ManuVAR publishable summary
CP-IP 211548
July 09, 2012

An executive summary

Manual work (MW) is a central and expensive component of manufacturing, assembly, testing and maintenance services in Europe. There are many industrial sectors that rely on the knowledge and skills of their manual workers, e.g. spacecraft assembly, maintenance of nuclear reactors, operation of complex machinery, design and manufacturing of highly customized products. In these sectors, MW constitutes the core operations and it cannot be off-shored or automated. According to Eurostat (2008), there are about 19 million people involved in the high knowledge high value MW in Europe, mainly as plant and machine assemblers and operators.

The ManuVAR objective is to provide a systematic technological and methodological system to support high knowledge high value MW throughout the product lifecycle (LC). The ManuVAR approach is based on a product LC management (PLM), and virtual and augmented reality (VR/AR) technology combined with the ergonomics methods. The following four main results have been achieved during the project.

1. Seven most prominent problem areas faced by European industries in the context of high knowledge high value MW: (1) hindered communication throughout the lifecycle; (2) poor interfaces; (3) inflexible design process; (4) inefficient knowledge management; (5) low productivity; (6) lack of supporting technology acceptance; (7) physical and cognitive stress.

2. Five industrial cluster cases including the scenarios, performance criteria for the evaluation of the laboratory trials and factory-floor demonstrations, business analysis, economic impact forecast, training, and technology transfer plans: (1) support of spacecraft assembly; (2) manufacturing design for SMEs; (3) remote support in train maintenance; (4) training for industrial plant maintenance; (5) design and maintenance of heavy machinery.

3. System architecture that is characterized by several features*:*

- *Bi-directional communication* throughout system LC (e.g. workers' feedback to designers, designers' recommendations to the workers) is accomplished by means of "virtual model" (VM). The VM plays the role of a communication mediator – a single systemic access point to the variety of data, information, models on the system for all users in the LC – which is accessed as an integral system by "virtual experiments";
- *Adaptive VR/AR user interfaces* to the complex virtual model that fit all actors in the lifecycle: from workers to engineers and managers. The VR/AR interfaces is implemented by component reconfiguration with the low-delay middleware;
- *Four groups of ergonomics methods* to cluster the principal ways to improve manual work from the system-cybernetics perspective: workplace design, ergonomics evaluation, instruction delivery, and training;

4. Four reconfigurable application tools, which can be combined together via the VM to solve a given industrial case: (1) contextual instruction delivery: AR, tracking; remote and local versions; (2) ergonomics evaluation: automatic physical and cognitive load analysis, full body motion capture; (3) task analysis and procedure validation: hierarchical task analysis, VR with haptics; (4) motor skill training: VR with haptics, precision teaching theory.

Manual work is an opportunity for Europe because it relies on the knowledge and skills of people rather than on minimizing labor costs. ManuVAR has developed methods and tools to help industries to (1) increase productivity and quality and reduce cost of manual work in the whole LC; (2) facilitate adaptation to product customization and changes; and (3) support efficient knowledge and skill management and bi-directional data and knowledge flows through the LC.

A summary description of project context and objectives

Project context: high value, high knowledge manual work can be strength and an opportunity to improve the competitiveness of European industries.

Manual work (MW) is one of the most crucial and expensive components of manufacturing. In the era of globalization, lowering cost associated with manual work stimulates offshoring, global outsourcing and the efflux of the work places from the industrially developed countries to the developing ones. Offshoring and global outsourcing pose problems such as increased lead times and transportation costs, weaker management, lower quality, slower learning and adaptation and have a negative effect on employment in the developed countries. As Europe’s population is ageing, the situation will become more acute in future because of growing need for offshoring.

> The ratio of the EU population over 65 to the labor force is 36% in 2007, it will rise to 43% by 2020 and 68% by 2050 (OECD, 2007). The EU Lisbon Strategy aims at increasing the employment rate in the EU to 70% by 2010 and requires the EU workers “*to be more flexible and adaptable to cope with technological change, rapidly eroding skills and increasing global competition*”. Compared with the 1970-80’s, when “manual work” used to be a synonym of “unskilled work”, now the situation must change radically.

Manufacturing accounts for only a portion of the total costs associated with the system because the proportion of the manual work is also high at other stages of the system lifecycle (LC) – design, operations, maintenance, recycling.

> According to Metso Minerals, a heavy machinery manufacturer, up to 50% of their revenue is due to the maintenance operations (source: VTT’s own research). Following the EU end-of-life vehicle directive 2000/53/EC, 95% of cars will have to be recycled by the year 2015 and the costs are to be included in the price of new cars or to be covered by taxpayers. Offshoring does not help to reduce the costs of non-manufacturing stages.

Automation, along with rationalization and integration, is one of the methods for reducing the manufacturing costs. However, automation is mostly suitable for moderate or large batch sizes. Nowadays, when the growing level of customization and shortening product lifecycle result in smaller batch sizes and more varying products, it is difficult to redeem the investments in automation unless it is extremely flexible. Furthermore, there exist operations inherently difficult to automate, e.g. assembling unique aerospace systems, maintaining highly customized complex equipment, recycling a large variety of car models.

Here, the intelligence and adaptability of human workers make them the most flexible part of the manufacturing process and of the entire system lifecycle. But to utilize this flexibility and to sustain the challenge of global competition, the productivity and cost of manual work in developed countries have to be improved considerably.

Problem formulation: seven most prominent problems related to manual work

Several interview sessions were conducted in the five ManuVAR clusters among senior and middle management and workers. As a result, we identified the seven most prominent problem areas faced by European industries in the context of high knowledge high value MW.

These problem areas quoted below were published in *Krassi, B., D’Cruz, M., Vink, P., ManuVAR: a framework for improving manual work through virtual and augmented reality // Proceedings of the 3rd International Conference on Applied Human Factors and Ergonomics (AHFE2010), Miami, Florida, USA, 17-20 July, 2010, 10 p. ISBN-13: 978-0-9796435-4-5.*

1. *Problems with communication throughout the lifecycle.* This applies to the situations when MW is involved in two or more stages of the LC, but bi-directional communication between them is not efficient. For example, when the documentation or instructions become out-of-date or out-of-sync due to product changes (forward flow) or when a worker has to provide feedback on the MW operation back to the designers, but there is only a verbal or paper-based system to do it (backward flow). This problem area is also related to the organizational barriers within companies, when companies' information is managed by different information systems creating islands of information and knowledge.

2. *Poor interfaces.* This means when an actor in the LC has either too little or too much information (e.g. documentation, instructions), this information is not contextualized (e.g. instructions are not focused on the current operation, product, part, situation), or when information is delivered by an improper medium (e.g. paper manuals that are hard to use and that quickly get obsolete).

3. *Inflexible design process.* This refers to the situations when product design (and, therefore, the associated MW) cannot handle quickly changing requirements and frequent re-designs, in other words, the product design process is not agile. It is especially acute when the physical mockups are not available (expensive, inflexible, out-of-date), while virtual prototyping is not used sufficiently. As a result, there is a lack of knowledge of how MW should be made, e.g. what implications a product change has on the assembly instructions or the maintenance procedures.

4. *Inefficient knowledge management.* This problem area is related to formalization, capture, processing, archiving, bi-directional transmission and training processes for high knowledge high value MW. By absorbing the facts obtainable from this whole system (product, machinery, work, environment, tools), the human accumulates and brings up tacit knowledge and skills. However, it is extremely difficult to capture tacit knowledge and to formalize it so that it could be manipulated in the same way as information.

5. *Low productivity.* This is manifested in delays, idle time, non-productive work, low-quality and re-work, i.e. falls into the conventional non-lean setting.

6. *Lack of the factory-floor technology acceptance* regarding such technology as virtual and augmented reality, computer aided design and product data management – those are perceived as overly complex, expensive, unreliable, and difficult to use.

7. *Physical and cognitive stress.* This is related to the traditional subject of physical (health and safety, physical stress) and cognitive (mental stress, motivation, team work environment) ergonomics. While cognitive stress is more relevant to the focus of the project, physical stress (e.g. difficult working postured, hazardous work environment) should also be considered because it distracts the attention of the human from the high knowledge operations.

Objectives – technology platform and methodological framework to support manual work

The objective of the project is to improve specifically high value high knowledge MW that cannot be automated or offshored. To accomplish this, the project has to develop a platform and methodology in order to

1. Increase productivity and quality and reduce cost of MW in the whole system (product and process) LC;

2. Facilitate adaptation to system customization and changes;

3. Support efficient knowledge and skill management for all actors across the system LC.

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A description of the main S&T results/foregrounds

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Manual work (MW) is a central and expensive component of manufacturing, assembly, testing and maintenance services in Europe. There are many industrial sectors that rely on the knowledge and skills of their manual workers, for example, satellite assembly, maintenance of nuclear reactors, operation of complex machinery, design and manufacturing of highly customized products. In these sectors, MW constitutes the core operations and it cannot be off-shored or automated. According to Eurostat (2008), there are about 19 million people involved in the high knowledge high value MW in Europe, mainly as plant and machine assemblers and operators. Considering the entire product lifecycle (LC) from design to recycling, the number of people related to MW is even larger.

The ManuVAR objective is to provide a systematic technological and methodological system to support high knowledge high value MW throughout the product LC. It combines the best potential of the lean and agile models with the knowledge and skill management in the product LC. The ultimate goal of ManuVAR is to advance "beyond lean manufacturing" in order to

1. Increase productivity and quality and reduce cost of manual work in the whole LC ("lean");
2. Facilitate adaptation to product customization and changes ("agile");
3. Support efficient knowledge and skill management and bi-directional data and knowledge flows through the LC ("beyond");

ManuVAR research methodology is based on combining several disciplines: product lifecycle management (PLM), Virtual and Augmented Reality (VR/AR) technology, and ergonomics methods with the special focus on high knowledge high value manual work.

The project workflow includes the following stages: (1) analyze the similarities of the most prominent problem areas regarding manual work across the five industry domains; (2) design and implement a set of tools and methods to tackle these problem areas; (3) test the tools and methods in the laboratory conditions and, finally, demonstrate their viability on the factory floor.

The strong feature of ManuVAR is that it comprises five application clusters that cover a number of industry sectors. The clusters provide the factual basis for the requirement analysis and the real-life test-bed for evaluation and demonstration of the project results across several industries, Figure 1.

Figure 1. ManuVAR clusters: AR/VR for the terrestrial satellite assembly, low-cost VR systems for improving the assembly lines in small and medium enterprises, AR/VR-enhanced remote online maintenance support in the railway sector, VR for training on the nondestructive techniques in the industrial plant maintenance, and VR/AR in the heavy machinery productization and maintenance

The following four main results have been achieved during the project.

1. *Seven most prominent problem areas* faced by European industries in the context of high knowledge high value MW: (1) hindered communication throughout the lifecycle; (2) poor interfaces; (3) inflexible design process; (4) inefficient knowledge management; (5) low productivity; (6) lack of supporting technology acceptance; (7) physical and cognitive stress.

2. *Five industrial cluster cases* including the scenarios, performance criteria for the evaluation of the laboratory trials and factory-floor demonstrations, business analysis, economic impact forecast, training and technology transfer plans:

- *Cluster 1: Support of Spacecraft Assembly*. Develop and validate critical procedures in VR that can be used to support integration assembly activities through AR instructions.
- *Cluster 2: Manufacturing design for SMEs.* Support workers in assembly line by means of the automatic work load evaluation tool and reduce learning time by means of the operator navigation tool.
- *Cluster 3: Remote support in train maintenance.* Support the maintenance of complex systems by exploiting the benefits of AR technology and reinforcing the communication between the actors involved in the task.
- *Cluster 4: Training for industrial plant maintenance.* Training for Metallographic Replica activities using a Virtual Environment (VE) with visual, audio and haptic interaction.
- *Cluster 5: Design and maintenance of heavy machinery*. Assembly and maintenance design reviews and instructions.

3. *System architecture* that is characterized by several features, Figure 2:

- *Bi-directional communication* throughout system lifecycle (e.g. workers' feedback to designers, designers' recommendations to the workers) is accomplished by means of "virtual model" (VM). The VM plays the role of a communication mediator – a single systemic access point to the variety of data, information, models on the system for all users in the LC – which is accessed as an integral system by "virtual experiments";
- *Adaptive VR/AR user interfaces* to the complex virtual model that fit all actors in the lifecycle: from workers to engineers and managers. The VR/AR interfaces is implemented by component reconfiguration with the low-delay middleware (haptics, tracking, VR/AR visualization, application logic, connection to PLM systems);

- *Four groups of ergonomics methods* to cluster the principal ways to improve manual work from the system-cybernetics perspective: workplace design, ergonomics evaluation, instruction delivery, and training;
- *Knowledge management concept* is based on Nonaka's organizational knowledge creation theory, with each modality of knowledge creation supported: externalization and internalization (adaptive and natural user interfaces with VR/AR), socialization (bi-directional communication and the virtual model), and combination (linking in the virtual model and connection to PLM systems).

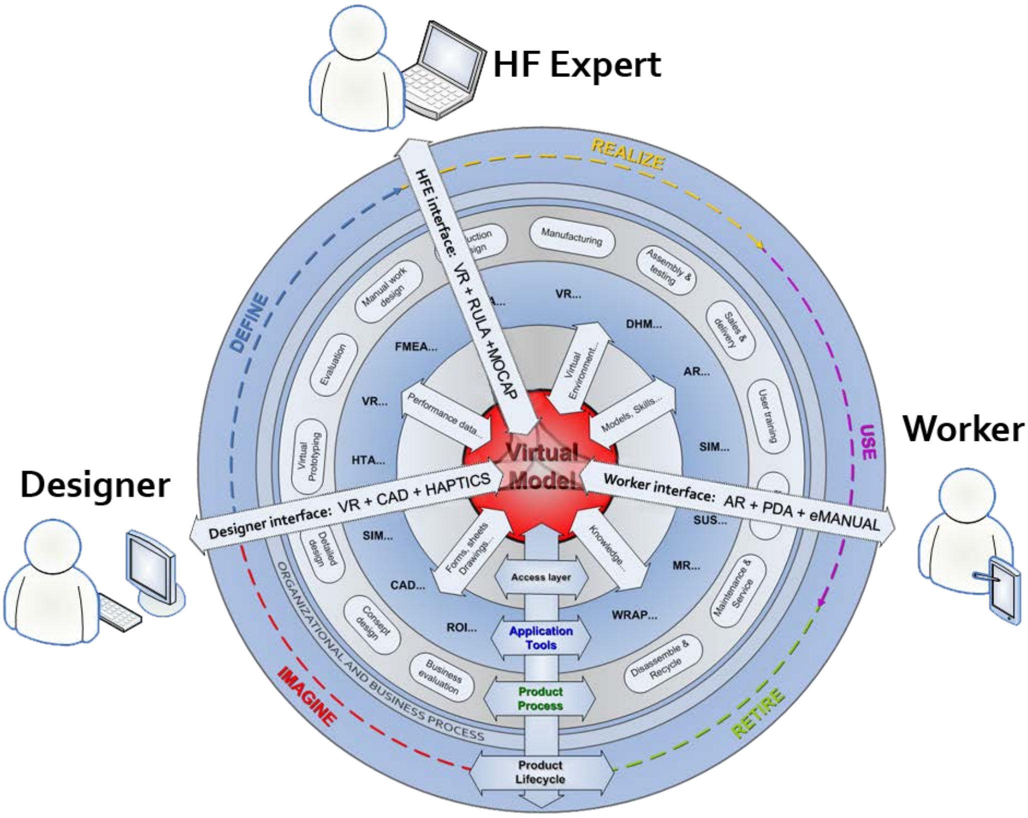


Figure 2. ManuVAR PLM model and the concept of bi-directional communication through the lifecycle. Several human actors (a worker, a designer and a human-factors expert) located at different stages of the lifecycle (outer layer), communicate off-line or on-line with each other via the virtual model (in the center). Each actor has a customized VR/AR-based view (user interface) to the shared virtual model. As soon as one actor affects the virtual model, all other actors are able to perceive the result. Compared to the process-driven communication in a chain, this communication is more flexible and it allows easier change management and synchronization among multiple actors. Source: ManuVAR consortium.

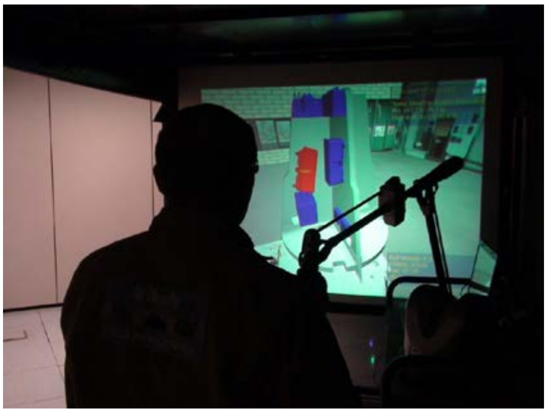
4. Four reconfigurable application tools, which can be combined together via the VM to solve a given industrial case, were designed, implemented and evaluated in the laboratory and in the company environment, Figure 3.

At the end of the project, during the combined three full calendar weeks of the demonstration activities, the clusters have actively engaged with around 110 workers, engineers, managers and customers, who had not been directly involved in ManuVAR. Also, 23 companies that were not partners of the ManuVAR consortium participated in the demonstration. The industry feedback was constructive and inspiring:

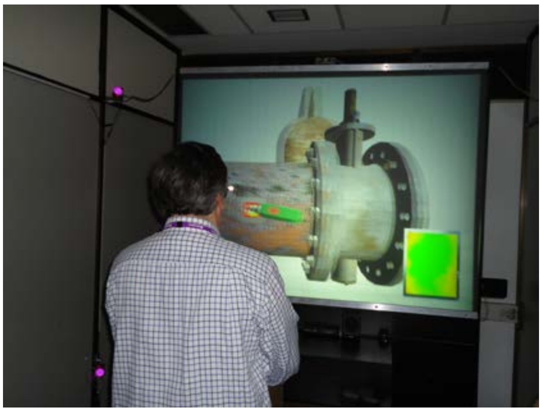
- “I think that training could be performed in less time, reducing ‘in-class’ training of trainers and thus, much more efficient with ManuVAR” [CEO]
- “Recording and analyzing postures and movements of operators will be accepted by those operators. By giving them the results and feedback immediately after registration, they will probably change their postures and movements” [CEO]
- “The connection to the company PDM would make possible to access/ use/ play to/with simulations and modify data models using an innovative recursive process rather than the normal waterfall approach” [CEO]

Contextual instruction delivery: AR, tracking; remote and local versions

Ergonomics evaluation: automatic physical and cognitive load analysis, full body motion capture



Task analysis and procedure validation: hierarchical task analysis, VR with haptics



Motor skill training: VR with haptics, precision teaching theory

Figure 3. ManuVAR application tools

Offshoring is a natural phenomenon. It will exist while there are large differences in labor cost. But European industries could turn their attention to the business that cannot be offshored, e.g. unique or deeply customized products, maintenance of fixed installations, operation and maintenance of machinery. This business is an opportunity for Europe because it relies on the knowledge and skills of people rather than on minimizing labor costs. ManuVAR has developed methods and tools for bi-directional communication and knowledge management for all actors in the LC, adaptive user interfaces with AR/VR, and application tools based on ergonomics methods improving high knowledge high value MW.

The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results

Wider social impact: the ManuVAR project reveals the potential of high value manual work for the European industries. There are common worries about an increasing global completion in terms of labor costs. But shifting the focus from the labor-intensive mass production to the type of work that cannot be offshored could help to ease the global pressures and to concentrate on something that Europe can really do well and should support – high value high knowledge manual work. ManuVAR has developed the technical and methodological basis for such a support as well as the evidence for the industries that this type of manual work, if properly organized and supported, may become their strategic global strength. The Europeans benefit from retaining and developing jobs in Europe and from the fact that there is a concrete mechanism how their knowledge and skills could be turned into the prosperity of the Union.

Business impact: at the beginning of the ManuVAR project, seven most prominent problem areas regarding manual work were identified. During the project, which was guided by these seven problems, the ManuVAR system was designed, implemented, tested in the laboratory conditions and demonstrated on the factory floor. The testimonials of the industry representatives, who were involved in the demonstrations, indicate that the ManuVAR system answers industry needs and has a high commercialization potential.

Problem area	***Industry feedback***
Support communication throughout the lifecycle	”It could be used for training operators, training within design, feedback from integration to design, and for improving critical… procedures” – *Engineer* “This is exactly what we need to provide efficient communication” – *Senior Manager*
Improve interfaces	“The system is a good advance in communication. It is clear that it eliminates confusion” – *Senior Manager*
Improve the design process	“With this system you may design a good workstation first time right, which is as important as the design of a new product” – *Engineer*
Enhance knowledge management	“Engineering and design issues are now discussed just internally among engineers. Using this system you bring operator, engineering and equipment supplier together. That will improve the discussion. Moreover you may immediately adjust the workstation design, based on the discussions” – *Engineer* “The remote maintenance support system will improve user capability for decision-making because you will be helped by people, equipment, optimized software” – *Senior Manager*
Increase productivity	“Not so many man hours wasted…both by people in the field and back at the office. The application would save us a ton of man hours. We would also improve customer service via the application. Also, the quality of our work would clearly be improved” – *Senior Manager*
Improve technology acceptance	”It is an innovative and interesting application that is easy to use” – *Trainee Worker*
Reduce physical and cognitive stresses	“I can clearly see the postures on the screen and this gives me the drive to improve the situation” – *Production Engineer*

Main dissemination activities:

- Applied Human Factors and Ergonomics conference AHFE 2010 (Miami, July 2010): special session on ManuVAR
- Joint Virtual Reality Conference JVRC 2011 (Nottingham, September 2011): exhibition booth and dedicated industrial track
- Web site www.manuvar.eu: central hub of all up-to-date material including news, results, videos, publications
- Posters and leaflets
- Social media: Twitter, Facebook, YouTube, and LinkedIn. YouTube was viewed by 3812 people, and the ManuVAR web site was visited by 3222 people. The ManuVAR Twitter had 492 Tweets; the profile had 1120 Followers and 1998 Followings
- Academic dissemination: the ManuVAR consortium had participated in 17 international conferences and industrial events and produced 51 publications including conference articles and posters, invited lectures and books. During the project 7 MSc and 1 BSc students graduated whose theses were related to the topics of ManuVAR. Among the project partners there was one PhD dissertation and there are still 4 PhD candidates who are expected to finalize their dissertation by the year 2013. Also two research exchanges took place during the project lasting altogether approximately 9 PMs
- Demonstration: the ManuVAR system demonstrated in five partner companies. During the combined three full calendar weeks of the demonstration activities, the clusters have actively engaged with around 110 workers, engineers, managers and customers, who had not been directly involved in ManuVAR. Also, 23 companies that were not partners of the ManuVAR consortium participated in the demonstration.

4.2.5. The address of the project public website, if applicable as well as relevant contact details

Project website address: www.manuvar.eu

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