CLASSIFICATION OF COBOTIC SYSTEMS FOR INDUSTRIAL APPLICATIONS

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1 INTRODUCTION

Cobotics is a neologism formed by the “collaborative” and “robotics” terms. It has been used for the first time in 1999 by Peshkin and Colgate to conceptualize the direct interaction between a robot and a human on a dedicated workstation (Peshkin & Colgate, 1999). Its meaning evolved towards different definitions according to the context of the application. In the present study, a cobot is defined as a robot that has been designed and built to collaborate with humans. A workstation including a robot and a human collaborating is called a cobotic system. Cobotics is defined by the science and techniques of designing, building, studying and evaluating cobotic systems.

A robot may have all mechanical and hardware characteristics for a possible collaboration with humans but if it used in full autonomy, it is not part of a cobotic system even if it can be called a cobot.

2 CHARACTERISTICS OF INDUSTRIAL COBOTIC SYSTEMS

2.1 COBOTIC SYSTEMS

Characterization and classification of cobotic systems is very important for industry in order to understand the feasibility, the efficiency and the relevance of designing and implementing a new cobotic system for an industrial application.

A cobotic system includes a cobot and a human collaborating in synergy to perform a task in the context of a workstation. In order to characterize a cobotic system, it is necessary to pay attention to the task, to the human operator, to human system interactions and to the cobot. Several humans and several cobots may be involved in a cobotic system but for the sake of simplicity, we will focus here on a simple cobotic system that involves a unique cobot and a unique operator.

2.2 TASK CHARACTERIZATION

A task is defined by numerous variables. The first one is the domain of application (industrial, domestic, medical, military, etc.). The proposed study is restricted to the industrial domain. Examples of tasks where a cobotic system can be used are: transporting, moving and carrying objects, assembling, surface processing, welding, cutting engraving, etc. The task can also be described by its unicity, its repetitiveness, and its necessary adaptation to application changes. Another important variable is the possible impact of a dysfunction or damage on the whole production process (Yanco & Drury, 2004). If there is an important risk of failure or a risk to human health, the use of a cobotic system might not be appropriate.

2.3 ROLE OF OPERATOR

In the past, robots were used by experts in robotics. Nowadays, more and more people are used to robots and it happens sometimes that newcomers are immediately asked to use and interact with industrial robots. However, knowledge and know-how greatly impact our perception and representation of robots, what they can do and what they cannot. It is of primary importance for the industry to design robots such that anyone can easily work and interact with it after very short training periods. The complexity of the interaction mainly depends on the role of the person at the workstation (Scholtz, 2002):

- OPERATOR : Pilots the robot (locally or remotely). The robot usually has a weak autonomy or even no autonomy at all. This interaction mode is sometimes used for an online training.
- COWORKER : Works with the robot.
- SUPERVISOR : Provides instructions and checks the work of the robot.
- BYSTANDER : Is present in the working zone of the robot without interaction. There is however a preliminary risk assessment to make sure that there is no risk with the current task.
- MAINTENANCE OPERATOR: Checks and eventually updates mechanical parts, hardware or software components.
- DESIGNER/PROGRAMMER : Expert in robotics. Designs, builds or develops sofware tools for the robot.
- SUBJECT : In some cases, humans can also play the role of subject, for instance in the robotic surgery domain.

An important parameter of the human role is the way the decision is taken in the cobotic system. It can be the result of a common planning, an order, a consensus between the cobot and the human, or an autonomous decision. Parasuraman & Sheridan (2000) propose 10 levels for the decision process, ranging from full assistance to no assistance at all.

2.4 HUMAN SYSTEMS INTERACTIONS

The design of a cobotic system involves a clear understanding of the possible human robot interactions, both needs, both constraints and the methodology to determine the best solution.

The proximity between the operator and the robot is a crucial parameter for obvious security reasons. Ergonomic reasons may also be taken into account. The robot can be in contact with the operator (comanipulation for instance), nearby, or very far (other planet). Sometimes, the robot can be carried by the user (exoskeleton) or the user can be carried by the robot (robotic vehicle) (Walther & Guhl, 2014). Interactions may occur in real time with immediate feedback or be differed. In addition, the interaction can be brief, e.g., pushing a button, or continuous (comanipulation). Yanco and Drury (2004) propose to characterize the cobotic system by the type of interaction and the type of interface. The sensor used for the interaction has an important impact on the abstraction of the message that is exchanged between the operator and the robot. A synthesis of the main interaction devices is provided Figure 1. In artificial intelligence, computer vision and speech recognition techniques allow high level interactions. However, in industrial applications, the complexity and robustness of these techniques are still considered not appropriate. Human vision (including interpretation) is typically one order of magnitude more efficient than computer vision techniques. For that reason, efficient cobotic systems are often made of a robotic manipulator that is directly operated by a human, who is in charge of the perception of the environment. The manipulation of excavators is a good example.

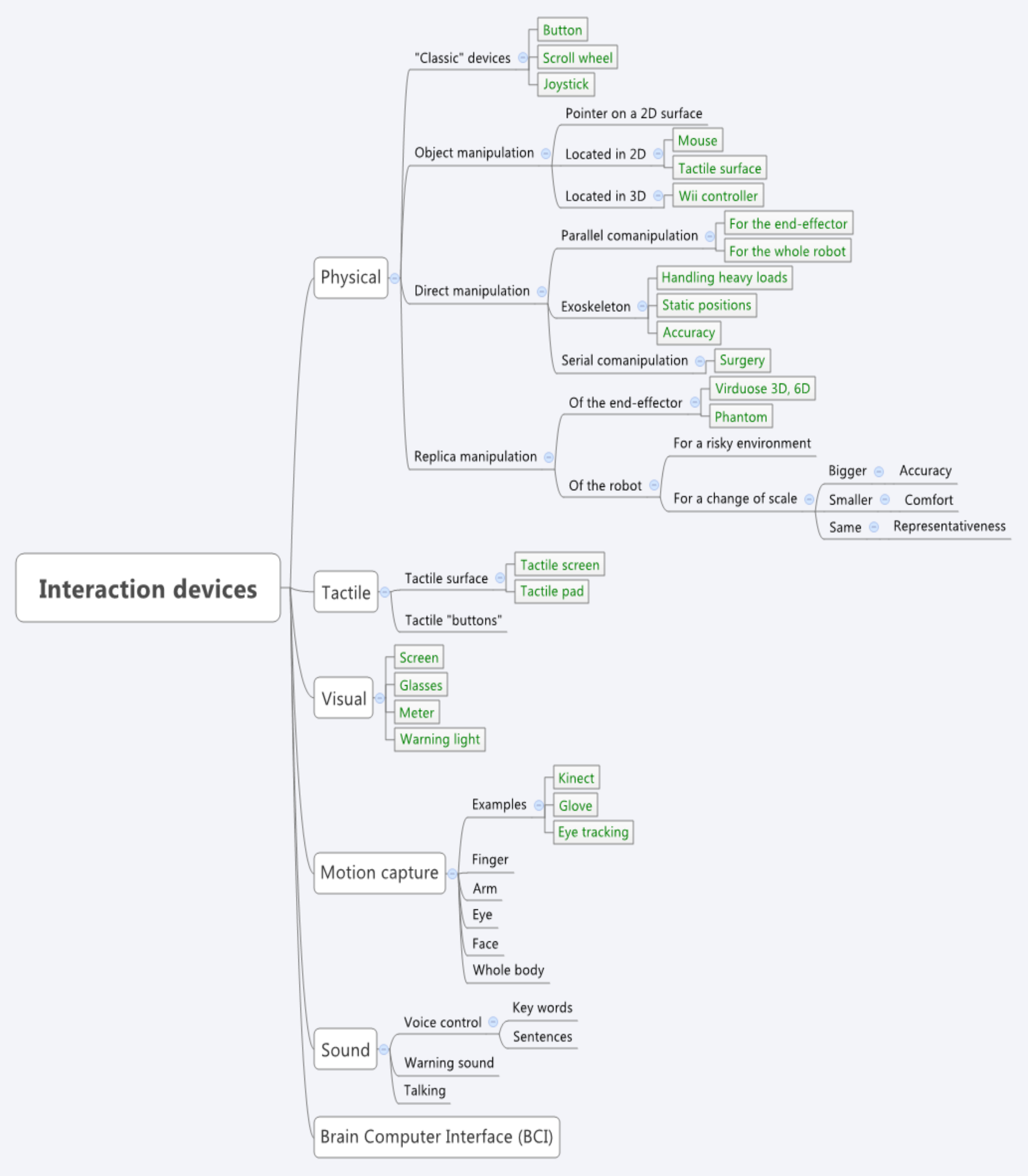

FIGURE 1: INTERACTION DEVICES FOR A COBOTIC SYSTEM

2.5 CLASSIFICATION OF ROBOTS

The traditional classification of robots is based on their morphology, which usually allows a visual and functional representation of their use:

- Robotic arm: It is made of a serial kinematic chain.
- Parallel robot: Robot with ending components linked to the base by several independent kinematic chains.
- Cartesian robot: Robot with prismatic articulations in which axes are placed according to Cartesian coordinates.
- Mobile robot: Robot that can move from its original position.

- Exoskeleton: Robot worn by a human to improve its performance or mitigate his handicap.
- Hybrid robot: Combination of the above.

There are other classification methods. One of them is based on the “intelligence” of the robot, as it is proposed by the American Robotic Industries Association and the JIRA (Japan Industrial Robot Association). The basic robot is an open loop command system and the most sophisticated is able to elaborate a complex planning process. A classification has been proposed by (Coiffet, 1996). It is an interesting approach that takes the environment and humans into account. See Table 1. However, there is no reference to the morphology of the robot.

Entity	**Human**	**Control system**	**Robot**	**Environment**
Features affecting performances during the execution of task	Continuous action	Open loop	Fixed	Known
	Intermittent action	Regulation	Mobile	Partially known
	No action	Regulation and reflex		Unknown
		Regulation, reflex and decision		

TABLE 1: ROBOTS CLASSIFICATION (COIFFET, 1996)

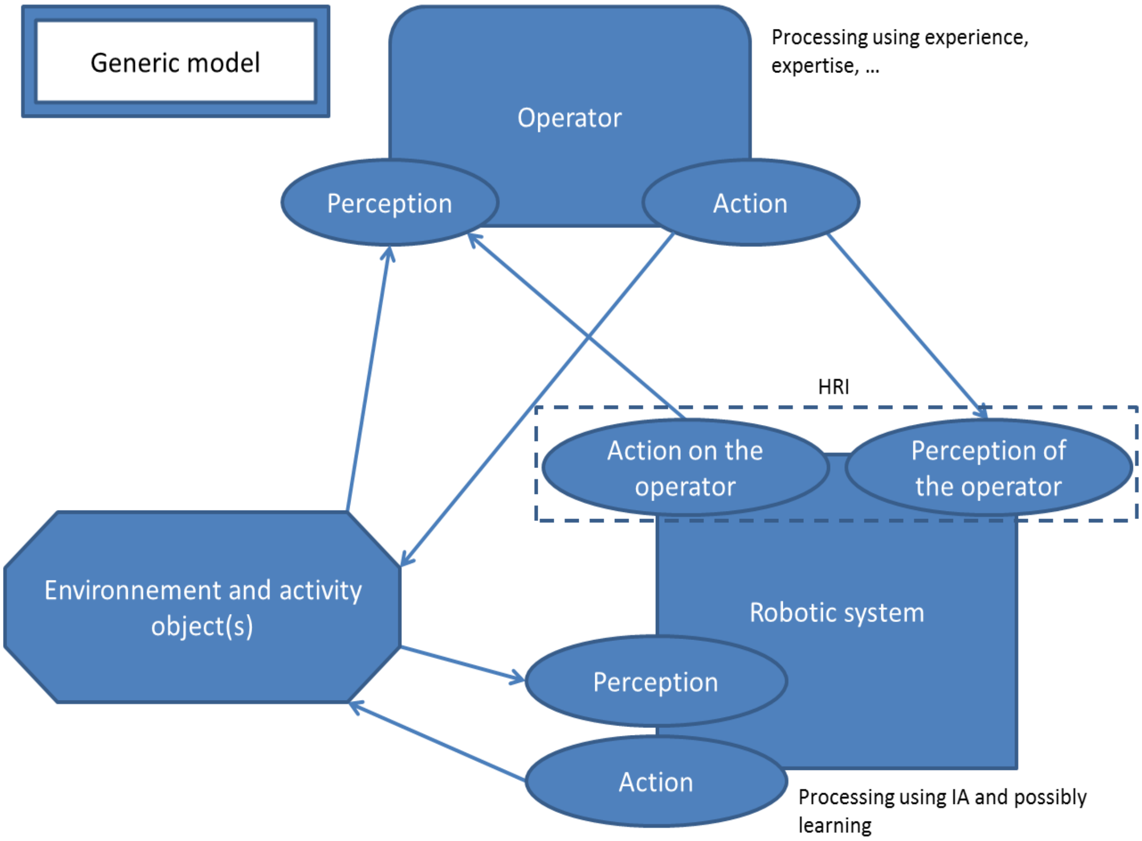

Figure 2 : Standard scheme.

3 CLASSIFICATION BY SCHEME

We propose a complementary classification method. It is based on the flow of information among the 3 components of a cobotic system: the environment of the workstation, the human and the cobot. The generic scheme is presented Figure 2. Interestingly, different cobotic systems have in general different schemes representing the flow of information. Several examples are proposed in appendix.

Going into the details, in a given environment, the robot is sensing information and acting onto that environment and on the objects and humans involved in the task. See Figure 3. The architecture of the robot allows information processing at different levels: perception, signal processing, planning, executing, acting, etc. (Alami, Chatila, Fleury, Ghallab, & Ingrand, 1998). The classification can take the architecture of the robot into account. Another important information that can directly be presented in the scheme is the type and abstraction of the information. For example, visual information can be captured by the camera of the robot and transmitted to the operator. Such information is not abstract. Even if the scheme would be the same, a robot capturing visual information but transmitting an interpretation of the scene by means of a synthetic voice would be completely different.

The work of the operator can also be described by a specific scheme representing the way information is processed. See Figure 4.

4 CONCLUSION

There are different classification methods to distinguish different cobotic systems. The morphology and the role of the operator are important. A complementary classification is suggested with the representation of the information flows. The schemes are different and characterize the use of the cobot. A perspective of this work is to define a guide based on the scheme analysis that would help in the design and finding of the best cobotic system configuration.

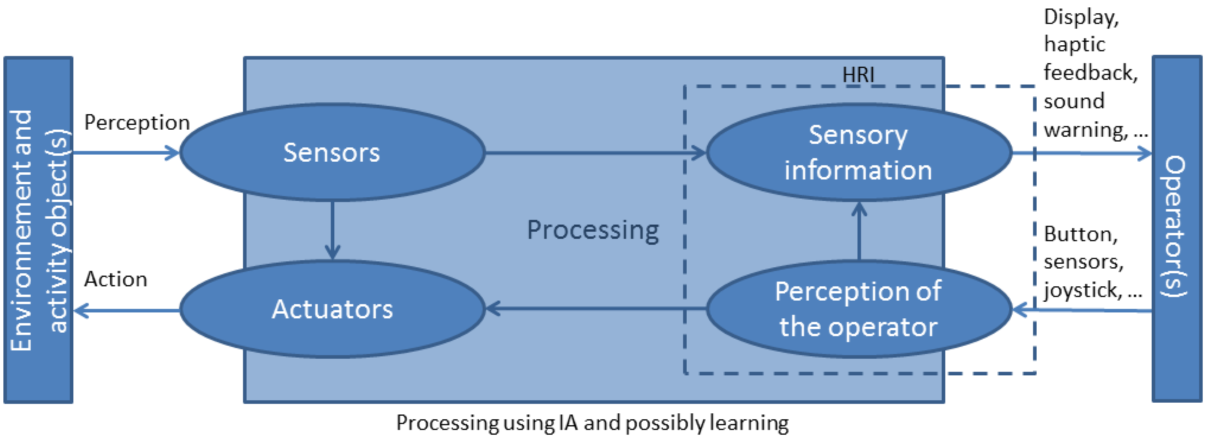

Figure 3: Information processing for the cobot.

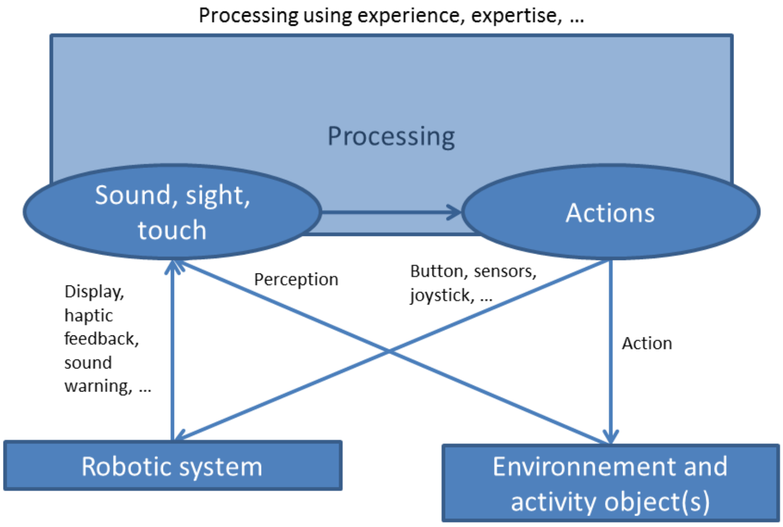

Figure 4: Information processing for the operator.

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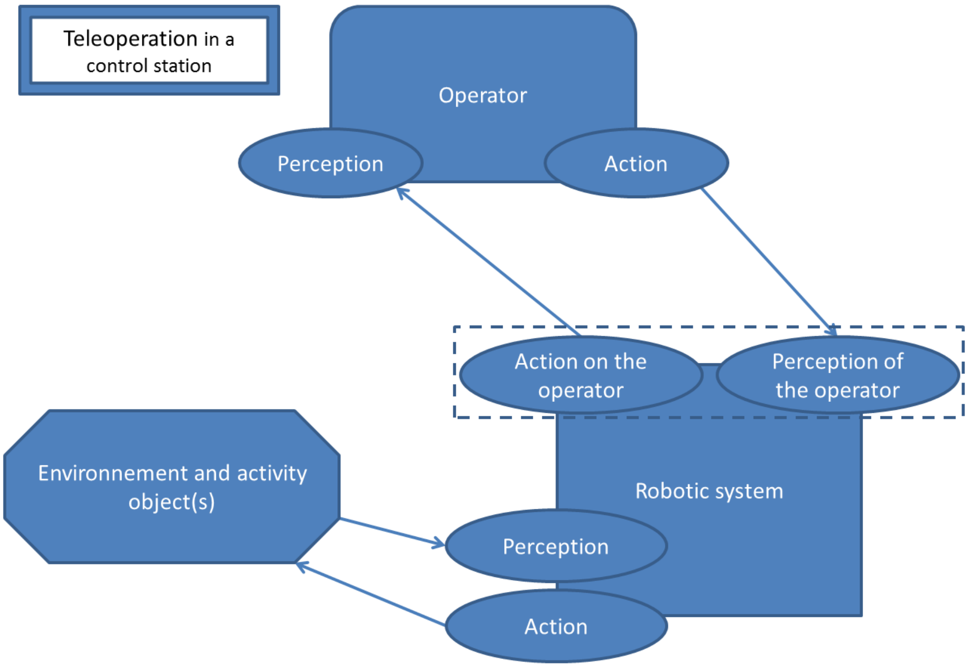
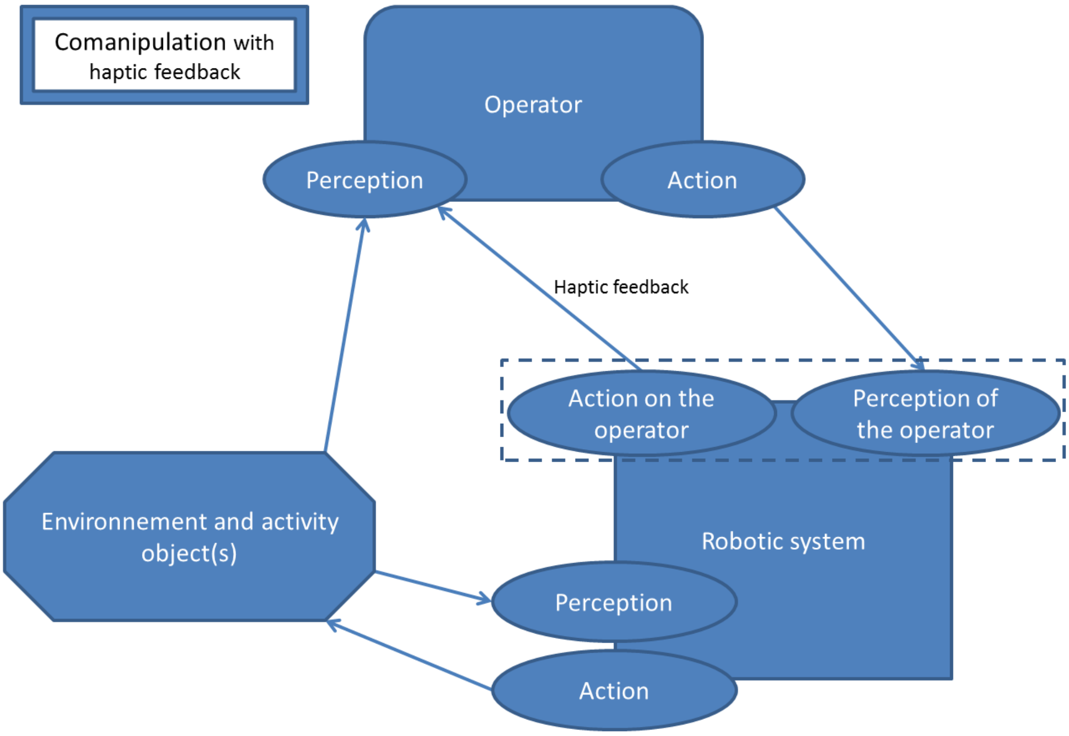
Appendix

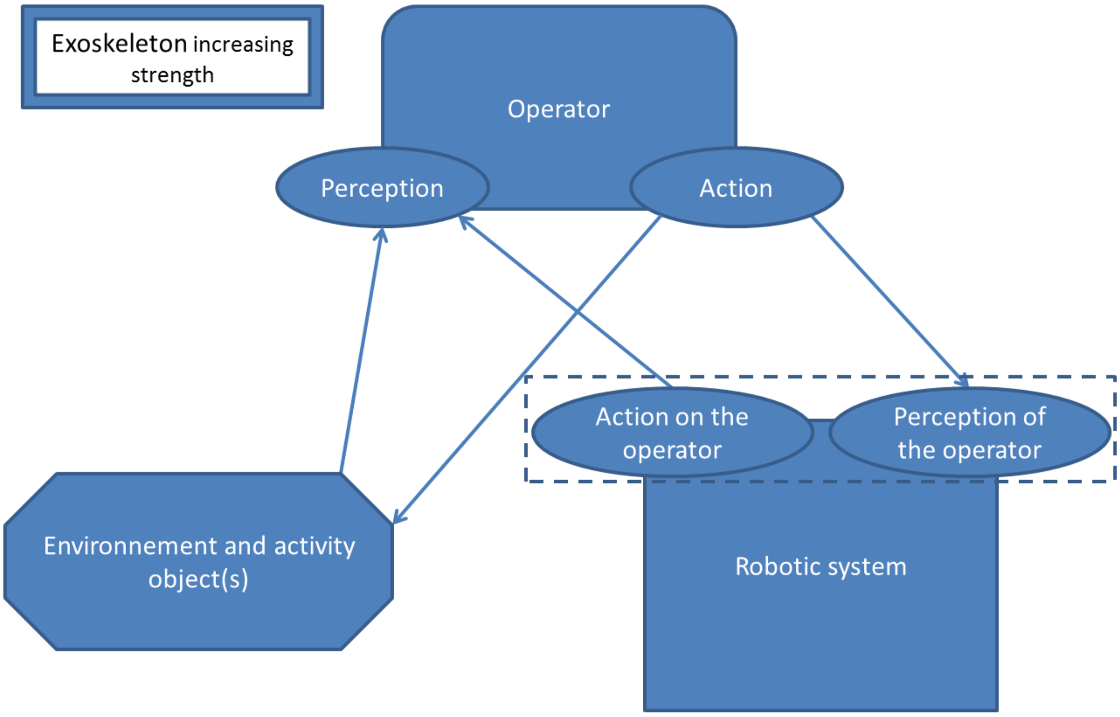
Case 1: An operator is teleoperating a robot through a camera. This is also the case of the Da Vinci robot that is teleoperated by the surgeon.



Case 2: Comanipulation with haptic feedback.



Case 3: Exoskeleton.



Case 4: Autonomous robot.