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Educable learning-oriented multilevel shared autonomy for inclusive mobility and healthcare

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Abstract. This paper proposes a new paradigm based on educable learning for multilevel shared autonomy between humans and machines on future inclusive mobility or healthcare. Multilevel shared autonomy is presented from the perspective of three groups of process: a group of interactive supports, a group of roles of humans and machine in the course of shared autonomy and a group of sources or targets for inclusive mobility or healthcare. Two literature reviews present advances of the first two groups. Educable learning oriented multilevel shared autonomy is then proposed to recover limits of current approaches and to update online or offline learning or education supports. A case study illustrates the feasibility of such educable learning process.

1 Introduction

Inclusivity is a large concept that aims to adapt systems or services to everybody, everywhere, whatever operational conditions. It relates to different paradigms like inclusive design, inclusive robotic, inclusive manufacturing, inclusive mobility or inclusive healthcare. It includes accessibility to services for mobility or healthcare, accessibility to education for people with reduced mobility, disabilities or healthcare needs, and accessibility to all life-cycle steps of products dedicated to education or service for mobility or healthcare. Artificial Intelligence (AI) based technology is useful to improve such inclusive mobility or healthcare. Technological integration facilitates empowerment of people with temporary or permanent disabilities. Inclusivity was then adapted for human-machine system considering both human-supported AI and AI-supported humans whatever limits or needs of humans or machines [1-4]. Such systems have all-in-one or all-inclusive configurations in order to handle any evolution of advantages, limits or needs of humans, machines or organizations in the short, medium or long term.

Concepts developed for Industry 4.0 or Industry 5.0 progressively reconsider human role on future human-machine systems. They are adapted to Operator 4.0 or Operator 5.0 respectively and develop paradigms like Human-In-The-Loop (HITL), human-system symbiosis, human well-being or human resilience [5-10]. These new paradigms aim at studying shared autonomy between humans and machines with regard to its positive and negative consequences.

HITL concept usually relates to any physical or virtual interactions between humans with machines. Considering cognitive, sensorial or physical factors from humans or machines, it is largely applied to different domains of application like transport, education, or health to design, analyze or evaluate future human-machine workplaces. This paper is inspired of such paradigms and makes relations between HITL with inclusive mobility or healthcare. It proposes a new paradigm based on multilevel shared autonomy between humans and machines for achieving inclusive mobility or healthcare goals. This new paradigm is named educable learning in order to design online or offline learning or education supports regarding successes or failures of cooperative or competitive behaviors during multilevel shared autonomy process.

Section II gives different applications of HITL-based interactions oriented to inclusive mobility or healthcare. Section III concerns principles around shared autonomy by making differences between physical control, supervisory or monitoring of systems by humans. The last section proposes a new challenging concept related to educable learning to be included in human-centered shared autonomy for future inclusive mobility or healthcare.

2 HITL-based interactive supports for inclusive mobility or healthcare

People can have permanent or temporary disabilities or vulnerabilities that need specific cares or health monitoring. Well-being monitoring for instance is an important issue for industries of the future because permanent stress or workload can impact negatively human health. As a matter of fact, everybody is concerned by such interest for studying inclusive mobility and healthcare. The development of inclusive

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mobility and healthcare supposes the identification of individual requirements without any discrimination about:

• accessibility to transport or healthcare services to make everyone mobile, healthy or cared [11, 12],

• accessibility to education services to train everybody for a job [13, 14],

• accessibility to manufacturing means and services to imply everybody in life-cycle steps of a product from its design to its use [15-17].

Information and communication technology can be used to facilitate, increase or improve these accessibilities or services at three interactive levels, Table 1: technology as facilitators of Human-To-Human Interactions (HuTHI), technology for Human-To-Machine Interactions (HuTMI), technology to simulate Virtual Human-To-Machine Interactions (ViHuTMI).

Table 1. Examples of HITL-based interactions for inclusive mobility or healthcare.

Interaction process	Context	Principle	References
HuTHI	Teamwork	Facilitation of teamwork with disable people	[18]
	Telemedecine	Facilitation of healthcare whatever the place	[19]
	Participatory design	Facilitation of the design of care technology with all stakeholders	[20]
	Education	Knowledge sharing, training and learning	[21, 22]
	Inter-communication	Communication between disabled people	[23]
HuTMI	Conversational system	Social inclusion and equity	[24, 25]
	Mono-level shared control	Individual transport or healthcare human-machine teaming	[26-31]
	Multi-level shared control	Multi-level transport or healthcare human-machine teaming	[32-34]
	Logistics	Organization of transport or healthcare services, infrastructures or supply chains	[35, 36]
	Augmented body	Physically augmented operator	[37, 38]
	Augmented cognition	Cognitively augmented operator	[39-43]
	Education	AI-based pedagogical supports for healthcare or transport	[1, 44]
	Competition	Impact of AI on competition for service quality	[45]
ViHuTMI	Virtual machine	Digital simulation interacting with operators	[46-50]
	Virtual operator	Metaverse or avatar	[51, 52]
	Virtual human-machine system	Entire digital human-machine system	[53]
	Ergonomics	Anthropometric or physical criteria to support the design of virtual workplace	[54, 55]

HuTHI use multimedia technologies to facilitate teamwork between disabled and non-disabled persons [18], to realize mobility or healthcare services remotely and anywhere [19], or to communicate between different stakeholders to design dedicated supports for inclusive mobility or healthcare [20]. Adapted supports can also be developed for educating staff to improve services [21, 22] or for facilitating communication between disabled people [23]. HuTMI are conversational systems like chatbots for social inclusion, or mobility or health equity [24, 25]. Individual or multi-level shared control processes aim to develop smart devices to share tasks with a human or with different decisional levels involving humans and machines [26-34]. Their applications depend on technical and human abilities and limitations. Logistics is another important factor by ensuring the smooth running of transport or care services or infrastructures, or of supply chains of materials and supports for inclusive mobility or healthcare [35, 36]. Augmented reality-based supports like exoskeletons or immersive glasses increase physical or cognitive human abilities [37-43]. Other systems can also improve human skills in an education or competition context [1, 44, 45].On ViHuTMI level, humans can be represented physically interacting with digital machines or virtually by implementing human models, human avatars or virtual dummies for instance [46-52]. Human-machine digital twin combines virtual operator with digital twins [53]. From an ergonomics viewpoint, its simulation can consider anthropometric or physical criteria like accessibility to support the design of virtual workplace [54-55].

HITL-based interactions focus on a joint consideration of physical or virtual, face-to-face or remotely shared autonomy between humans and technical supports. Next section develops the HuTMI-centered shared autonomy paradigms that includes interactive flows of data or actions from humans to machines or from machines to humans.

3 HuTMI- centered shared autonomy

Shared autonomy between humans and machines is one of the challenging issues for inclusive mobility or healthcare, Table 2.

Table 2. Shared autonomy paradigms, adapted from [57-61]

Concept	Human Role
Human-Alone-In-The-Loop (HAITL)	Entire human control
Human-In-The-Loop (HITL)	Validation of technical decisions Control of a predefined number of tasks Action performed in face-to-face or remotely
Human-On-The-Loop (HOTL)	Monitoring of the system Interruption of the system action if necessary Taking over the control if requested by human or if necessary
Human-Out-Of-The-Loop (HOOTL)	No human control/role

The HITL implies that users control physically the system, and monitor current control situations. However, without any assistance, humans control alone the process in Human-Alone-In-The-Loop (HAITL) level. On the other hand, for the Human-Out-Of-The-Loop (HOOTL) humans do not monitor dynamic situations whatever their contribution to physical system control. The intermediary level, called Human-On-The-Loop (HOTL), considers that users are initially not in physical control of the system, but monitor dynamic situations [56]. In case of system dysfunction, humans are then obliged to go back in the physical control of the system.

Allocation and communication systems between humans and machines can limit mutual misunderstanding by considering structural and functional task characteristics and their associated models of representation [62-63]. Allocation system has different possible modes. It can dynamically change over time with regard to evolution of criteria like human workload, performance or preference, or can be done in a static manner once and for all, that is to say without the possibility of modify the initial allocation. This dynamic or static allocation can be managed by humans themselves or automatically by machines with regard to technical or human availability, competence, or possibility to act, or to environmental conditions. Communication system aims to transfer information between decision-makers about controlled process states, about human states or about AI-based tools states. Communication content is variable and human or machines can transfer data, knowledge, an action, their own state or the state of other system entities. These communications are carried out face-to-face, remotely, deferred, with or without acknowledgment of receipt, on demand, or continuously. They used modalities like gestural, verbal, tactile or haptic interactions. The design of AI-based systems, of allocation and communication systems at HITL or HOTL levels can be supported by online or offline analysis methods or connected systems like eye-trackers, connected watches or cameras [64-72]. Despite these considerations for design, some weak signals based undesirable scenarios can occur when humans use AI-based assistant tools [73-78]. Some of them are due to interactions between groups of humans or machines with different levels of shared autonomy, others to failures of cooperative or competitive based behaviors. Next section proposes a new shared autonomy configuration integrating an educable learning process in order to consider possible undesirable scenarios for inclusive mobility or healthcare.

4 Toward educable learning oriented multilevel shared autonomy

The multilevel shared autonomy principle considers assistive, digital or connected technologies and includes them into three different groups of process, Fig 1. The first one concerns human-machine interactions, i.e. HuTHI, HuTMI or ViHuTMI). The second group relates to the role of humans or machines, i.e. HAITL, HITL, HOTL, HOOTL). The last one distinguishes different sources or targets for achieving inclusive mobility or healthcare goals, i.e. infrastructures, services, humans or AI-based supports. Educable learning process considers a knowledge base K implemented into merged or cumulative AI-based learning systems and into natural human reasoning, Fig 2.

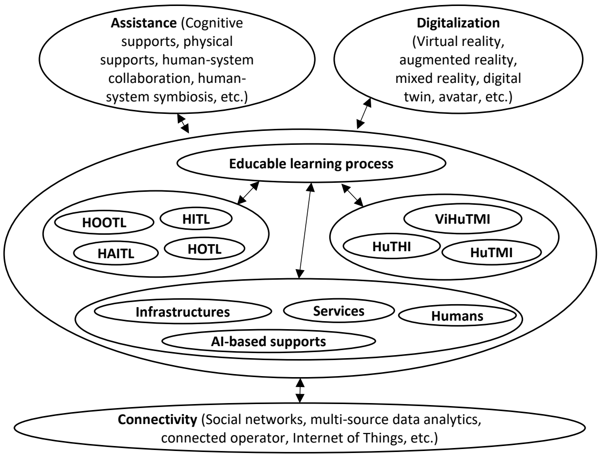

Fig. 1. Multilevel shared autonomy principle.

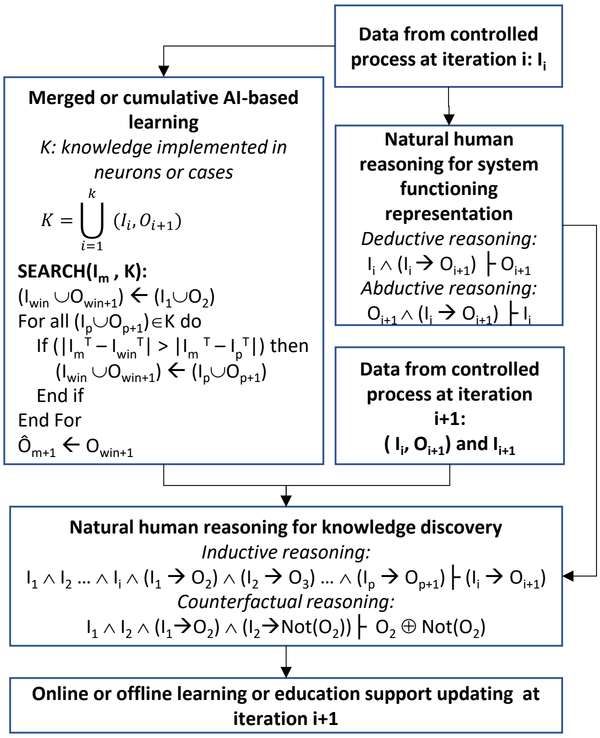

Fig. 2. Educable learning process.

Merged systems relate to knowledge implemented into neurons and are neuron-based models while cumulative ones are case-based reasoning models for which knowledge is represented by data associated to cases or scenarios [79-83]. Knowledge is usually represented by input and output vectors. With regard to input data I_m at iteration m, AI-based systems estimate $\hat{O}_{m+1}$ by searching on K the vector I_{win} for which the content of I_{win} is closest to the content of I_m. The output $\hat{O}_{m+1}$ is then equal to O_{win}. In parallel, this knowledge is interpreted in terms of natural human reasoning like deductive or abductive reasoning [84-86]. On deductive reasoning, the observation of data of a vector I_i and the existence of a rule such as $(I_i \rightarrow O_{i+1})$ make possible the observation of O_{i+1}. Abductive reasoning includes the existence of the same rule but the observation of O_{i+1} to make possible the observation of I_i. The real couples (I_i, O_{i+1}) observed in the field can then be useful to reinforce online or offline supports dedicated to learning or education processes. When unforeseen situations occur, the reinforcement differs because an updating of knowledge is required. This updating is supported by two other natural human reasoning: the inductive reasoning or the counterfactual reasoning [86]. The repetition of similar relations ($I_m \rightarrow O_{m+1}$) combined with observations of I_m can generate the creation of a generic rule $I_i \rightarrow O_{i+1}$) in inductive reasoning. For counterfactual reasoning, the observation of two different vectors I_1 and I_2 and the existence of rules ($I_1 \rightarrow O_2$) and ($I_2 \rightarrow Not(O_2)$) can imply the creation of a warning on inconsistent observations about ($O_2 \oplus Not(O_2)$). The proposed case study to illustrate the application of the educable learning process is adapted from an example presented on [87], Fig. 3.

Fig. 3. Case-study context involving autonomous car for disabled persons.

It considers an autonomous driving process for disabled person in an urban context. The traffic light is green therefore the autonomous car will move but will stop to avoid a collision with another vehicle. Unfortunately, this stop may be on a tramway track and the waiting time can be sufficient for the light to turn red to announce the arrival of a tram. A potential collision exists between this autonomous vehicle and the tram, which endangers the passengers of the tram and the vehicle. An example of the modelling of AI-based learning systems and human reasoning-based rules and the genesis of the possible education supports is given on Fig 4 and on Fig. 5.

It considers initially three variables, i.e. the state of the car ("state-car" associated with values "moved" or "stopped"), the state of the traffic light ("state-light" associated with values "red" or "green") and the gap between cars (state-gap associated with values "≥2s" or "<2s"). The input vector (1, 1, 0) for state-car=moved, state-light=green and state-gap="≥2s" returns the output vector (1) for state-car=moved for both AI-based learning systems and natural human reasoning. Observations on field about possible collision between tram and autonomous car may generate new rules about the position of the car or inconsistency between actions, a new state of the car, i.e. collided, and variables like state-track for the state of the tramway track (with values as "free", "obstructed" or "occupied") or state-tram for the state of a tramway (with values as "moved" or "stopped") for instance. These new constraints require an updating of learning or education supports. Two examples, one based on Petri nets graphical formalism and one simulated by the MissRail® platform, are proposed on Fig 5.

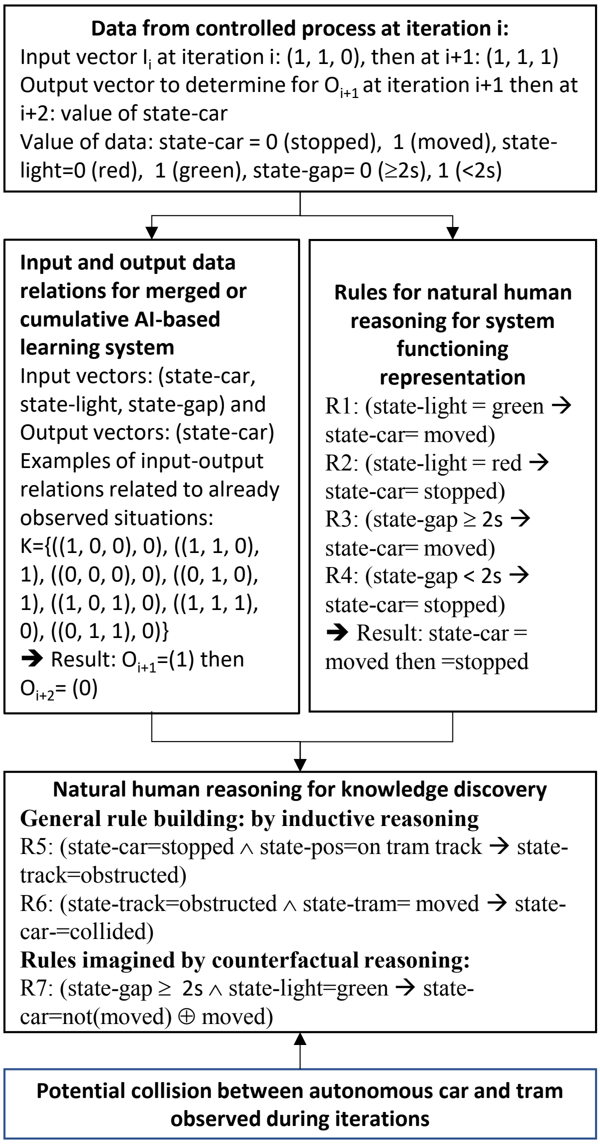

Fig. 4. Application of the educable learning process.

5 Conclusion

This paper has presented the multilevel shared autonomy principle based on three groups of interactive processes for inclusive mobility or healthcare: the process related to interactions (i.e., HuTHI, HuTMI, ViHuTMI), the process related to the role of humans and machines (i.e., HAITL, HITL, HOTL, HOOTL) and the process related to sources or targets for inclusive mobility or healthcare organization (i.e., Infrastructures, Services, Humans, AI-based supports). It has developed a new challenging process for human-AI interactions: the educable learning to update learning and education supports for machines or humans. It can be applied between machines with disabled humans or with humans without disabilities but delivering services for disabled persons. Educable learning combines AI-based cumulative or merged learning approaches with natural human reasoning like deductive, inductive, abductive or counterfactual reasoning. A case study illustrated the interest of such educable learning development for future AI-based supports to improve inclusive mobility or healthcare.

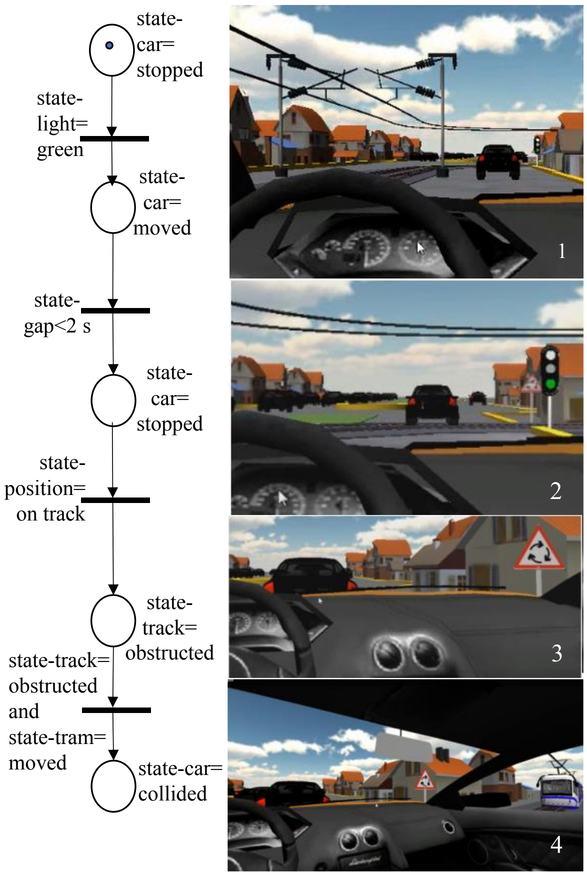

Fig. 5. Example of a graphic-based (left picture) and video-based (right picture done with MissRail® platform [88]) education supports.

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