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Abstract: The objective of the paper is to present an approach used in order to define task sharing between human operator and robot, when new functions have to be defined for human operator and new autonomous functions are available for robot. A study of complementarities between levels of automation and human machine cooperation approaches is firstly proposed, and leads to the definition of three main axes necessary to design and evaluate human-machine systems and cooperation. An example of use of these definitions is then proposed to study of cooperation between a human operator and an unmanned ground vehicle with various levels of autonomy.

Keywords: Human-centered design, Cooperation, Autonomous mobile robots, Cognitive science.

1. INTRODUCTION

Like in several industrial projects, main concerns of robotics' research are the technological point of view and the improvement of the functions of robots. Robots have now more and more competences and they can be autonomous to perform several tasks but not all the tasks. Human operator is still essential to ensure safety and performance of the global system. Our study deals with the send of unmanned ground vehicles for reconnaissance purposes. Robot maneuvering in unstructured environment defines a global dynamic process. Objectives are to reach process stability and to keep overall performance using Human-Machine Cooperation (HMC) principles. This communication aims at presenting these principles and their applications to robotics. So, the first point deals with HMC with a focus on levels of automation and their impacts on HMC definition. Complementary definitions are hence provided. Third part proposes an application of HMC to robotics. Fourth part presents two experiments conducted with one human operator for whom the work has to be defined and an unmanned ground vehicle.

2. FROM LEVELS OF AUTOMATION TO HUMAN-MACHINE COOPERATION

HMC principles were elaborated in order to early take into account human factors in the design and evaluation of human-machine system (Pacaux, 10). First steps are the analysis of process and commands in order to analyze prescribed tasks of human operator. Next steps are the choice of the assistance tool, especially the tasks sharing between human operator and assistance tool. Next paragraph presents studies about the definition of levels of automation which constitute one way to realize the sharing.

2.1 Levels of automation

One way to study how human operator and assistance tool can work together consists already in knowing the competences of each one. In other words the objective is to identify the ability of each agent. Sheridan proposed a machine centered approach by defining levels of automation (Sheridan, 92). The ten levels are presented as following, where the assistance tool:

1. Offers no assistance
2. Offers a complete set of decision/action alternatives
3. Narrows the selection down to a few
4. Suggests one alternative
5. Executes that suggestion if the human approves
6. Allows the human a restricted time to veto before automatic execution
7. Executes automatically, then necessarily informs the human
8. Informs the human only if asked
9. Informs the human only if it, the computer, decides to
10. Decides everything, acts autonomously, ignoring the human

One more level was added by Inagaki. At 6.5 level, the assistance tool executes automatically after telling the human what it is going to do (Inagaki, 2006).

In this definition, the ability of the assistance tool is based on two main activities: decision making and execution of decision. The ability to make a decision would be split into three levels (from 2 to 4): a proposition of set of decisions/alternatives, a selection of decisions or one selected decision. Concerning the ability to execute a decision, two levels of decision making would be done (from 5 to 10). One

level is the ability for the assistance tool to perform the execution. Second level is the ability for the assistance tool to decide the allocation of a task. The fourth last levels differ from communication aspects. To sum up, Sheridan organized the ten levels according to the precision of the decision making, the ability to decide allocation and the ability to communicate to human operator.

Another taxonomy of levels of automation was proposed by Kaber and Endsley. It concerns a more human centered approach. Ten levels were also proposed but according to four types of activity: Monitoring, Generating, Selecting and Implementing (Kaber & Endsley, 04). The two first main activities are detailed by the authors as roles and allocated to one agent, the human operator or the assistance tool, or both. Monitoring includes information gathering in order to perceive system status. Generating allows formulating of task strategies for achieving goals. Selecting leads to choose a particular strategy. Implementing carries out the chosen strategy.

A similar approach was proposed by Parasuraman by defining automation at four stages (Parasuraman, 00).

Assistance tool:

- Involves acquisition of multiple sources of information and includes sensory processing, preprocessing of data, and selective attention.
- Involves manipulation of information in working memory and cognitive operations such as integration, diagnosis, and inference, occurring prior to the point of decision.
- Involves decisions based on such cognitive processing.
- Entails an action consistent with the decision choice.

Activities presented in stages appear to be a detail of activities presented by Endsley and Kaber. But, while these authors try to look at levels of automation with a gradual increase of assistance tool ability and control, Parasuraman proposes three levels or types of autonomy:

- Autonomous sensing (information acquisition and data transformation) to make observations and to refine information,
- Autonomous planning (information interpretation and decision selection) to react to information or to decide actions and schedule, and
- Autonomous acting (action implementation) to execute a planned task or to produce reflexive reactions.

Table 1: Synthesis for levels of automation taxonomy: H for Human operator, M for Machine (Kaber and Endsley's levels in brackets, Sheridan's levels without brackets) according to the four stages proposed by Parasuraman.

	Levels of automation	Criteria of task allocation	Information acquisition	Information analysis	Decision and action selection	Action implementation
1-(1)	No assistance		H	H	H	H
2	Set of decisions		H/M	M	H	H
3	Selection of a few decisions		H/M	M	H	H
4	Selection of one decision		H/M	M	H	H
(2)	Action support		H/M	H	H	H & M
(3)	Batch Processing	Explicit allocation of action	H/M	H	H	M
(4)	Sharing control	Explicit allocation of action	H/M	H & M	H	H & M
(5)	Decision support	Explicit allocation of action	H/M	H & M	H	M
5	Carrying out of one solution	if $t_c(H) \neq 0$	H/M	M	H	H/M
(6)	Blended decision making	Explicit allocation for each step	H/M	H & M	H or M	M
6	Carrying out of one solution	if $t_c(H) < t_{limit}$	H/M	M	H/M	H/M
(7)	Rigid system	Explicit allocation of action	H/M	M	H	M
(8)	Automated decision making	Implicit allocation for each step	H/M	M & H	M	M
(9)	Supervisory control	Implicit allocation for each step	H/M	M or H	M	M
6.5	Carrying out of one solution	$t_i(M) < t_a(M)$	H/M	M	M	M
7	Carrying out of one solution	$t_i(M) > t_a(M)$ & implicit feedback	H/M	M	M	M
8	Carrying out of one solution	$t_i(M) > t_a(M)$ & explicit feedback	H/M	M	M	M
9	Carrying out of one solution	$t_i(M) > t_a(M)$ & assessed feedback	H/M	M	M	M
10-(10)	Full automation		M	M	M	M

Table 1 proposes a synthesis mixing the three approaches presented before, by integrating progressively more ability of the assistance tool and according to types of activity. We try to formalize criteria in order to distinguish levels for which assistance tool is able to carry out a solution or/and to decide an allocation. Explicit allocation differs from implicit allocation by the fact that human operator confirms or not the allocation respectively. In order to complete these two types of allocation, we define three kinds of time.

The first one used by the level 5 is t_c. It makes reference to the ability for the assistance tool to control the allocation of the solution implementation. If human operator consents to allocate the implementation to assistance tool by answering to a question from it, t_c is different from zero and implementation is automated. This value is also used by the level 6 but in order to be compared to a time limit. If human operator doesn't veto the allocation of decision and/or action, these activities are automated. The other defined times are t_i and t_a. They are respectively the time to provide or to require information to the other, and the time to perform the action. Levels from 6.5 to 9 are different according to these times. The action is performed by the assistance tool before or after giving feedback. Communication between human operator and assistance tool only deals with feedback about automated implementation. The feedback is implicit when it is always provided by the assistance tool. It is explicit when it is on human operator demand. It is assessed when the assistance tool assesses the necessity to provide the feedback.

Contrary to Sheridan, Kaber and Endsley do not discuss in terms of elapsed time to decide allocation or to give feedback. They focus on the need for the human operator to validate the allocation. Moreover, the allocation do not relate to action but also to diagnosis and decision making. The representation of levels of automation proposed by the table 1 underlines what would be a sharing of the role according to the type of ability human operator and assistance tool have. A look at this table (from level 2 until 9) shows that both agents need to gather information. But information acquisition can be different between the two agents, especially if human operator and assistance tool have not the same access to process information.

To sum up, table 1 underlines the task that can be allocated to the human operator, to the assistance tool or both. When only one agent can perform a task, it is a predefined task sharing. When two agents can perform a task, criteria must be defined in order to select one, or to know how a task can be split into subtasks in order to share the load. But table 1 also underlines some lacks. For example, new levels can be imagined by combining differently the four stages proposed by Parasuraman. Moreover, more criteria than time, feedback or allocation decision making can be imagined in order to share tasks. Such thoughts define main bases of Human-Machine Cooperation domain.

2.2 Human-Machine Cooperation

The three main aspects studied by Human-Machine Cooperation domain are the identification of the abilities of each agent to be involved in the process control, the identification of the abilities of each agent to exchange information with the other, and the identification of the criteria to define the sharing of a task. These three aspects are similar to task sharing criteria proposed by Rasmussen et al. (94): abilities, coordination demand, safety/reliability and workload, access to information. They are presented in (Millot, 98) and (Pacaux-Lemoine, 02) and defined such as know-how, know-how-to-cooperate and task allocation criteria. Each aspect is detailed in the following paragraphs.

Agent's know-how

As detailed by levels of automation, know-how of each agent, human operator and assistance tool, can be specialized in one type of activity and main differences appear between the agent ability to diagnosis, to make decision and to act. But these activities are also dispatched among levels of activity. In Air Traffic Control domain, we usually used three levels: the operational, tactical and strategic level. Other domains, like car driving, usually used the control, guided and planned levels. Operational level is about task carrying out, tactical level is about plan carrying out and strategic level is about definition of plan and task allocation. For each level, the performance of a task is cut into four stages. These stages are similar to the ones defined by Parasuraman or Kaber and Endlsey, and are the information gathering, diagnosis, decision making and action implementation.

In order to perform a task agents build a current representation of the situation. In other words, they gather information on the process to diagnose its state. We called the current representation of the situation the internal current representation (Pacaux & Loiselet, 02). The current representation is also called frame of reference (Hoc, 01). It is a kind of model an agent has of the process all the time. It is updated according to process change or when another agent interferes with it by challenging some parts, like common goals, resources or procedure. The detection of interference is a first step to trigger cooperative activity, but cooperation also involves that agents try to facilitate these parts of activity of the other (Hoc & Pacaux-Lemoine, 98). Interference detection and management are the two necessary conditions in order to be able to deal with cooperative activity, also called the know-how-to-cooperate. This notion is detailed in the next paragraph.

Agent's know-how-to-cooperate

Cooperative activities can be presented according time spans and level of abstraction. Author distinguishes three cooperation levels: action, plan levels and meta-level (Hoc, 01):

- Cooperation in action level groups together activities that have direct implications in the short-term, and includes local interference creation, detection, and resolution. It also integrates the anticipation of interference by identifying the goals of the other agents in the short-term. An interference is negative or positive.
- Cooperation in plan level consists in maintaining or/and elaborating the common frame of reference. Its maintenance and elaboration concern common goals, common plans, role allocation, action monitoring and evaluation and common representations of the environment. So, agents exchange information, problems, strategies, solutions and commands for sharing internal frame of reference. Three forms of negative interference management may be used: negotiation, acceptance, imposition (Pacaux & Debernard, 02). These forms imply, for human agent, cognitive and communication costs which are different. The negotiation aims at reducing the differences between both internal current representations by modifying one of them, on the basis of explanations between the agents. The acceptance is the update of the internal current representation from the interpretation of the internal current representation of the other agent. This acceptance is chosen when the cost of a negotiation is too important or when an agent wants to facilitate the activities of the other. The imposition corresponds to the opposite of the acceptance.
- Meta-cooperation, i.e. cooperation at the meta-level situated at a much higher abstraction level, allows the agents to improve the cooperative activities described above by elaborating long-term constructs, such as a common code to communicate easily and shortly, compatible representations formats, and above all models of one self and of the other agents. The meta-cooperation provides the agent with a model of the other agents. The model allows the agent to build an interpretation of the internal current representation of the other agent. Nevertheless this interpretation can be false.

When agents do not share the same workplace, or when they do not speak the same language, or when one agent is human and the other a machine, it is necessary to design a work

space. When the objective is to support cooperative activity, the work space has to support the common frame of reference. We called this support tool the common work space (Pacaux & Debernard, 02). It is the gathering of the external current representation of each agent, which is the current representation that one agent wants to share with the others (Pacaux & Loiselet, 02). But more than sharing information about process and their understanding of it, with the common work space each agent can also express its understanding and its will of cooperative activity. Common work space is often materialized by a display. Other researches have a similar approach by underlining the necessity for one agent to show her/his/its activity to the other (Schmidt, 04), by elaborating shared cognitive environment (set of events manifested to both agents), and/or mutual cognitive environment (agents' identity is manifested) and/or externalization of representations (Zhang & Norman, 94). The notions of egocentric vs. exocentric frame of reference were also defined for the local navigational task vs. spatial awareness task; redundancy between these frame of references would lead to better coordination (Perush, 86). Common work space would make up for asynchronous cooperation or the increase of time delay feedback (Sarter, 97).

Task allocation criteria

The trend is often to have a machine centered approach by predefining task sharing by fixing information and actions. Usually, the criterion is to have an optimal performance of the global human-machine system in certain conditions. But system needs to be more flexible in order to be able to cope with unexpected events. This necessity introduces the interest of dynamic task allocation domain. As presented before one way to decide allocation is to identify the level of automation corresponding to the instantaneous state of the process and to identify who has the control of the allocation: if both agents can have the control, the question is which criteria should be used to select the agent.

Improving the reliability of human-machine system:

The debative form of cooperation proposed by Schmidt (91) has this objective. That implies that the know-how of the agents is the same. The task is not decomposed into sub-tasks but realised by each agent at the same time to underline interferences and to choose the best result. Sheridan (92) made the distinction between the task sharing and the task trading. Task trading is similar to the objective of the debative form because one task is allocated to human operator or assistance tool and either of them can transfer the control to the other. With task sharing, human operator and assistance tool control different aspects of the process at the same time. Task sharing is used by following criteria.

Improving the capacity of human-machine system:

In this case Schmidt (91) proposed the augmentative form of cooperation. This form appears when the capacity of an agent is not sufficient to perform a task (problem of overload). The know-how of the agents is similar so the task is decomposed into similar sub-tasks allocated to each agent. With the same idea, Sheridan (92) proposed a task sharing with the relief type in order to avoid human operator overloaded.

Improving the adaptability of human-machine system:

The integrative form of cooperation appears when the know-how of an agent is not sufficient to perform a task (Schmidt, 91). Other agents with different know-how have to participate to reach the goal. The task is decomposed into many sub-tasks which are allocated to agents according to their know-how. In this case, Sheridan (92) proposed task sharing with extension type in order to extend the capabilities of the human-machine system.

Once criteria are defined, next step is to know whom from human operator and assistance tool controls the allocation.

Allocation by the human operator

This case was mentioned by Rieger and Greenstein (82) who defined the explicit mode of allocation when human operator decides to allocate a task to assistance tool. Similar approach was proposed by Inagaki (03) with the human-initiated automation invocation.

Allocation by the assistance tool

To the opposite of the explicit mode of allocation, Rieger and Greenstein (82) defined the implicit mode of allocation when assistance tool decides to take the control over. System-initiated automation invocation was also mentioned by Inagaki (03). But task allocation is an additional task which can increase human operator workload. So, a third mode was defined and called the assisted explicit mode (Pacaux-Lemoine, 96). A first allocation was realized by the assistance tool but the human operator can change it. The assistance tool decides the allocation according to criteria defined with human operator. If criteria are well respected by the assistance tool workload of human operator would decrease. Executive and automated display logic proposed by Inagaki (03) is similar; assistance tool prepares an action and waits for human operator agreement. The last of the three logics proposed by Inagaki is the emergency logic during which there's no enough time to let the human operator to make decision. This logic is similar to the time limit defined by Sheridan (cf. table 1). But how defining this time limit? Among the three strategies proposed by Inagaki two can be used for that. Called critical-event driven strategy and measurement-based driven strategy, assistance tool respectively gathers information from process and from human operator state in order to decide allocation. The last strategy, called model-based driven strategy, is based on the use of models to predict the performance of agents according to their intents, instantaneous abilities and resources.

Synthesis

So, in order to set up a "good" cooperation, i.e. easy but efficient, with obvious interests, adaptive and understandable, three main notions manage cooperative activity:

- Agents' know-how which is necessary in order to define the level of automation for one time span and the purpose of the cooperation.
- Agents' know-how-to-cooperate which is necessary to define the form of cooperation for a time span and the tools to support cooperation such as common work space.
- Dynamic allocation criteria which are necessary to define time span for one level of automation or form of

cooperation, and the rules to change from one time span to another.

These notions should now be compared to the ones used by robotics approaches. In the past, robotic systems were mainly designed following a machine-centered paradigm but showed some limitations. Taking into the human factors has thus become an increasing concern. One way to achieve this goal is to complement the well formalized and computerized aspect of robotics with the notions used in human-machine cooperation. This work is presented in the following paragraph.

3. COOPERATION IN ROBOTICS

Human-machine cooperation was not the theoretical base of robotics studies. They rather deal with robot autonomy even if the objective is similar. Most of researches deal with full autonomy of robots and cooperation between several robots, but some of researches involve human aspect mainly to support communication. Some approaches such as adaptive automation (Kaber, 06), (Woods, 04), adjustable autonomy (Baker, 04), situation adaptive autonomy (Inagaki, 06) or mixed-autonomy (Goodrich, 01), (Finzi, 05) were so proposed, but they mainly take into account workload as human factors criteria to share task between robot and human operator, but nevertheless common frame of reference, one of the main support of situation awareness, is not enough considered.

So, in order to elaborate "good" cooperation a mixed of the several approaches presented in the above paragraphs is proposed and illustrated with the sample of cooperative activities studied during experiments presented afterwards.

3.1 Human operator's and robot know-how

Know-how of each agent must be identified. It is realized according to a table describing, for each level of activity, the agent's needs in terms of information acquisition, information analysis, decision and action selection, and action implementation (for example, cf. table 2). This information is usually mainly identified concerning robot. Engineers know the abilities of the robot they build but they are not used to split functionalities as proposed here. This translation is a necessary work to make robot abilities understandable by future users. Technical features are translated in order to be adapted to human operator vocabulary and activity.

Fig. 2. The R-Trooper of Thales Optronic SA

The know-how of human operator is less easy to identify especially when it is a new job to imagine, such as the situation we have to study. A robot, called R-Trooper, designed by Thales group, is an unmanned ground vehicle, a multi-role six-wheeled platform with a maximum speed of 50 km/h, powered by a hybrid system (cf. Fig. 2).

Several sensorimotor functions were developed in order to make the robot autonomous for particular tasks such as edge and target tracking.

Human operator's work was not well defined but the objective of the global human-robot system was to complete a reconnaissance mission. Teleoperators have the requested know-how to complete this type of mission they are used to do in pairs, even if they can execute it with a decrease of performance by achieving the task more slowly or with more risks to not perceive important information. So, the objective was to allocate, if possible, the management of robot's moving to robot using its sensorimotor behaviors, and to allocate information tracking to human operator. Nevertheless when robot has not the know-how to move because of an environment too difficult (lost of target or edge), human operator must take back the control, temporarily or until the end of the mission. This know-how is situated at the operational level and concerns the choice and use of sensorimotor behaviors. Tactical level is more oriented mission-completion-oriented by respecting the plan of the mission. A mission is described by several points called goals and a sensorimotor behavior can be associated to each segment defined by two goals (for example cf. Fig. 4). Both agents have the know-how to identify goals and to change from one to another. New goal can also be added by human operator. Strategic level is dedicated to the definition of the plan. An example of studied know-how is presented in the table 2.

3.2 Human operator's and robot know-how-to-cooperate

Know-how-to-cooperate of agents has the objective to allow them to build a model of the other in order to know, more or less precisely, what would be the other's understanding of the current process and what the other would do or plan to control it according to the level of automation and the form of cooperation. Level of automation allows knowing which of the two agents has the better know-how to do something. The form of cooperation allows knowing, if both agents have similar know-how, which of diagnosis and/or decision making and/or actions of each agent are better to reach the global goal. No optimal solution solves this question but a cooperation mode can be found based on some criteria, such as the ones mentioned above. Know-how-to-cooperate also allows to provide the other with information if this other would need it and if it is not overloading. In the case of robotics, information is mainly provided by robot and little by human operator who supervises the mission and intervenes when a problem appears or when new information or goals are provided by more strategic level or by the environment. In the case of R-Trooper, all exchanges between human operator and robot are supported by two displays, one about the mission plan and the other about the task in progress. These displays make up the common work space. It gives information about the mission which is the

process the human operator and the robot have to control, and information about agents' know-how and know-how-to-cooperate such as the ones presented in the table 2. Task allocation is the most important provided information and other information mainly justify it. Task allocation is presented in the following paragraph.

Table 2: Human operator's and robot know-how and know-how-to-cooperate according to level of activity and type of activity

	Information acquisition		**Information analysis**		**Decision and action selection**		**Action implementation**	
Know-how								
	Human	**Robot**	**Human**	**Robot**	**Human**	**Robot**	**Human**	**Robot**
Strategic level	Commands / orders		Mission completion		Plan modification		To modify plan	
Tactical level	Current objectives (mobility and reconnaissance)	Current objectives (only mobility)	Goal and object identification for reconnaissance	Next goal	Goals modification and reconnaissance of objects	Goal use or lost	To modify goal	
Operational level	All objects	Specific objects (edge, target, obstacle)	Trajectory	Choise of its sensorimotor behaviors	Stopping or not the mobility	About stopping or not the mobility	To teleoperate or to stop mobility	To continue or to stop mobility
Know-how-to-cooperate								
Strategic level	Task allocation for all the mission	Task allocation for all the mission	Task allocation analysis according to criteria	Allocation problem	Allocation modification	Allocation modification	To decrease or increase level of autonomy	To decrease level of autonomy
Tactical level	Robot behaviour	Object to use as goal	Robot behaviour analysis according current or new goal	Problem with current goal	New goal to add in the plan and robot behaviour to change or to learn	Selection of next goal	To provide information concerning new goal	To choice next goal or to ask information
Operational level	Using robot sensors	Feedback about sensorimotor behavior	Robot behaviour according to trajectory	Information human operator can't have		Use of new sensorimotor behavior and obstacle		To provide information concerning trajectory

3.3 Dynamic task allocation criteria

The control of robot moving is the shareable task, i.e. the task that human operator as well as robot can perform. In other words it is the intersection between agent's know-how. Four modes of autonomy were defined regarding the allocation of moving control, based on the classification presented in section 2.1:

- M0: human operator controls robot moves (teleoperation with safety functions) (operational level)
- M1: human operator decides which sensorimotor behavior the robot has to use and when to start,
- M2: robot chooses the sensorimotor behavior to use and when to start if there is no veto from the human operator,
- M3: robot chooses the sensorimotor behavior to use and when to start.

But, as a precaution whichever the mode of autonomy, the human operator has always the authority and can get the control back. Task allocation criteria were based on robot's know-how, i.e. all the moves the robot can perform alone were allocated to it. These modes of autonomy were evaluated in the following experiments.

4. EXPERIMENTS: METHOD AND RESULTS

Two experiments were conducted. The first one had the objective to evaluate the possibility and the interest to give the control to robot, and no other objective than respecting trajectory was asked. During the second experiment, human operator had the objective to do reconnaissance by searching for objects in the environment (a private car, a van and a red and white round target). Only the human operator can perform this task. In the first experiment, human operators have all the time to supervise robot's actions. In the second experiment they need to trust robot in order to perform their own tasks. Objectives of these experiments were to evaluate modes of autonomy but moreover to identify the needs in terms of know-how.

4.1 Participants

Because there was already no job corresponding to the task to perform during these experiments, two types of experts were chosen. For the first experiment, three participants were professional teleoperators of the French Department of Defence, and two participants were robotics experts of Thales group. For the second experiment, two professional teleoperators including one of the first experiment performed experimental scenarios.

4.2 Apparatus

Each experiment was conducted with one participant and the R-Trooper. Participant performed task from a specific workstation in a room near experimenters during first experiment, in a special vehicle in the second experiment. They were not able to see the robot in its environment. Participants kept in touch with experimenters, by radio, in order to be assisted if they did not understand something or if they did not know how to perform a task. This way allows to identify lacks and needs in terms of systems design or human operators training about know-how and know-how-to-cooperate.

The first experiment was conducted with the technique of the Wizard of Oz. The main goal of this technique is to avoid spending to much time in programming systems without interest. So, modes of autonomy were not designed but they were simulated by a hidden human operator. Participants were not aware of this simulation and behaved as the modes were real ones (Fig. 3). Agent 1 (A1) simulated the robot know-how for the operational level. Agent 2 (A2) simulated the robot know-how for the tactical level. Agent 3 (A3) simulated the robot know-how-to-cooperate for the tactical level (tasks' state update). Agent 4 (A4) simulated the robot know-how-to-cooperate for the operational level (tracking).

The second experiment was performed with real modes of autonomy, i.e. the programmed modes.

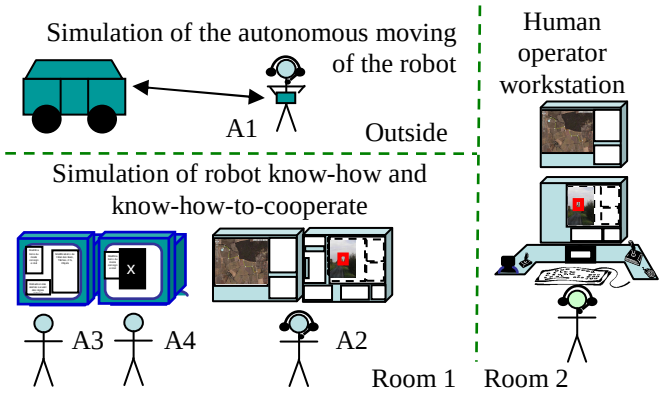

Fig. 3. Wizard of Oz's method to simulate robot autonomy.

4.3 Scenario

The missions took place within Thales group infrastructures for the first experiment and on an industrial wasteland for the second one. The first one was well limited so easier for the robot to perform task; the second one had several sparse vegetation and pieces of slab of destroyed factory, so several potential obstacles.

The missions are different but similar according to the difficulty they present. Each mission was designed in order to test autonomy modes. An example of mission is presented on the figure 4.

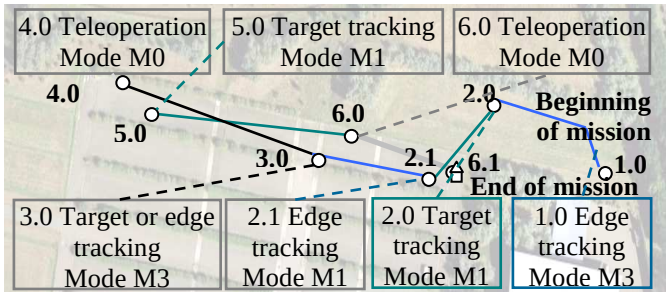

Fig. 4. Scenario of the first experiment.

Some unexpected events, obstacles and lost of communication between robot and human operator appeared. The objectives of these events were to test the confidence the human operator had in himself, in the robot or in the relation he had with the robot (Rajaonah et al., 06). Each mission took around fifteen minutes.

4.4 Collected data

Objective and subjective data were recorded. All actions of human operator and robot were recorded with a time code. Information presented on the workstation displays was video recorded. Human operator's verbalizations and movement were also video recorded in order to have the context of human operator decision and actions making. Answers to questionnaires and verbalizations during debriefing were other types of collected subjective data. Questionnaires requested the participants' opinion about the proposed modes of autonomy, the performance of workstation display, robot and themselves, about the level of vigilance, of required attention, and effort.

4.5 Procedure

Before experimentations an expert of the R-Trooper presented to participants explanations about the robot role and capacities. Some samples of mission were provided to participants with ideas about what would be the organization of the human operator with this robot. After this phase during which participants would learn a minimum of principles to supervise and control the robot, they trained themselves. They performed one training mission in order to use all the functions they would have to use during the experimental scenarios. At the end of the training, each participant performed the two experimental missions. The objectives of the mission were described in a document provided to participants. After the reading of this document a briefing of mission was conducted in order to present its main difficulties. After each experimental scenario, participants filled questionnaires and realized a debriefing of the mission.

4.6 Results and discussion

Results come from the analysis of human operators' and robot activity during the experiment. A coding of the know-how and know-how-to-cooperate were realized according to the recording of the objective data but completed by the verbalizations during the experiments or during the debriefing. The base of the coding is know-how and know-how-to-cooperate models.

Results of both experiments can be presented in a same time according to performance, the use of the autonomy modes, the quality of cooperation, mission plan achievement.

Performance

Performance can be calculated according to the time taken to complete the mission and the number of reached goals in the case of the second experiment. However it was difficult to take into account the time taken to complete the mission, because of technical problem or mission stop because human operator needs assistance from experimenters.

About the first experiment, some times were also calculated: (1) time for human operator to answer to robot request, (2) time to change allocation from robot to human operator (kind of human operator reaction time), (3) time to change allocation from human operator to robot (kind of robot reaction time). The first time (1) underlines that communication may be improved. In fact answers were

sometime delayed. But this result underlines too that tasks of each agent were not enough synchronized. The second time (2) was sometimes important but it was due to technical problems and not cooperation problem. Robot took quickly into account human operator's requests. The third time (3) highlighted differences between two robots know-how-to-cooperate. Sometimes it stopped and sent information; sometimes it did the opposite by giving first the information. The time seems to be shorter in the second case perhaps because human operator had directly the intention of the robot without needing to imagine it.

About the second experiment, the analysis of the reconnaissance task underlined that all objects had been found and participants had well located these objects.

Autonomy modes use

Mode 1 and mode 2 (cf. §3.3) were used in a same way. Human operators felt the need to validate the allocation of control to robot even if it was not necessary. They said that they wanted to verify that all was right before giving the control to the robot. But another explanation would result from scenarios because each scenario presented three of the four modes. So at each step of the scenario, when there was a task change, human operator checked which autonomy mode was planned and in the same time confirmed the mode even if it is not necessary.

Quality of cooperation

Whatever the mode of autonomy, participants seemed to have more confidence in robot during the first experiment than the second. Three types of explanation can be provided.

The second experiment imposed to do reconnaissance. It was a second task which forced participants to have less time to supervise robot, and moreover this task was dependant on robot moving. During debriefing participants said that they preferred to stop robot in order to find objects requested by the mission. This difficulty would result from a lack of coordination between decision making and action of each agent at the operational level. These activities are so tied that know-how-to-cooperate must be detailed. For example, human operator needs information about the direction followed by robot and the time of the end of the task. Another approach would be to increase robot know-how-to-cooperate by improving the human operator's model the robot has, in order to have the robot be to recognize human operator's intentions.

During the second experiment, participants had less training, and training sessions unveiled technical problems. During the first experiment Wizard of Oz method avoided to have sensors technical problems such as losing a target because of fog or rain. Finally, training session leads human operator to build a not really optimal robot model.

Scenarios of both experiments were similar but the field was much more difficult in the second experiment than in the first one. Because this field presented several obstacles and ditches human operators were afraid to do something wrong and to damage the robot. This point is very interesting regarding experiments realized with micro worlds. Responsibility is of course much more important when a real machine performs tasks in the real world, so human operator needs to have an accurate model of robot know-how and know-how-to-cooperate. It is the reason why it seems judicious to build a machine with simple but strong know-how. The same way can be followed for know-how-to-cooperate, cooperative rules, information exchanges must be simple and clear.

Mission plan

During debriefing, human operators underlined the importance to prepare the mission plan themselves. According to the objective of the mission and a map of the field in which the robot will have to move, they would be able to prepare the mission. A good knowledge of robot know-how and know-how-to-cooperate would allow them to better prepare task allocation. They would have their own task allocation criteria which would be defined according to their estimated know-how. So, contrary to what was proposed at first, it would be better to maintain the human operator who has to use the robot at the strategic level to build the mission plan and not only to update the plan.

5. CONCLUSION

Conclusion may be divided into two parts, a first one about the interest of human-machine cooperation approach to design and evaluate human-robot interaction, and a second one about the identification of lacks in existing definitions in automation to be able to identify the level of automation corresponding to a current situation and the task allocation criteria.

Firstly, a positive assessment can be done about the use of human-machine cooperation definitions in order to evaluate human-robot interaction. They allow analyzing in details cooperative activity. Individual and cooperative behaviors of each agent were coded using definition and analyses of coding underlined some positive aspects and not so positive ones. Better synchronization between robot and human operator's know-how at the operational and tactical levels has to be done. During the presented experiment the following way to design human-robot interaction was to use all the know-how the robot has but teleoperators said that another way would to study how two human operators are cooperating today, when one teleoperates robot (which is only a platform without know-how) and the other does reconnaissance. A design of human-robot interaction using human-machine cooperation could have avoided the observed lacks mainly because human factors could have been taken into account earlier, analyzing human-human cooperation for example. Several methods exist for such design and evaluation, an example of method is provided in Pacaux-Lemoine & Crevits (2010).

Secondly, definitions and rules have already to be done about levels of automation, human-machine cooperation and several other approaches which have the goal to well understand interactions between human operator and more or less "intelligible" assistance tools. An attempt to gather and compare approaches was done but a principal lack appears when task allocation criteria must be identified. They would be expressed according to time for negotiation, time to incident event, abilities, responsibility, authority and other not yet identified. Criteria could also be combined in order to verify their complementarities. One way would be to obtain

many kinds of data from all parts of the global system, from human operator, from assistance tools and from environment and/or process.

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