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# Cooperative patterns to support Human, Robot and Brain Computer Interface Interactions

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**Abstract— Brain-Computer Interface technology will be soon available to the general public. It would be to replace or compensate physical disability in the case of handicap. However, it would also be for all people looking for peaceful consciousness, to control environment from no other types of command but directly from the brain. Such a device that could be easily and quickly handled by untrained and novice users has been proposed by Mentalista. The company designed and trained a Brain-Computer Interface and in this paper, we propose a method to identify how such a device may be used to control a robot. The method proposes to identify the cooperative patterns that suit users' states and robot's abilities regarding the environment constraints. The Human-Machine Cooperation principles support the methodological approach.**

**Keywords— Cooperative patterns; Human-Machine Cooperation; Human-Computer Interface; Robotics**

## I. INTRODUCTION

When new interactions have to be designed between human and new technology, you have to invent almost everything. Designers from different fields cooperate to tackle human factors aspects as well as technical aspects. The use of a method could promote such a cooperation by providing a common language and tools to understand each other and to gradually design the new human-machine system. Among several methods, we use one that has been defined with a focus on human-machine cooperation [1], especially when cooperative patterns have to be extracted [2]. Indeed, the objective of our project is to design a system able to support humans to control a robot through a Brain-Computer Interface (BCI) made up of only one electrode for the analysis of visual cortex signals, but trained with many users. This type of BCI has been selected to find the best balance between the time spent to set up the BCI and the user satisfaction and comfort. Few literature exists on this tight scope [3], [4]. Human, BCI and robot, these three agents still have, or may have their own abilities to complete their functions, and their own abilities to cooperate with the other agents. The objective

of this paper is to propose a method to determine individual and cooperative functions of each agent, as well as their combinations in order to identify the best ones with the associated cooperative patterns. The results of this analysis are then used to program and implement the selected functions in a system based on BCI, robot and visual interface, and to train human to use this system. The method is presented in the next part. The third part deals with main results of the method used, regarding cooperative patterns that could be interesting to implement and evaluate. The fourth part presents the designed system, and the last part concludes the work in progress and introduce the perspectives.

## II. METHODOLOGY

The method applied in this work has been developed and already used to design cooperation of car and train drivers with embedded assistance systems (*e.g.* [5], [6]). The method is based on the Human-Machine Cooperation principles, especially on the model of a cooperative agent, defined by two main functions, the Know-How(-to-Operate) (KHO) and the Know-How-to-Cooperate (KHC) [7]. The KHO concerns the individual work of an agent, and KHC concerns the cooperative work of an agent. Respectively defined according to the extraction of simple functions from Rasmussen's model [8], as well as the definition of levels of automation provided by Parasuraman et al. [9], and definition of cooperation provided by Hoc [10], the main sub-functions are:

- for the Know-How:
  - to gather information from the environment
  - to analyze these information
  - to select decision
  - to implement action
- for the Know-How-to-Cooperate
  - to gather information on/from the partner
  - to detect interferences between partner and own work
  - to manage these interferences
  - to decide function allocation

The KHO and KHC functions and their sub-functions can be applied at several decisional levels such as strategic, tactical and operational levels. Agents may be involved in one or several levels. To cooperate inside one decisional level (levels of cooperation [11]) or between decisional levels (layers of cooperation [12]), agents use the so-called Common Work Space (CWS) [7]. This space, in the mind for human, in a memory space for system (e.g. a cloud) is a work space that shares not only the information about the environment but also information about agents (their KHO and KHC). Then, the CWS supports the situation awareness [13], as well as the team situation awareness (e.g. [14], [15]) and agents transparency (e.g. [16], [17]). The external representation of the CWS could be one or a combination of visual, sound, tactile and haptic interfaces.

In the present study, three decisional levels (operational, tactical and planning levels) [18] consider three agents, the Human, the BCI and the robot (cf. Fig. 1:). Then, three types of objectives could be addressed: (1) a set of trajectories to reach a precise destination, (2) one trajectory, updated according to foreseeable obstacles and (3) positions to manage unexpected events. The CWS of each decisional level is enriched by human intention. long-, medium- or short-term human intention must be recognized by BCI and then by robot. However, all CWSs are connected to enable complementary information and decision. Both BCI and robot provide feedback to the human through CWS so that the human can verify that the intent has been understood correctly.

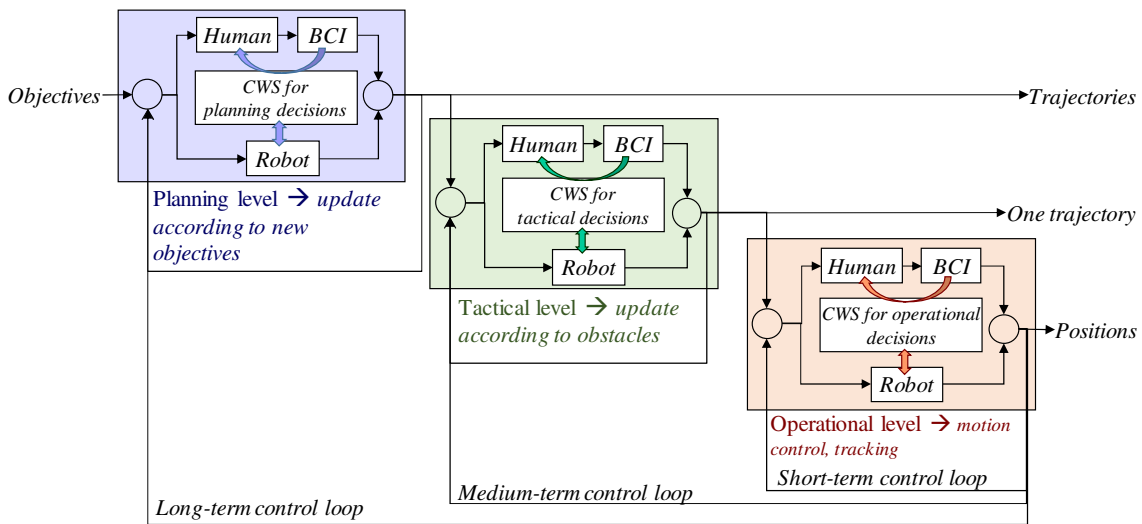


Fig. 1: Levels and layers of cooperation for human-BCI-Robot interactions: Human and robot cooperate at the planning, tactical and operational decisional levels, taking into account interaction between those levels, so-called layers of cooperation

Intention is only one entity among several ones that must be analyzed through cooperation. To support such an analysis, the methodology proposes to orient the design by providing grids to incite designers to ask themselves the right questions. Cooperation between agents is analyzed in pairs. The Fig. 2: provides an example of how to use the grid to study the cooperation between two agents, one human and one robot. Cooperation based on KHO only focuses on the abilities of each agent to control an environment or a process. Functions can be shared or traded between agents (upper-left part of the grid). KHC functions (upper-right and lower-left parts of the grid) support the way agents obtain information about each other. The Common Work Space (lower-right part) supports the sharing and communication of KHO and KHC information. In our study, three pairs can be analyzed: human/robot, human/BCI and robot/BCI cooperation.

Human has a direct cooperation with robot on two functions, IA, DS, because IG and AI can only be performed by robot. The robot gathers information from the environment through its sensors and implements actions by controlling motion to

reach a position (operational level), to follow a trajectory (tactical level) or to adapt trajectories (strategic level). Humans cannot gather information by themselves if they are not in the environment. This is the case when humans remotely control robot for telepresence. The robot provides information, then the human and the robot analyze information and both can make decisions. They share control when each agent's decision balances the other's decision. This type of control is useful for short-term trajectory updating. They trade control when they alternate on function control according to criteria such as performance, workload and situation awareness. One agent can perform better thanks to capabilities or capacities. The selection and application of those criteria are supported by cooperation, through the CWS, when each agent is able to assess the intention or current behavior of the other. The human can assess robot's IA, DS and AI according to the right functioning of its sensors, algorithms and motors. However, the robot is not able to assess human's behavior because wrong decision could be provided by BCI. However, robot can learn from user habits. Cooperative patterns could be learned and recognized by the

robot if the user tries to behave in a same way to reach same goals. The Human-Machine Interface can support such understanding and learning.

Indeed, BCI makes the link between human and robot, and, in our case, using only one electrode. In this study, BCI has been trained with many users and needs no more train to be used by new users. However, new users must be trained to use the BCI, but quickly and only on how they should behave for BCI being able to recognize correct patterns. In this work, BCI detects user visual attention, i.e. visual concentration. This signal is easily disrupted by parasitic thoughts. Then, users must be well-concentrated to cooperate with BCI to provide their intention. BCI has no KHO regarding the

general goal with robot. It only has KHC with robot and with human, and it shares information through CWS. Then, when users are cooperating with BCI, users must stop to cooperate, or at least stop to interact with robot, because brain signals would be disrupted. Robot can continue moving if user is fully confident in its behavior, or robot stops to avoid disturbing user. It depends on cooperation between human and robot, and cooperative patterns that are learned. Users know which kind of brain state they must have to cooperate with BCI. It could be complicated for people who can perform tasks using mouse or joystick, but less for people who really feels the need to only control with BCI (to compensate for a disability or to improve wellness by a better self-control).

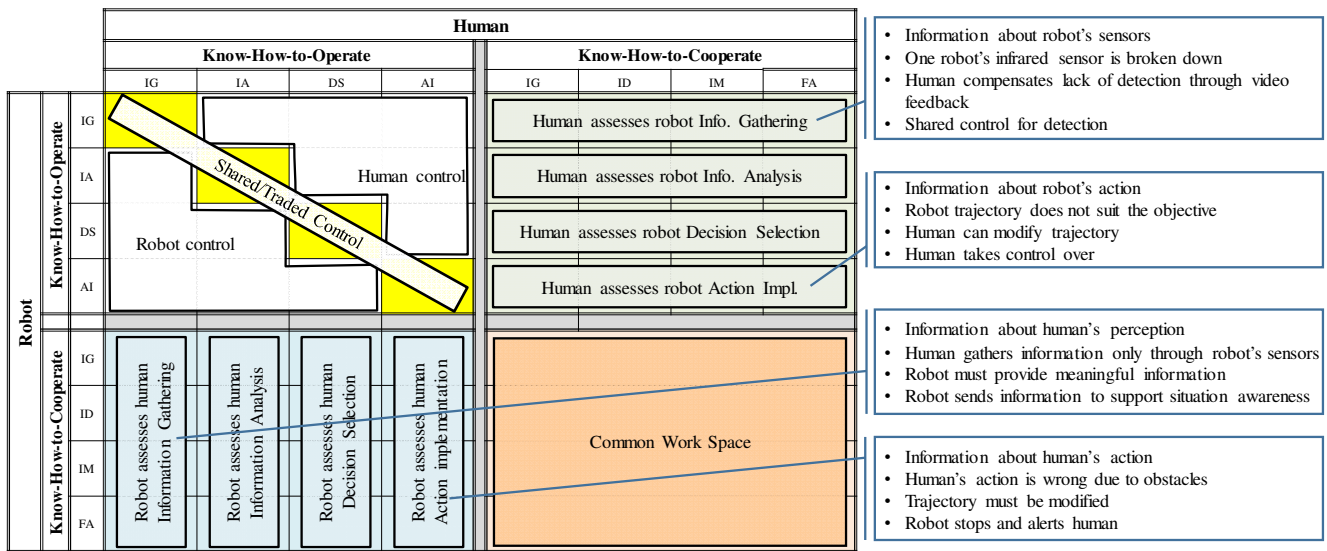


Fig. 2: Grid to support the analysis of agents cooperation. Example of Human-Robot cooperation analysis  
 Know-How-to-Operate (IG: Information Gathering, IA: Information Analysis, DS: Decision Selection, AI: Action Implementation;  
 Know-How-to-Cooperate (IG: Information Gathering on the other, ID: Interference Detection, IM: Interference management, FA: Function allocation)

BCI and robot cooperate if robot detects an interference about the human/BCI decision, i.e. the order it must apply. Robot can manage interference by requesting BCI/human if the decision is right.

The size of this paper does not allow to detail all functions involved in the Human-BCI-Robot cooperation, but few are presented to describe some cooperative patterns in the next part.

### III. COOPERATIVE PATTERNS

Identifying Cooperative patterns is the main way to be able to control a robot to complete several tasks with several levels of autonomy using only one electrode to send orders. Human, BCI and robot have specific procedures (for human) and programs (for BCI and robot), to cooperate. Patterns defined according to agents' competences and capacities, are applied depending on current situation and human intention and state.

As proposed in the second paragraph, human intention may address strategic, tactical and operational objectives. For humans to be able to provide their intention, the Common Work Space proposes a Human-Machine Interface (HMI) with three displays, one per objective. One display is selected among the three depending on the situation (e.g. short-term control to go to a precise position), or all three displays are slowly scanned until human selects one with visual attention (cf. Fig. 3):

- At the strategic level, a display dealing with the selection of functions is used. Functions deal with global objectives such as "find and catch an object", "go and turn inside a room".
- At the tactical level, a display dealing with trajectories is proposed. Using a HMI displaying the digital representation of the environment, predefined areas are proposed and human selects one.

- At the operational level, the display is based on the video feedback of the robot and a pointer scans the video to provide human with potential geographic target.

After the selection of one objective, the robot proposes one or more trajectories, depending on the predefined level of autonomy or the situation. Predefined levels of autonomy are identified during the design of the system. These levels of

autonomy are used at the strategic level to plan the function allocation, or at the tactical level to update the plan.

If human has no difficulty sending orders with BCI, the remote control can be used. On the opposite, once the objective is identified, robot can become autonomous to reach it.

When most of the cooperative patterns and functions are identified, the human-machine system can be programmed. The description of the system is detailed in the fourth part.

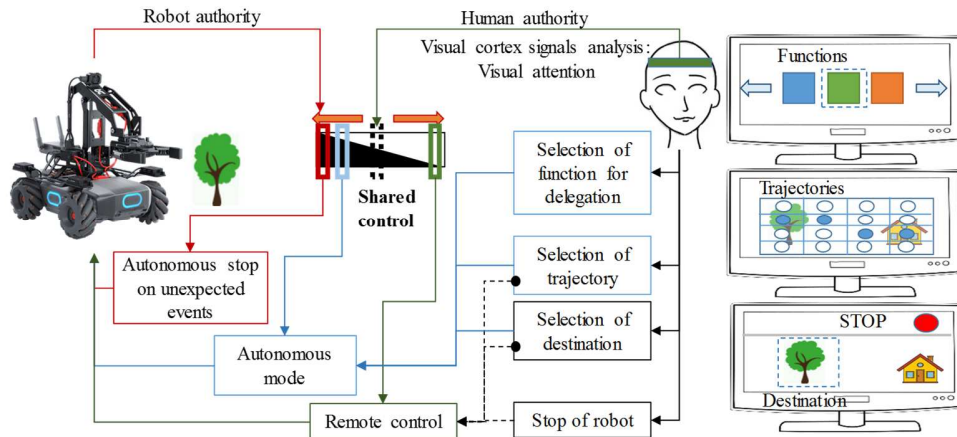


Fig. 3: Human intentions and agents authority control (shared control scale)  
Three displays in the CWS to reach three types of objective: function, trajectory and destination selection (right part of the figure)

#### IV. HUMAN-BCI-ROBOT SYSTEM

The system is based on an existing BCI and the associated HMI, but the robot and the HMI supporting its cooperation with human and BCI have been completely programmed for the study based on the previous analysis. The four parts of the system communicate through USB, Bluetooth and Wi-Fi (cf. Fig. 4:).

#### A. Brain-Computer Interface

The BCI has been provided by Mentalista, as well as the associated software, which is an adapted version of the OpenBCI software (open-source platform on <https://openbci.com/>), used with Processing and Java environment.

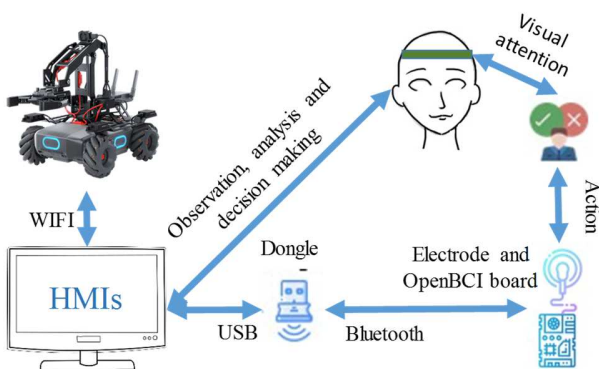


Fig. 4: Connections between a human wearing a headband with one electrode, a Human-Machine Interface and a robot.

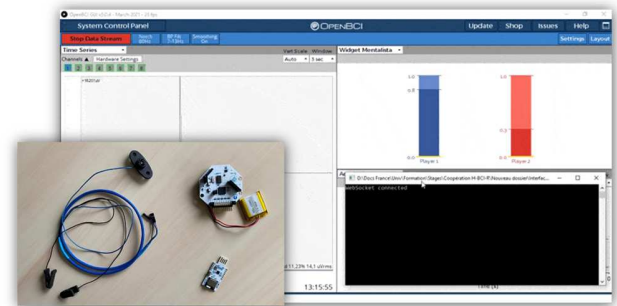


Fig. 5: Electrode, OpenBCI board, Dongle, and OpenBCI HMI (Baregraphs: level of visual attention of users)

In this study, OpenBCI software is used to detect level of visual attention of users. Users can check this level thanks to the associated HMI (cf. Fig. 5:), and adapt their brain state when their intention is not or wrongly detected. This HMI is part of the CWS. The signal is also sent to the general HMI in order to facilitate Human-BCI-Robot communication. This HMI is presented in the next part.

## B. Visual Interface.

The visual interface is a Python program that centralizes information from all agents, user, BCI and robot. From this HMI, all connections are managed (right part), and cooperation is supported (cf. Fig. 6:). Two displays, one for control (cf. Fig. 6) and one for robot positions and trajectories in the environment (cf. Fig. 7:) compose it.



Fig. 6: Main HMI to support Human-BCI-Robot cooperation: selection of autonomous control (upper-left part), remote control (lower-left part), robot feedback (center part), connection (right part)

The left part of the main HMI is used by experimenters or users in another context of using the robot, as explained in the next paragraph.

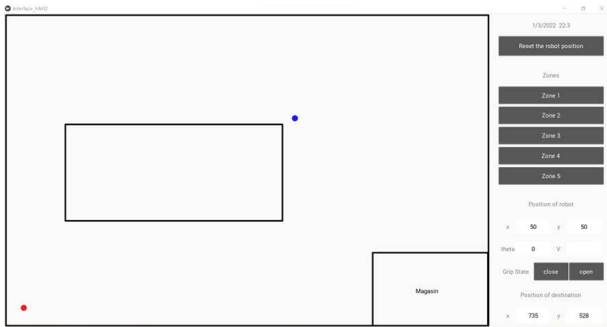


Fig. 7: HMI to supervise robots position (blue and red points on a bird's eye view of the area), selection of a pre-defined area for robot's destination (right part of the figure)

The HMI for supervision provides information about robot state and its position in the environment (red or blue point). Several areas of the environment can be predefined and scanned to support cooperation with the user.

## C. Robot

The robot is a Robomaster EP CORE. It is controlled through the above HMI with Python commands. Three control modes have been defined:

- the remote control using buttons on the HMI, or a joystick, or with BCI; only BCI mode is used in this study;
- the semi-autonomous control when only directions are provided;

- the autonomous control when the robot has to reach a destination autonomously.

The robot has one camera to provide video feedback to the user, the video is augmented by an analysis of the environment using existing libraries and a data base of objects. Built with four mecanum wheels that can be controlled independently, this robot can have left and right translations. Its robotic arm and grip can extend the number of scenario and therefore, the number of delegated tasks. Its four LED lights can be used to communicate with nearby users. Three infrared sensors (front, left and right sides) support semi-autonomous and autonomous control. Model Predictive Control (MPC) has been used to implement autonomous function.

$$J_i(k) = J_i^{navigation}(k) + J_i^{control}(k) + J_i^{safety}(k)$$

$$J_i^{direct}(k) + J_i^{partners}(k)$$

$$J_i^{partner}(k) + J_i^{obstacle}(k)$$

Fig. 8: Robomaster EP CORE – Cost function

A dynamic model of robot and a cost function have been defined for MPC implementation and trajectory optimization. Three costs have been calculated (cf. Fig. 8:). The first one addresses navigation aspects by taking into account destination and organization with partners such as human or other robots. The second one is the control of energy consumption. The third one tackles safety constraints and especially mobile or static obstacle, like human or robot partner or furniture.

## V. CONCLUSION AND PERSPECTIVES

This paper had the objective to present a method to support the design of a new system. Thanks to this method several individual and cooperative functions have been identified for human, BCI and robot. The method also supports the design of HMIs. The system is not fully implemented yet. Connections between the three technical entities are made (HMIs, robot, BCI), BCI is programmed, but HMIs and robot must be finalized.

Many technical questions are still arise. Algorithms other than MPC will be implemented and tested; the goal is to be sure of the behavior of the robot because it would be difficult to modify a wrong trajectory with BCI. Depending on the experience and background, user concentration would be difficult to control, and it would be worse if the technical entities did not behave as expected.

The dynamic aspect of the overall system must also be taken into account. Response time and synchronization between all entities (BCI, robot, camera...) must be evaluated and controlled. One way to control risks of delay or desynchronization would be to identify criteria that would be

used to decide which human and robot has the authority on robot's motion.

Once the system implementation is finished, we will define the experimental protocol to evaluate the Human-Machines System (HMS), especially its usefulness but from several points of view. Indeed, objectives are different if the HMS is used in the case of handicap or wellness. Human needs would be different, as well as human objectives. In the case of handicap, the human needs to reach the goal to see something or someone, or to catch an object. Robot behavior must be well known by user, well trained, and adapted to such goals. The control of the robot must be easy to really support the user. In this example, machine learning could be useful for the robot to learn from the user habits, *e.g.* trajectories or objects or areas are usually the same. In that case, robot and BCI can build up cooperative patterns about the usual way a user is proceeding.

In the case of wellness, the objective of the user is to be able to be concentrated enough to control the robot. In this example, users do not have strong needs, but must train themselves to shut down all thoughts except the one for the visual concentration. Then, the robot or the BCI will not be able to learn usual actions of the users, so they will not facilitate users' control.

To sum up, some works remain to be done before being able to evaluate the HMS, but experiments are likely to be fruitful, especially regarding all the possible combinations of human, robot and BCI individual and cooperative functions. Human needs, background and experience can influence such combinations and define the right cooperative patterns to implement.

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