (<6 kg)	

A human-computer interface and in general a UI refers to the modalities through which people interact with computational technologies. These include different data input and output devices [18]. Input is how a person communicates his/her needs to the computer (e.g. keyboard, trackball, finger for touch sensitive screens, gestures, voice for spoken instructions). Output is how the computer conveys the result of its computations and requirements to the users (e.g. display screen, sound and haptic displays). Due to the variety and complexity of means for communication, the analysis of the main interface components is limited to Graphic User Interfaces (GUI) for web applications [16, 19], as follows:

- Interaction style, which is the method by which the user and the computer communicate each other. Among them, three have been selected: (i) command line - it requires the user to press a function key into a designed entry area on a screen; (ii) menu selection - it is a set of options or choices from which the user must choose by using a pointing device or keystroke. Labels must be meaningful and understandable to be effective; and (iii) form fill-in - it is useful for easily entering and collecting information.
- Graphics, which refers to styling fonts, size and distribution of elements, colours and shape of icons and their relative position in the graphic interface area. In particular among graphics the research focus is on the following elements: Menu, Frame, Navigation bar, Icons and buttons, and Text. They can differ in terms of colours, size and arrangement.
- Semantics, which comprehends the used language, metaphors and meaning of the words in texts.
- Dynamics, which concerns the sequence of displaying a series of icons, texts as well as the modality to navigate across the information hierarchical structure.

According to the adopted I/O devices, the interaction style, graphics and dynamics can vary. For instance the frame of graphics will be different in case of touchpad or mobile phones. This variation is expressed according a 0–1-3–9 scale according to the following meaning:

0 – functionality not available;
1 – functionality implementation at low level;
2 – functionality implementation at average level;
3 – functionality implementation level at high level.

Such correlation is presented in Matrix 4 (Fig. 2). When the technology is defined, such features can be established and mapped on the y-axis in Matrix 5. Once identified the patterns of Matrix 5, the definition of the knowledge-based rules can start. Rules consider that the interface can be described by means of its logical sections or pages and, for each of them, a set of items are defined. The rules will indicate how such items will be adapted when certain conditions will occur according to the usual syntax of the *if-then-else* logics, which are common across many programming languages. For instance, the interface can be described by its main pages and page sections, and items can be changed according to specific conditions. The mechanism to define the set of adaptive rules is described in Fig. 3.

For a specific user with a particular role located into certain environmental, each interface item will be configured by a set of rules describing:

- *type of contents* to be presented by the interface (i.e. text, video, pictures, acoustic messages, etc.), that mainly depends on the specific task to be executed, the operator skills and role, the specific content of application and scopes, user frailties and finally the interface semantics;
- *quantity of contents* shown by the interface (i.e. full details, partial or minimum level of detail), that depends on the task to be executed, the user profile, the specific content of application and scopes;

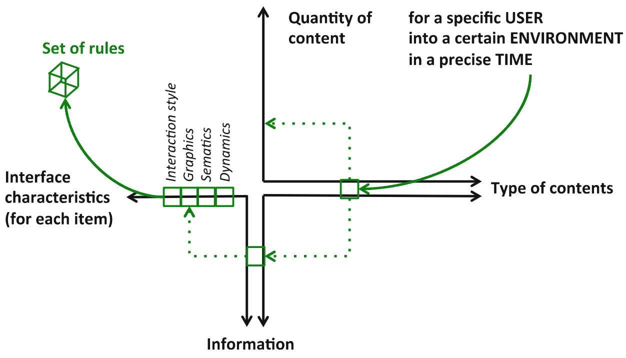

Fig. 3. Rules for the definition of the interface feature

– *information* to be displayed, that consists of data to be shown to the user depending on his/her role and education profile, the specific context and the tasks;
– *interface characteristics* for each specific item of the interface, that refer to how the interface features are configured in term of font, text, icons, color, navigation way (i.e. bigger font, higher contrast, red color, round shapes). They are mainly influenced by the specific user physical and cognitive frailties.

3.2 The AUI Architecture and the Preliminary Prototype

The overall system architecture is reported in Fig. 4. It implements the proposed methodology for UI configuration. It allows the reader to focus on the research objectives and to identify the main system modules.

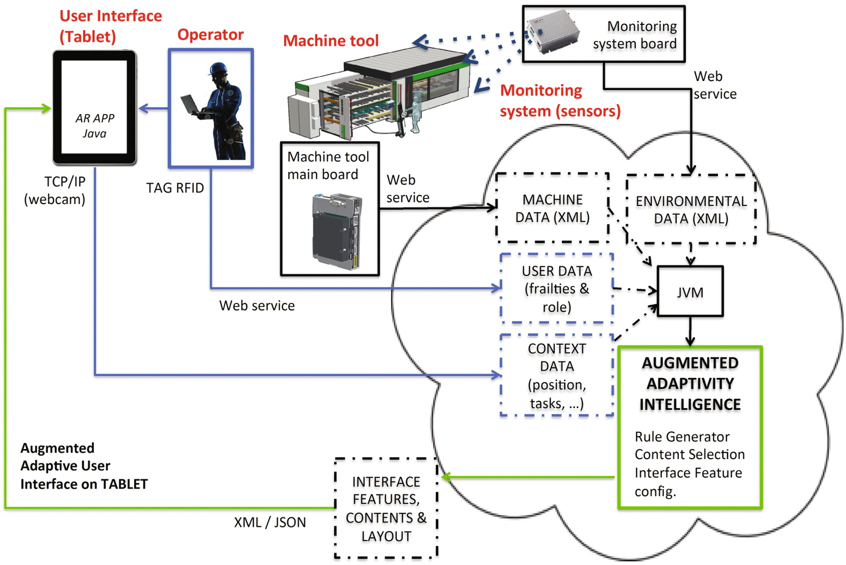

Fig. 4. Overall system architecture

The main modules are:

- a machine main board, that collects and sends data about the specific machine to a server by web services;
- a monitoring system board, that collects data about the manufacturing environment thanks to a dedicated sensor network and sends those data to a server by web services;
- a RFID tag placed on the operator, that monitors the user behaviours and sends data to the central system engine on the server;
- a web-based UI visualized on tablet, that represents the HW-SE user interface where adaptivity is enabled;
- an AR application based on Java to manage the tablet webcam and the Augmented Reality contents on the tablet interface;
- an Augmented Adaptivity Intelligence on the server side, that allows the data collected from the other modules to be managed, the knowledge-based rules to be created according to the proposed method and the interface features to be then configured. It exploits a Java Virtual Machine and web
- a Java Virtual Machine (JVM) to merge data and create/configure the web-based interface visualized by the tablet.

According to such architecture, a preliminary AUI prototype is developed. It is a web-based interface running on tablets that includes a commercial AR application, used by operators in manufacturing context. The system uses RFID tags to identify the specific operator and recover information about its characteristics (i.e. skills, age, education and frailties). In the case study, the machine tool is a machine dedicated to wood processing; it is composed by a loading-unloading area where the operator can load/unload the piece of wood to be processed, and a closed area within which the piece of wood is processed. All data coming from the machine are stored in the machine tool main board. A set of sensors are embedded in the machine to measure vibration and noise, smoke, and dust. All these sensors send data via wireless connection to the machine main board and the monitoring system board located close to the machine; from the boards data are sent via web-services to the central server. The Java Virtual Machine (JVM) on the server side accepts those data and interprets them through XML files that are parsed and stored into database. As soon as the interface webcam is activated and recognizes the AR marker, specific information about the position on the machine and/or the task to be performed are sent to the JVM. These data, combined with the user profile, are used by the augmented adaptivity intelligence to generate specific rules, select proper contents and configure UI features. These new data are sent back to the Augmented AUI trough XML and/or JSON files.

4 A Use Case to Assess the AUI Performance

An industrial case study offered by a large-sized company producing machines for working wood, metal and glass is presented in the paper to demonstrate the approach applicability, validity and potentiality. The industrial partner aimed to realize an AUI integrated in a pilot machine that assists operators with frailties in everyday task execution. In particular, the pilot machine is represented by a woodworking machine, which is living a rapid technological evolution but where the age of the operators is increasing due to the lack of new generations involved. According to the proposed method, the case study is described in terms of:

- *context*: machine control and basic operations for windows furniture production;
- *tasks*: tasks mainly consists of machine loading and unloading, labelling of the machined piece of wood and monitoring of the working conditions;
- *target users*: we consider an operator with a basic role (i.e. Op1), who takes care about the load and unload of the machine, machine status monitoring and alert identification. In our case he is a man of 60 years old (3) with a medium level of education (3) and high skills (5). About its frailties, he is long-sighted and cannot lift more than 25 kg;
- *interface features*: the features to be designed and adapted are described in Table 3. A set of sections are defined and, for each of them, a list of items to be configured in their graphics, dynamics and semantics when possible.

Table 3. Interface features to be adapted

Interface sections	Interface features
Header	F1. Multicolour status bar for environmental parameters
	F2. Multicolour status bar for machine parameters
Load /Unload main page	F3. Loading minutes
	F4. Information about the part processed
	F5. Part volume
	F6. Part weight
	F7. Load button
	F8. Unload button
	F9. Information about parts that have been already loaded
	F10. Label to be put on the part processed
Detailed information page	F11. Information about parts to be loaded next
	F12. Information about running process
Video control panel page	F13. Video about manual lading information
	F14. Video about automatic lading information
	F15. Video about machine internal movements
	F16. Video about machine external locking clamps
Detailed diagram pages	F17. Diagram of dusts
	F18. Diagram of steams /fumes
	F19. Diagram of sound pressure
	F20. Diagram of vibrations
	F21. Diagram of internal noises
	F22. Combined graphs
Multi-level pages	F23. Multi-level information
Alert	F24. Alert and warning messages

In order to preliminary demonstrate the AUI usability and acceptability, preliminary usability tests are carried out. 5 sample users aged from 60 to 65 are involved. At the beginning the machine is properly programmed; the users are asked to execute their tasks about Op1 functions. It means that they are asked to perform tasks such as (T1) Read the status of the environment, (T2) Read the status of the machine, (T3) Load/unload the parts, (T4) Read the next part label to be loaded, (T5) Supply staples and labels, (T6) Recognize an alert and its typology. During task execution a set of metrics are measured and ad hoc questionnaires submitted to the sample users. Quantitative metrics are as follows: execution time, number of errors or percentage, task completion. Qualitative metrics regard perceived simplicity in use and provided information comprehensibility. Judges are expressed according to 1–5 scale. Figure 5 shows a user involved in the experimental testing using the AUI on the tablet and collecting information about the tasks and environment by pointing the AR marker. As soon as the webcam of the tablet recognizes the AR marker (highlighted in the red circle), the system is able to automatically recognize if and when the operator has to load/unload a new piece of wood and help him/her during the operation by providing additional information (i.e. how to load or unload the piece in the right way, check to verify).

Fig. 5. Experimentation: AR application reading the marker positioned on the machine tool

From the results of the experimental phases, it can be stated that introducing assistive technology can really bring advantages to both operators and companies. Operators can work more safely and with better performances, and the company can benefit of the improved productivity. Table 4 shows the average results on all tasks for Op1.

Table 4. Usability test and results

Metrics	Unit. of meas.	Traditional system without AUI (average)	New system with AUI (average)	Improvement
Execution time	Sec.	45	33	−26 %
Number of errors	No.	5	1	−80 %
Task completion	%	60 %	85 %	+41 %
Simplicity in use	1–5 judge	3,0	4,2	+40 %
Comprehensibility	1–5 judge	2,8	4,5	+60,0 %
Order perceived	1–5 judge	2,5	3,9	+56 %
Intuitiveness	1–5 judge	2,1	3,5	+66 %
Pleasure in use	1–5 judge	3,0	4,6	+53 %

5 Conclusion and Future Work

The paper presents an approach for designing AUI to support elderly in using machines in manufacturing. The key element of this approach is the use of a set of 3D correlation matrices able to link the User, the Interface and the Environment and define then some knowledge-based rules to configure the AUI components. The proposed approach enables the interface to change itself on the basis of the user demands, his/her cognitive and physical abilities and the tasks he/she has to perform. The approach has been applied in case of wood working machines. A software platform has been developed and preliminary tested. Future work will be focused on the demonstration of the approach reliability by collecting further case histories and on the analysis of the platform usability and acceptability.

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