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Implementation of Eye-Tracking technology in Holonic Manufacturing Systems

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Abstract

During the last decade, Eye-Tracking technology has been popular amongst practitioners and researchers from various disciplines. In spite of widespread applications of Eye-Tracking technology`, considerably less attention has been paid to the potential of this technology in manufacturing system. An holonic manufacturing system is a manufacturing system with high agility, which is an important characteristic for future manufacturing systems. This paper provides a theoretical overview and guidance for the implementation of Eye-Tracking technology in the holonic manufacturing system. The description of the Eye-Tracking technology and a brief discussion of potential application and the limitations is provided. This study discusses the implementation of Eye-Tracking technology as an holon.

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Keywords: Eye-Tracking, holon, holonic manufacturing system, holarchy

1. Introduction

The control of the manufacturing systems is a difficult task due to their complexity and large-scale size. In order to meet this challenges one of the manufacturing systems was highlighted by Arthur Koestler [1]. It explains how complex systems derive from the union of stable and autonomous sub-systems, which are able to survive turbulences and, at the same time, cooperate to shape a more complex system. According to Koestler in order to understand

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complex systems, it is not enough to study atoms, molecules, cells, individuals or systems as independent entities, but it is essential to consider such unities as concurrently parts of a larger whole; in other words, we have to consider the holon. The term holon is a blend of the ancient Greek "ὅλος" with the meaning of "whole" and the suffix "ὄν" meaning entity or part [2]. Holons are simultaneously part and whole. A holon can be part of another holon. Holons act as intelligent, autonomous and cooperative entities which work together inside temporary hierarchies called holarchies. A holarchy is a hierarchy of self-regulating holons functioning, (a) as autonomous (b) as dependent parts (c) in coordination with their local environment [3].

The application of holonic concepts to manufacturing was initially motivated by the inability of existing manufacturing systems (i) to deal with the evolution of products within an existing production facility and (ii) to maintain satisfactory performance levels outside normal operating conditions. The holonic manufacturing system concept combines the best features of hierarchical and heterarchical organization. It preserves the stability of hierarchy while providing the dynamic flexibility of heterarchy [3]. In an holonic manufacturing system, each holon's activities are determined through the cooperation with other holons, as opposed to being determined by a centralized mechanism. An holonic manufacturing system could therefore enjoy high agility, which is an important characteristic for future manufacturing systems. However, there still is no standard approach for companies to develop their holonic manufacturing systems as they often have unique and proprietary operational strategies and practices. It is stated that acquiring valid specification of system requirements has an increased influence on productivity and manufacturing performance. Technologies like Eye-Tracking and Virtual Reality can be considered a solution for such problems, as the user and the information support elements are put in direct relation with the operation of the system in a realistic environment [3].

Eye-Tracking is the process of measuring the point of gaze and has several applications in various fields like in aviation, driving safety, etc. Eye-Tracking is a great method to assess the eye movement (as a dependent variable) in the anticipation of stimuli (as an independent variable) [4] [5]. Visual search has drawn much attention from researchers, who have attempted to examine the observer's cognitive process with the vast amount of visual information. In this study this technology of Eye-Tracking has been implemented as a holon in a holonic system [6].

2. Holonic Architecture and Operation

The objective is to define a methodology and architecture to effectively facilitate the use of manual labor in modern manufacturing systems. The exchange and management of information, concerning task execution, performance and safety are some of the areas of interest. A holonic systems approach – which involves the division of a complex system into autonomous and cooperating functional entities (holons) – exhibit significant advantages for the facilitation of human workers as flexible resources. Figure 1. shows a holonic system based on PROSA architecture. Holons can also consist of a collection of holons, as shown for a human resource holon in Figure 2.

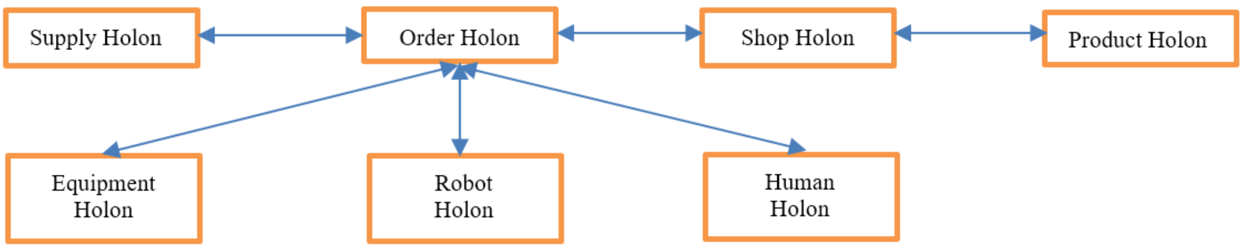

Figure 1: The holonic systems approach to a manufacturing System.

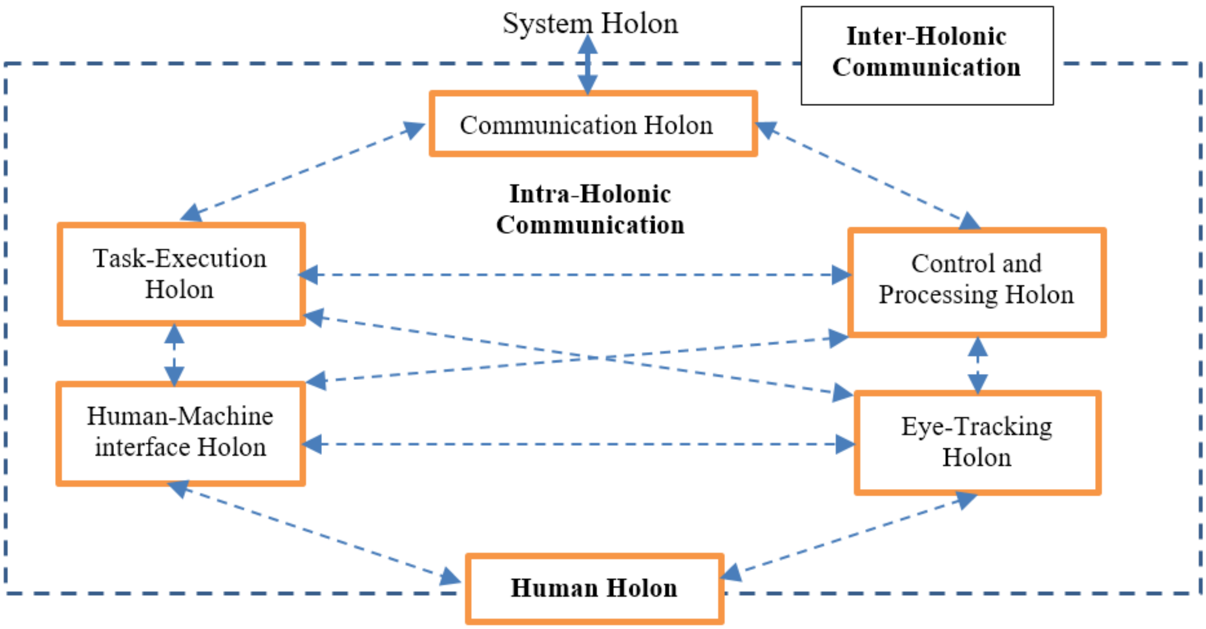

Figure 2: The holonic systems approach to a human worker as a resource holon.

To effectively exploit the flexibility and intelligence of human worker as resources, a challenge lies in the exchange of information. The incorporation of modern technology in the development of human-machine interfaces can present significant advantages.

Eye-Tracking technology presents several interesting advantages for the interaction of human workers with the manufacturing system. Previous research findings have proved and shown us the advantages in the fields like safety management, quality management, ergonomics, production development, design analysis etc.

The results from previous research findings provide us various parameters which can easily and successfully be adopted in a manufacturing system, such as: •

- Providing a mechanism to monitor worker safety [6].
- Providing feedback of the worker activity during task execution [7].
- Providing a means of validation (for quality assurance) [8].
- Improving productivity and value-adding [7].
- Providing a means of validation and analysis of design [9] [10].
- Providing a measure of usability [8].
- Providing new methods of automation control [11].
- Detecting worker fatigue and drowsiness [12].

These advantages can be encapsulated within an “Eye-Tracking Holon” with information exchange interfaces to the other holons within the human resource holon as shown in Figure 2.

3. Holonic Control

3.1 Control requirements

Here we take a look at some of the consequences of the new manufacturing requirements for the control, regardless of the actual design and implementation of the control system [13].

1. The architecture of the control should be decentralized and product-/resource-based.

For even small manufacturing systems, a centralized approach to control is practically impossible. There must be at least some kind of decentralization. In a resource-based architecture, every resource contains all control capabilities necessary to process jobs. In particular, a set of resources is able to allocate jobs to resources without a centralized support. The advantage of the resource-oriented approach is that the system can be changed and scaled up fairly easily. Furthermore, the control corresponds in its structure to the manufacturing system and thus reduces the complexity added by the control system to a minimum.

2. Control interactions should be abstract, generalized and flexible.

Maximum changeability, however, is only achieved if dependencies between resources are reduced to a minimum. In order to achieve maximum changeability, resources should be de-coupled in three steps:

- abstract interaction – make no assumption about the internals of other components
- generalized interaction – make as few assumptions about the other components behaviour
- flexible acquaintances and interaction – dynamically decide with whom and how to interact

3. The control should be reactive and pro-active.

In order to respond to short-term changes and disturbances, the control must be reactive. This includes the ability to recognize critical situations, make decisions about the reaction, and perform corresponding actions. Hence, a resource for an instance must also participate in the allocation of jobs or the sequencing of operations. As a result, the control must be reactive and proactive at the same time.

4. The control should be self-organizing.

The need to adapt the manufacturing process in the face of changes or disturbances will not only affect the resources, but also the organisation of the manufacturing process as a whole. Obviously, in a highly responsive manufacturing system, the organisation must be responsive too and this responsiveness should emerge from any (re-) configuration of the resources and rearrangement of the process.

3.2 Holonic Control activities

In this section, some works related to implementation for holonic control are presented. These works can be grouped into four categories of controlling activities [3]:

1. Work-order programming:

These approaches usually deal with an interaction scenario in which the holon is in charge of determining the necessary parts or sub-assemblies and the manufacturing operations. The type of resources associated with every operation and the sequence is determined by means of a set of cooperation interactions with the resource holons. The benefits of the holonic approach compared with traditional production programming approaches are due to the distributed nature, the interactive cooperation and the easy incorporation of resources.

2. Scheduling:

The major feature of a holonic scheduling approach is that every holon is a problem-solver and a decision-making entity. They use cooperation strategies in order to exchange information and mutually accepted solutions. There is a mechanism to assure that global system constraints are satisfied. And finally, there is a central coordination mechanism.

The benefits of a holonic scheduling approach compared with traditional approaches are due to the computation and decision-making distribution, and the interactive nature of holons.

3. Work-order execution and job-shop control:

This activity involves the initiation, control, monitoring and termination of tasks and involves actual plans and actual settings. The new elements of the holonic approach in contrast to conventional execution controlling algorithms are: the execution is implemented by means of a negotiation interaction sequence; and the resources (machines) executing the manufacturing operations are responsible for the decision-making regarding the timing and the type of execution.

4. Device controlling:

The device control – which involves actuation, sensing and feedback control of the physical operations that support a machine.

3.3 Holonic Control framework

Figure 3 has the feature that it internally converts goals or requirements into an allowable set of parameters or trajectories of behaviour via some form of decision function. The actual control action is then carried out. Figure 3 has the feature that it internally converts goals or requirements into an allowable set of parameters or trajectories of behaviour via some form of decision function. The actual control action is then carried out. The development of appropriate (and flexible) decision problems is the key to embedding control activity within holonic systems whose goals may differ depending on the environment that they operate in. It is clear that a distributed optimization based decision principle is well suited to holonic systems, and the goal-seeking methods could help with the integration of complex optimization based control algorithms into manufacturing operations - a relatively uncommon event at present [14].

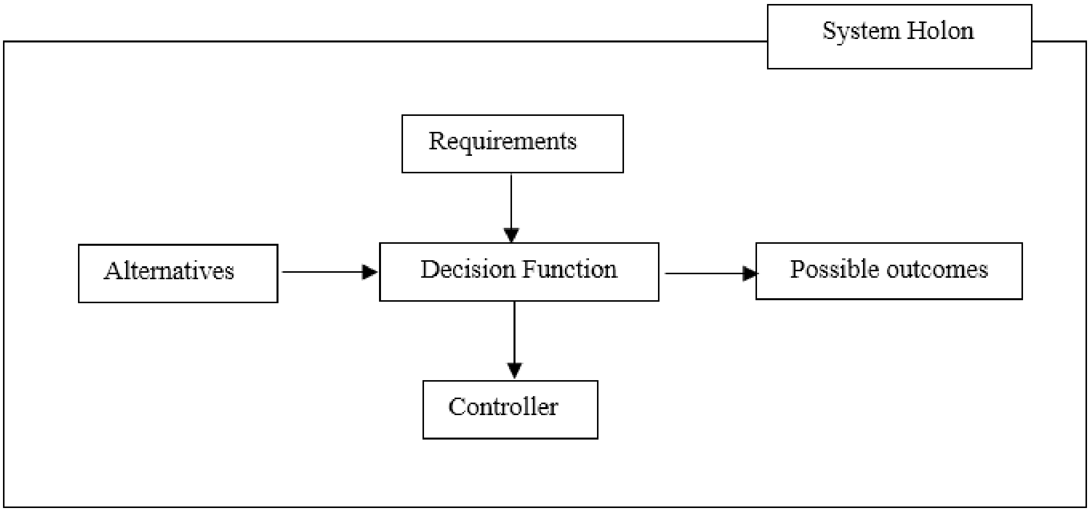

Figure 3: Control framework to support requirement for Holonic Manufacturing System

4. Eye-tracking Holon Architecture

Individual holons have at least two basic parts: a functional component and a communication and cooperation component. The functional component can be represented by a purely software entity or, as in resource holons, it could be a hardware interface represented by a software entity. The communication component is responsible for the inter-holon information exchange. The decision-making component is responsible for the manufacturing control functions, regulating the behaviour and activities of the holon. The interfacing component handles the intra-holon

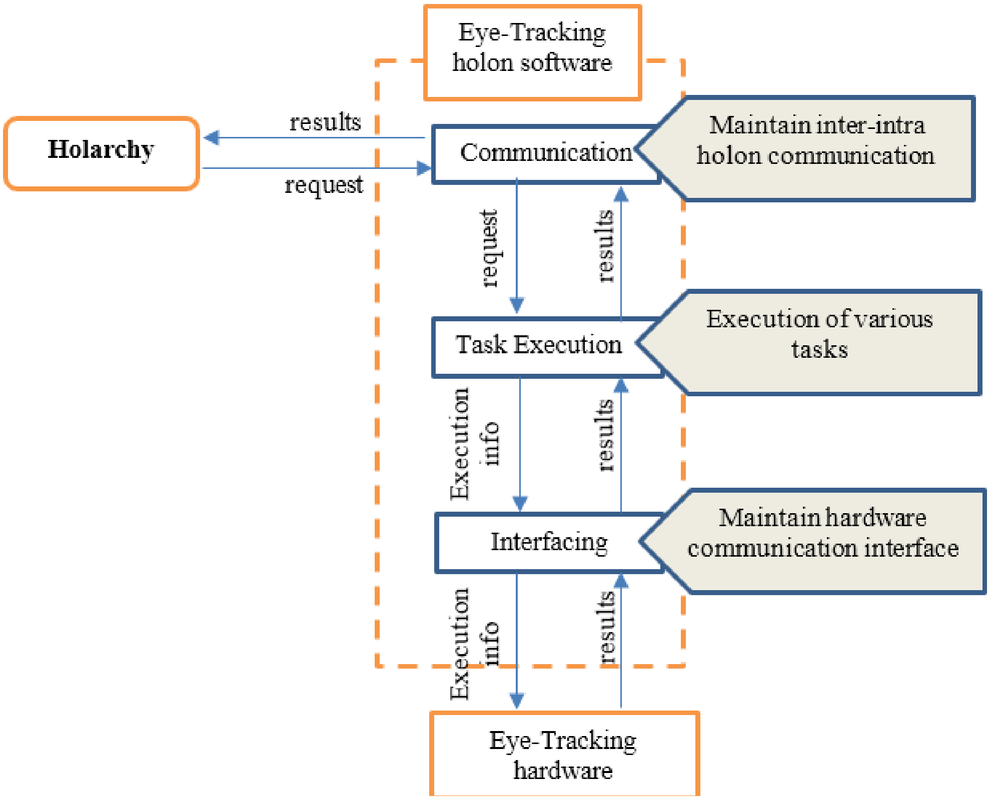

Figure 4: The holon model for the Eye-Tracking implementation [15].

interaction, providing mechanisms to access the manufacturing resources, monitor resource data and execute commands in the resource [17].

5. Implementation of Eye-Tracking Holon [15]

This section presents a methodology of implementing Eye-Tracking technology in holonic manufacturing system. A generic approach to facilitating communication and implementing the holon functional components is described.

5.1 Inter- and Intra-Holon Communication

In holonic systems, communication is either inter- or intra-holonic. Inter-holon communication takes place in between different holons in the system, while intra-holon communication is in between the internal components of a holon.

The inter-holon communication shown in Figure 4 request and results are interchanged by the holarchy and the resource holon communication component. In addition, Figure 4 also shows intra-holon communication indicated as the exchange of requests, results and execution information between the functional components of the resource holon.

5.2 Communication in Functional Components

For the components to cooperate, information must be exchanged by means of messages. For this reason, each functional component must employ a process which handles this communication. A simple way to facilitate the communication is to spawn a concurrent process running a receive-evaluate loop. Upon successfully matching to a pattern, some action can be taken (usually the sending of another message). After each matching case, the function calls itself, resulting in a continuous loop.

The communication process described above separates the communication functionality within a functional component, from the execution logic. This separation increases the reconfigurability and maintainability of the implementation, as changes can be made to one process without influencing the functionality of the other.

5.3 Implementing the Holon Functional Components

5.3.1 Communication Component

The communication component of the resource holon is responsible for maintaining the communication interface with the rest of the holarchy – i.e. all messages to and from other holons are handled by this component.

This component can be implemented using only the communication process discussed in section 5.2. This process then allows a concurrency in the communication and execution functionality of the holon – i.e. the communication component can operate uninterrupted and independent of the other functional components.

5.3.2 Task-Execution Component

The task-execution component of the holon is responsible for driving the hardware actions related to the service of the resource holon. This component activates the execution of hardware functions, with the necessary execution information and in a specified sequence, to perform the service of the holon and provides opportunity for the implementation of strategies to improve the model.

5.3.3 Interfacing Component

The interfacing component maintains the communication interface between the Eye-Tracking software and the hardware. This component isolates the hardware specific communication structures from the execution logic.

6. Conclusion

Manufacturing systems are very large and complex. Accordingly, the holonic systems that control or implement them are also large and complex. The development process of these kinds of systems has to be guided by software engineering methods and principles in order to help the engineer in the development process of the Holonic Manufacturing System itself.

A new holon in the form of an Eye-Tracking holon which is based on the usage of Eye-Tracking technology can be introduced. The implementation of Eye-Tracking technology in a manufacturing system has several advantages which were discussed. The technology can set higher standardization boundaries which so far were unnoticed in daily work and by normal human eye observation. As Eye-Tracking systems can work independently once the standards are set, this will massively influence the whole working system. As a result, a new Eye-Tracking holon will facilitate the work process for the worker and lead at the long run to cost benefits in the manufacturing system. It will aoslo offer opportunities for additional value added services [15,16]

It will be left to future research to extend and detail the holonic-Eye-tracking vision in order to cover all the requirements. It will also be a future task to show implementation of Eye-tracking technology in holonic systems in the factory that this approach can also meet the all the requirements like guaranteed performance, quality assurance, maintainability, or operability, which have not been discussed in this paper, but which still apply. An open question remains as to how far the current research addresses the holonic-Eye-tracking vision. In other words, to what extent there is a gap between the holonic vision and the techniques available to realise this holonic-Eye-tracking vision. This discussion will be topic of an upcoming paper [16].

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