Abstract:
This paper presents a virtual reality system in order to train operators on a complex machine for tire production. Physical benches are used to train the user on specific gestures, while a real control panel and a virtual environment provide a tire manufacturing interactive visualization. Implicit knowledge in a traditional plant is not often capitalized. That is why we assume that a knowledge basis integrated in the virtual environment will improve the competency level of the users. New metaphors have to be designed to interact with this knowledge basis.

Keywords: virtual reality, manufacturing, tire production, industrial process representation

1. Introduction

Manufacturing processes are more and more difficult to learn as one goes along with high technological products. Even if the technology improves the process, its human comprehension is often neglected and leads to the under exploitation of the systems. When examining training for manufacturing, several parameters are emerging:

- the increasing level of technological tools (numeric machines, automates, …)
- the lack of qualified operators
- the need to reduce the training duration

Western plants with a high production cost have to evolve quickly to remain competitive or will disappear. The impact of training on production is very heavy: reducing the length and improving the quality means reducing the production cost.

A virtual reality system can satisfy these requests and offers the possibility to free the real system for training, allowing by this way a productivity gain. A welding simulator developed for the AFPA (French Association for Technical Learning) named CS-Wave [1] trains the user to the technical gestures, and improves his understanding of invisible phenomena in the real world. Arévi [2] allows fire fighters to be immersed in fire or a catastrophe crisis through a virtual environment. Fiacre [3] is a system where high speed train drivers are trained on railway interventions.

Virtual reality is a good choice to show what is invisible, or what happens sometimes and cannot be induced easily. Using scnearii in the virtual environment, it becomes possible to propose a modular process representation in the usual and deteriorated modes. The dysfunction simulation is very rich to study the manufacturing problems, in order to perform a diagnostic and to understand the method to repair the dysfunction.

In this mind, we present our project RVPI (Réalité Virtuelle pour la Production Industrielle) presently designed at the University of Technology of Compiègne with the German tire manufacturer, Continental SNC France (Clairoix plant).

2. Virtual reality and manufacturing

Virtual reality takes an increasingly significant place in all the fields of the product’s design and its manufacturing (figure 1). We can include all these fields in the virtual-manufacturing [4]. Concerning the design, Mujber T.S. finds two disciplines: shape design concerns the visual aspects, and prototyping concerns the dimensioning and ergonomic aspects. Operations management with virtual reality may be divided in three fields of industrial activity:

- the first one is the planning which makes possible to envisage flows of production and to organize the various production stages
- the second one is the simulation as a mean of displaying results and sharing visualization
- the last one is the training where virtual reality allows tasks learning on a virtual machine without danger, stress and stops.

And the manufacturing is also divided in three fields:

- in first position, machining is used to evaluate the feasibility of a part of the design and the selection of processing equipment, and to study the factors affecting the quality, machining time and costs.
- assembly is used to reduce design cycle time, re-design efforts, design prototypes and predict the quality of an assembly, the product cycle and the costs.
- to finish, inspection is used to model and simulate the inspection process, and the
physical and mechanical properties of the inspection equipment.

Figure 1: Publications progression in manufacturing with VR systems from 1990 to 2005

Marinov V.R. [5] distinguishes design and manufacturing, considering that virtual manufacturing is only depending on the production process, and specifically on the virtual process. The last one is divided in several elementary manufacturing operations. He evaluates a virtual manufacturing system with several criteria: accuracy, precision and depth. Accuracy determines the deviation of the results obtained by the virtual manufacturing system from the results produced by the real system under the same conditions.

Tire manufacturing with VR is a new application to train operators on a complex and very expensive machine. Our main goal is the user understanding of all security and quality rules as well as the whole tire assembly process.

3. Tire manufacturing

To enforce security functionalities and comfort while resisting to aggressions (UV, wear, heat, etc.) a tire is composed of at least fifteen different gums [6], each one destined to a specific location: side wall, tread, innerliner, bead apexing, etc. Among the 75 to 80 products used for tire manufacturing, we can distinguish the natural gum (12%), the synthetic gum, silicium, carbon powder, oils (specially turnip oil which owns a plasticizing capacity and a resistance to low temperatures), sulfur for vulcanization, activators and accelerators to allow a better homogeneity of the mix.

The French plant of Clairoix (Oise, 8 millions of tires per year) of the German tire manufacturer Continental [7][8] develops with the University of Technology of Compiègne a virtual reality system to train operators on a complex machine. This high level semi-automatic machine assemble before vulcanization the external part of the tire, which means the carcass constituted with the tread and its internal part which serves as a tube.

Our VR system has been designed with a methodology of co-engineering between a research laboratory and the Continental production team. A systematic procedure has been used: knowledge extraction, validation, and implementation.

4. Co-engineering a VR system for tire manufacturing

According to [9] a design operation is constituted “a priori” by the scaling of a model whatever it is. The idea is that the design transforms a given state in another state via an operation which holds a repetition on one hand and a reduction on the other hand. When representing the machine there is an effort to synthesize all the parts in a computational way and to give different viewpoints to the user concerning some manufacturing, quality, and security points.

Designing a 3D model with a realistic behaviour means designing a model which is a repetition of the reality. A reduction of the model is therefore necessary to represent only what is needed for the user in order to memorize the process. The question of the precision degree of this representation needs to be carefully examined according to some criteria:

- manufacturing
- pedagogy
- computation
- shared visualization

The knowledge extraction in classical industries begins with the definition of temporal constraints in the process, recommendations for security and quality, manual or automatic tasks... The virtual environment provides a metaphor of these viewpoints. Each one is a reduction which focuses attention on an objective. We assume that every support is important: pictures, videos, sounds, physical benches, interactive animated mock up, avatars with realistic behaviour, real plant environment.

Designing this representation means a choice between what is visible and what is hidden [10]. The cognitive overload of the user with heavy and complex representations may be lowered with interactions. For example, all the information needed for one aspect of the process can be displayed if needed by the trainer or the trainee. Our method is to collect all the experts’ knowledge: production team, ergonom, VR expert in training, computer science and mechanical systems engineers. The procedures are extracted, the specifications are defined with all the actors, some media are realized, and these data are validated.
Then a technical description of the VR system is modelled and implemented.

Two different interfaces are provided:
- a VR interface where it is possible to navigate and interact in a virtual world.
- a “real” interface, the Control Panel connected to the VR system.

We describe the system in next part.

5. Description of the RVPI system (VR for industrial production of tires)

The physical process is not represented in the 3D scene; our goal is to understand the tire building process and the adjustments on the machine instead of simulating the physical assembly of tires.

This VR system is composed of two interfaces and a real bench (figure 2). The first one is an interface in 3D representing the operator's station (production machine and its environment), it looks like a video game (figure 3) or a “serious-game”, in which the operator’s aim is to produce a part of the tire. The second interface is the machine Control Panel; it allows the user to control the manufacturing machine in the real world and its numeric representation in the VR system. We suppose that our system is useful on the point of the comprehension of the machine functions, but not on the gestures training. We have therefore added to the VR system some “physical benches” (figure 4) in order to train the operator on specific tasks. On the virtual machine we can visualize the complete tire building process. This process can be carried out in a correct way or a degraded way. In the second case, we can modify several parameters of the machine to simulate a dysfunction, thus allowing the operator to learn how to adjust them.

The physical bench is used to train on technical gestures directly on material (here rubber). These gestures require a great dexterity which is not reproducible easily in the virtual environment. This bench is in fact an old generation machine part.

The system is composed of four modules (figure 5). The first one is a virtual visit to discover all the machine parts. The specific vocabulary and all the
functions for each part of the system are displayed. The second one concerns the process and is represented step by step. The third one presents the control panel to adjust some machine parameters. The last module simulates dysfunctions for diagnostic and adjustments on the control panel.

To design this system, we have adopted the methodology described in figure 6.

![Figure 6: designing the RVPI system](image)

We consider rubber matter kinematics included in the machine kinematics. The developments are validated with the trainers to optimize the system for each module.

### 6. Discussion

Our VR system is still in progress: dysfunctions scenarios are implemented, pedagogical notebooks are defined, and the modules 3 and 4 have to be completed.

However the first experimentations of our VR system in the plant are very encouraging, even if we do not have all the results: an evaluation (manufacturing, quality, security) of the completed training use with and without VR will be done next fall in the plant with different trainers and trainees. We have got some feedback from a first evaluation of the two first modules. This evaluation was done by seven persons, four operators (trainee), two trainers and one quality manager, on specific aspects of environment and production process realism. All final results were positive. The environment was considered representative of the real workplace. And the production process was perceived as a realistic process.

The most important difficulty in our project is to give the user some data resulting from many years of experience. Implicit knowledge (like dysfunction resolution) is not formalized, and the system evolves very quickly: each new trainee has to build its own understanding of the process and dysfunctions.

We plan to extract implicit knowledge for tire manufacturing and store it in a basis integrated in our VR system. A knowledge management concept can be defined as in a previous project [11] [12]. The idea is to capitalize manufacturing procedures, dysfunctions in the process, materials defaults, security and quality constraints, machine adjustments and workflow organisation in the virtual environment as a support for common representation and shared perception of the production. This system will be based on specific domain ontology (here on tire manufacturing). Many metaphors [13] can help the user to navigate in the 3D environment and in our case in the knowledge model. Knowledge capture related to the product and its use through a knowledge basis will be the first step of the project. New interaction metaphors for data manipulation and visualization will be proposed as a construction of meaning.

These metaphors [14] are supposed to guide the user in the virtual environment in order to reach concepts, criteria, data, annotations, project memory, operators’ experience and explore the tire building process from different viewpoints.

### 7. Conclusion and future work

We have designed a new VR system for training operators on a complex machine for tire building manufacturing. The system is composed of a real interface (control panel), a VR environment, and physical benches. Four modules are provided in
order to explore the virtual machine in a 3D environment, to interact with the virtual machine with a real control panel, to simulate and diagnose some dysfunctions, and to adjust the parameters precisely for a better security and quality constraints respect.

The perspectives of this work are to design new dysfunctions, to share a common VR system from distant sites, to explore knowledge capitalization for integration in virtual environment and to design interaction and visualization metaphors.

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8. Références


