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Review article

A literature review on the levels of automation during the years. What are the different taxonomies that have been proposed?

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ABSTRACT

In this paper we present a literature review of the evolution of the levels of autonomy from the end of the 1950s up until now. The motivation of this study was primarily to gather and to compare the literature that exists, on taxonomies on levels of automation. Technical developments within both computer hardware and software have made it possible to introduce autonomy into virtually all aspects of human-machine systems. The current study, is focusing on how different authors treat the problem of different levels of automation. The outcome of this study is to present the differences between the proposed levels of automation and the various taxonomies, giving the potential users a number of choices in order to decide which taxonomy satisfies their needs better. In addition, this paper surveys deals with the term adaptive automation, which seems to be a new trend in the literature on autonomy.

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1. Introduction

Looking through history, people have confronted the introduction of automation with scepticism especially in the beginning. The first major demonstration of concern for the potentially negative social impacts of labour-saving machinery was the Luddite movement in the early 1800s (Brain, 1998). During that time English workmen attempted to prevent the use of knitting machinery in their industry by destroying it. Later on, in the 1950s Diebold coined the term "automation" (Diebold, 1952). To his disappointment he discovered soon after that the term had already been used by an executive of the Ford Motor Company. Diebold, however, still stated that "automation is a new word denoting both automatic operation and the process of making things automatic" (Diebold, 1952).

Since then, automation has made a lasting entry into the world of manual labour, and as a result many functions and operations previously performed by humans have been taken over by

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machines. This change has come with the benefit of replacing lots of manual labour, and has resulted in an increase of productivity in terms of energy and materials saving, improvement of quality, accuracy and precision. What has been really achieved with automation, however, is the shift of the role of the operator from manual to supervisory control (Sheridan and Verplank, 1978). As a result, instead of performing tasks like activating manual switches and following operation procedures, they perform the intellectual or cognitive tasks of diagnosis, planning and problem solving (Liu and Hwang, 2000). Automation systems can be designed and employed in a way to secure a best-fit for the capabilities, advantages and disadvantages of both human and machine.

All this human-machine interaction and cooperation can be expressed by various Levels of Automation (LOA). Each of these levels specify a different degree to which a task is automated. This implies that automation is not all or none, but can vary across a continuum of intermediate levels, between fully manual performance and fully autonomous conditions at the two extremes. Several different LOA have been proposed by different researchers, resulting in numerous taxonomies describing the interaction between humans and machines.

The scope of this paper is to gather the proposed approaches on taxonomies of LOA in an attempt to bring this vast literature together. In addition, the authors try to summarize, categorize and compare the different approaches.

When we started to dig into the literature concerning the LOA, the authors came across with the two words "*autonomy*" and "*automation*". In Section 2, we tried to find (if any) similarities/differences between them and clarify the way they should be used. Furthermore, subsection 3.1 deals with the different LOA proposed by different researchers and subsection 3.2 presents a comparison and summary of them. In Section 4, we present the terms of adaptive, adjustable and adaptable automation. Finally, in Section 5 the conclusions are drawn. The tables describing analytically the taxonomies proposed by different authors are presented in the Appendix of the document, in an attempt to keep the core of the paper shorter and simpler for the reader to follow. We make some short descriptions of the proposed taxonomies in Section 3.1 and in addition the full taxonomy is presented in the Appendix.

2. Autonomy versus automation

In this section, the interpretation of the words *autonomy* and *automation* is discussed. Our scope is to investigate if there exists any difference between them. In fact knowing how these two terms are used is a necessary precondition for analysing the literature on this subject.

Historically the word autonomy appears first while the word autonomy is launched later on (http://www.oxforddictiona). Many authors do understand the difference between these two words and several amongst them tend to use them interchangeably. On the other hand, there are some studies in which the two words are used as distinct terms ((Clough, 2002a), (Clough, 2002b)). We have made an extensive search into what exists in the literature and how different authors treat both words. Let us introduce first the etymologies of the two words as they exist in the dictionaries and in addition an extended study on how authors tend to use them is going to be presented.

The word "*autonomy*" has been launched in the early 17*th* century, originating from the greek word "autonomia/autonomous" which means "auto = self" and "nomos = law", independent and self-governing ((http://dictionary.cambrid), (http://dictionary.referen)). The word by itself is a concept found in different kinds of sciences, like engineering, philosophy, biology and medicine. As far as the engineering etymology is concerned, the word autonomy is used in order to describe the ability of an engineering system to make its own decisions about its actions while performing different tasks, without the need for the involvement of an exogenous system or operator (Albus et al., 1998). Since each engineering system has a certain degree of autonomy associated with it, autonomy means independence from an outside supervisor, which may be another engineering system or a human. As a result, autonomous systems can make a choice free from outside influence since they have some perceivable notion of "free will", and autonomy is the ability of the system to change its initially programmed way of action, to the degree that it has been decided a priori by the designer of the system.

The word "*automation*" was introduced in the mid of the 19*th* century and is inspired by the earlier word automatic ((http://dictionary.cambrid), (http://dictionary.referen)). Automation includes the execution by a machine agent of a function that was previously carried out by a human ((Parasuraman, 2000), (Parasuraman and Riley, 1997)). This can concern different control systems for operating equipment in numerous applications such as chemical and power plants, aircraft and air traffic control, automobiles, ships, unmanned vehicles and robots, heating and air conditioning in buildings, business systems, medical devices, home appliances, military systems and stand-alone computers are used in order to name only a few examples. However, the concept of automation has changed through time. It can e.g. mean a simple reallocation of a function from human to machine which is complete and permanent. In that case, the function will tend to be seen simply as machine operation not as automation (Parasuraman and Riley, 1997). To summarize, the word automation refers to a system that will do exactly what it is programmed by the programmer to do without having any choice or possibility to act in any different way dependent on the situation at hand. Its actions are predefined from the beginning and it has no ability to change them into the future.

It seems that at least as far as the etymologies are concerned the two words have two different meanings ((http://dictionary.cambrid), (http://dictionary.referen)). The question that arises is: "Do these terminologies follow the scientific literature as well?" The answer to that question is not easy. It seems that in engineering terms the authors tend to use them interchangeably.

In Table 1 we have summarized scientific papers dealing with autonomy and/or automation. This summary indicates that most of the authors tend to use the word automation over the word autonomy even when referring to a system that is "free to make choices". One conjecture is that many authors are more familiar with the word automation and hence tend to use that in favor of the word autonomy. This is done even when referring to what other authors call the Levels of Autonomy ((Johnson et al., 2009), (Parasuraman, 2005)), thereby denoting what seems to be the more or less identical term Levels of Automation ((Parasuraman, 2000), (Endsley and Kaber, 1999), (Fereidunian et al., 2007a), (Hancock, 2013), (Hancock et al., 2013), (Miller and Parasuraman, 2007), (Onnasch et al., 2014), (Parasuraman et al., 2000)). We have no indication that there is a difference one word has been used over the other.

All the previous observations lead to the conclusion that there is no constant way of using both words and that there is quite a lot of flexibility on how they can be used. As far as this paper is concerned we decided to treat the two words as distinct, being constant to the meanings described in dictionaries - thereby using the term "autonomous system" when we refer to a system that "has the freedom to make choices". Although we try to be consistent with the usage of the words autonomy and automation, quite often we need to reproduce them both, in the way the authors use them since we think it is inappropriate to change their terminology. So, when presenting a taxonomy, or reproducing some points from another study we do that without criticising or distinguishing the