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Layers of Shared and Cooperative Control, assistance and automation

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Abstract: Over the last centuries we have experienced scientific, technological and societal progress that enabled the creation of intelligent assisted and automated machines with increasing abilities, and require a conscious distribution of roles and control between humans and machines. Machines can be more than either fully automated or manually controlled, but can work together with the human on different levels of assistance and automation in a hopefully beneficial cooperation. One way of cooperation is that the automation and the human have a shared control over a situation, e.g. a vehicle in an environment. The objective of this paper is to provide a common meta model of shared and cooperative assistance and automation. The meta models based on insight from the H(orse)-methaphor (Flemisch et al., 2003; Goodrich et al., 2006) and Human-Machine Cooperation principles (Hoc and Lemoine, 1998; Pacaux-Lemoine and Debernard, 2002; Pacaux-Lemoine, 2014), are presented and combined in order to propose a framework and criteria to design safe, efficient, ecological and attractive systems. Cooperation is presented from different points of view such as levels of activity (operational, tactical and strategic levels) (Lemoine et al., 1996) as well as the type of function shared between Human and machine (information gathering, information analysis, decision selection, action implementation) (Parasuraman et al., 2000). Examples will be provided in the aviation domain (e.g. Goodrich et. al 2012) and the automotive domain with the automation of driving (Hoeger et al., 2008; Flemisch et al., 2016; Tricot et al., 2004; Pacaux-Lemoine et al., 2004; Pacaux-Lemoine et al., 2015).

Keywords: Man/machine systems, Human-centered design, Multilevel systems, shared control, co-operative control, co-operation.

1. INTRODUCTION

One of the biggest differences between homo sapiens and other species on planet earth is the heavy use of tools. From the early stone tools over a million years ago, the oldest wooden spears e.g. found in Schoeningen, more than 270.000 years old, to the invention of wheels, water power machines etc., humans have strived to increase their physical power and influence on the physical world in order to improve live. With the invention of machines to do calculus, also mental operations are increasingly transferred to machines. Now in the 20th and 21st century, more and more can be automated. Automated production lines are producing the goods of daily life relatively cheap, highly automated airplanes are making flying relatively easy and safe, robots will invade our daily lives, assisted and automated cars promise to make driving safer and more comfortable. How do we continue with this development? How do we work and live together with these machines?

With increasing knowledge not only about tools, but also about our own history and characteristics, it comes increasingly clear, that since the very early days of mankind our tools also shape the way how we think and act, and vice versa. As one of many examples, Michael Tomasello describes how the human thinking evolved over the millenniums. It seems that the invention and use of tools like spears had a heavy influence, but even more, the way how to use these tools cooperatively seems to be the real breakthrough of homo sapiens compared to other primates.

Tomasello describes the ability to estimate the impact of an action on the cooperation partner, i.e. to mirror oneself in the partner, as one of the most important mechanism of cooperation.

Can we use the knowhow and inspiration of our past to shape our future relationship with machines? How do we use the increasing power of automation while keeping our authority as humans and clear roles? Do we need a similar quality of cooperation as we have developed between humans, or between humans and some animals, now with our machines?

2. FROM ASSISTANCE AND AUTOMATION TO HUMAN-MACHINE COOPERATION

Automation has been long thought in a quite black-and-white way of either automated or completely manual. At the end of the last millennium, this simple scheme was increasingly refined, describing that machines can be automated on different levels of automation (e.g. Parasuraman et al. 2000), or can serve as assistance systems (e.g. Onken 1999). As a combination of assistance and automation, (Flemisch et al

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2003) described the relationship between rider and horse as a design metaphor for human-machine cooperation with varying and fluid levels of assistance and automation.

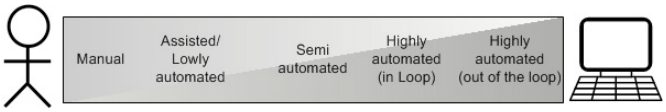

Fig.1. Simplified model of assistance and automation. (Flemisch et al., 2003)

On the one hand this sparked the world wide activities on highly automated driving, e.g (Hoeger et al 2008), on the other hand this motivated an increasing cooperation with the rich French and increasingly international research on human machine cooperation, described further down in the paper, reflected on the German side with work e.g. by Biester (2009), Hakuli et al. (2008), Loeper et al. (2008), or Flemisch et al. (2014), who describe cooperative guidance and control automation as a cluster concept with the starting point of sufficient autonomy, and qualities like outer and inner compatibility, and the ability to arbitrate different conflicts, and to adapt to the cooperation partner and to changing situations.

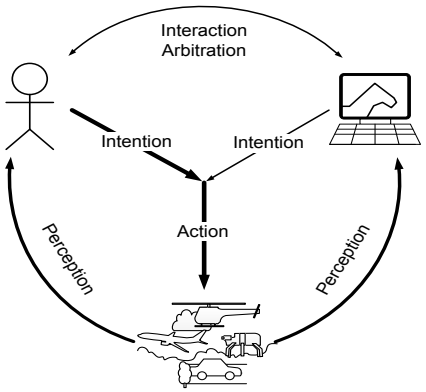

Fig.2. Simplified model of assistance and automation. (Flemisch et al., 2011, based on 2003)

Human-machine Cooperation is also one of the main topics studied by the Automation department of LAMIH for over twenty years. Many works managed with various investigations and exchanges with research partners from different disciplines, automation, computer sciences, cognitive and social psychology, have allowed exploring several ideas to build efficient and desired cooperation between Human and machine. First works dealt with task allocation and authority management. Millot and Mandiau (1995) defined the "vertical" and "horizontal" structures of cooperation. In the vertical structure, the machine is only able to provide an analysis of the situation and a set of solutions.

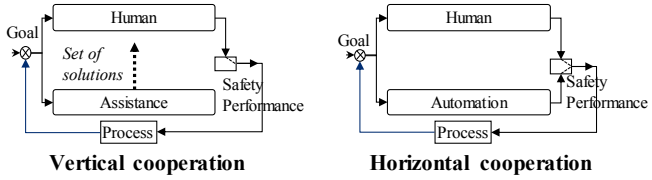

Fig.3. Cooperative structures. (Millot & Mandiau, 1995)

The human selects one solution and implements it. In the horizontal structure, Human and machine can fulfill all solving problem tasks from the analysis of the situation to the implementation of action. So structures depend on abilities of each agent to select the best action to be implemented.

Rieger and Greenstein (1982) proposed "explicit" and "implicit" modes of cooperation. In the explicit mode, machine proposes its solution and the human has to choice between his/her solution and the pro-posed one. In the implicit mode, machine implements directly its solution. Lemoine et al. (1996) added the assisted explicit mode in order to have an intermediate mode. In this third mode, machine proposes to implement its solution and another human at an upper decisional level than the one concerned by the control task, decides the allocation. The assisted explicit mode involves more acceptability and less workload induced by cooperative tasks.

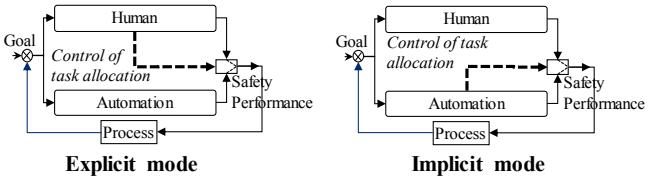

Fig.4. Cooperative modes. (Rieger & Greenstein, 1982)

So modes of cooperation are more dealing with authority management for task allocation. But allocation can also be analyzed according to competences and capacities. Schmidt (1991) proposed three forms of cooperation. The "augmentative" form is used when human and machine have similar competences to perform the task and they can share the task in order to adapt the capacity. The "integrative" form is used when human and machine have complementary competences and they can share the task in order to improve adaptability. The "debative" form is used when Human and machine have similar competences and they can debate the best solution in order to improve reliability (Sheridan, 1992). These forms of cooperation are more dealing with the identification of criteria to organize task sharing.

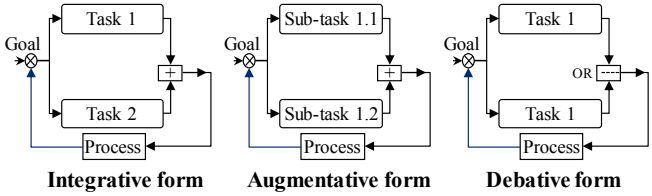

Fig.5. Cooperative forms. (Schmidt, 1991)

Forms, modes and structures of cooperation have been used to study Human-Machine Cooperation in several domains. In air traffic control mixed of modes and forms of cooperation have been proposed and evaluated to support the air traffic controllers to manage conflicts in a traffic still increasing.

In car driving, embedded warning and control systems have been designed for nominal and degraded driving situation. Adaptive Cruise Control (Tricot et al., 2004), Collision Avoidance Systems (Pacaux-Lemoine et al., 2004) and