DR 5.2: Expectation Management in Common Ground

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We report progress achieved in Year 2 of the TRADR project in WP5: *Persistent models for human-robot teaming.* The reported work concerns investigation of coordination requirements in teams, analysis of team communication and relationships within teams, tools for recognizing and monitoring team activity, decision support tools and frameworks for user interfaces that allow users to share and review information about mission progress to enable shared situation awareness and common ground.

Executive Summary

This report presents the progress achieved in Year 2 of the TRADR project in WP5: *Persistent models for human-robot teaming*, addressing Task 5.2: *Expectation Management in Common Ground* leading to Milestone MS5.2.

The main focus of work in Year 2 was on making insights from the investigations on human-robot teaming in Year 1 operational by providing tools and frameworks to support the TRADR human-robot teams to establish "common ground" as shared mutual knowledge and understanding of the situation, the activities of team members and for planning the next steps. Tools were developed to recognize and monitor activities of team members, their physical activity, the verbal communication of the human team members and robot states. User interfaces were designed to facilitate the access to gathered information in high-level form to team members but especially to team leaders and other decision makers. Also, documentation tasks get supported by the new tools.

The TRADR Joint Exercise in May 2015 and the TRADR End-User Evaluation in September 2015 at the Phönix site in Dortmund provided excellent opportunities for collecting development data for the design and implementation of the new tools as well as for their first evaluation. The data, interviews and discussions with end-users at these events also provided background for further analysis and investigation of coordination requirements and decision support in multi-agent teams.

Role of Human-Robot Teaming in TRADR

WP5 deals with the issue of how a human-robot team can operate, and grow over time through its experience of working together. Approaching this from the viewpoint of the robot as well as from a human perspective, WP5 aims at developing models and algorithms for determining and recognizing human as well as robot behaviour at the (social) team-level. This encompasses the analysis and modeling of team-level communication and coordination, reasoning with role-based social behaviour at a team level, learning how to adapt that reasoning to better anticipate social behaviour, and learning how to adapt (pre-defined) strategies for team-level interaction.

Contribution to the TRADR scenarios and prototypes

Issues of human-robot teaming are of central importance in the scenario chosen for TRADR, namely the response to an industrial accident consisting of multiple sorties over an extended period. The Year 2 use cases (cf. DR 7.2 of WP7) extend those of Year 1. They involve several teams consisting of a team leader, two UGV operators and UGVs, an infield rescuer, and an UAV-operator with a UAV on multiple sorties in a larger and dynamic environment. The teams are performing an initial assessment of an accident site, followed by subsequent information gathering sorties. The use cases provide an abundance of opportunities for teamwork. Control as well as task and resource allocation become more challenging in the larger teams. An important issue with respect to team changes and multiple sorties is how information gathered by one team in one sortie can be transferred and used by new teams in other, later sorties. The work carried out in WP5 Year 2 improved the understanding of the issues involved in these challenges and developed supportive tools and methodologies to address them.

Persistence

Persistence in WP5 is addressed by monitoring events from on-going sorties in persistent databases. The stored information is exploited for creating interactive reports that allow users anytime and anywhere to get an overview of the progress of operations to survey their success and to provide decision support in preparing next steps and future sorties. The provided tools help users to establish common ground as shared information state about the mission.

1 Tasks, objectives, results

1.1 Planned work

The plan for Year 2 had foreseen WP5 to address *Expectation Management in Common Ground* (Milestone MS5.2). The goal was to develop an account of what expectations, conflicts, and needs for alignment (typically) arise in a human-robot team, in the setting of building up a mutual understanding of the disaster area (common ground) over a period of up to 2.5 days. The focus in Year 2 was to be primarily on the relation between communicating and/or confirming understanding between team-members, given role-based responsibilities.

1.2 Addressing reviewers' comments

1. **Perceived disconnection between WP5 and other WPs**
During Year 2 we collaborated closely with WP3 with respect to monitoring agent activities to enable shared situation awareness for the teams and the persistency framework. The collaboration with WP7 in analyzing user requirements had impact on the development of our tools. Also, we collaborated with WP6 to integrate the tools developed in WP5 into the TRADR system environment. The reporting tool ([30] (Annex Overview 2.9)) is fully integrated into the TRADR core system. We plan a closer collaboration with WP2 on robot action planning and with WP4 on multi-robot collaboration. The main challenges in these fields will be in how to provide high-level representations of robot tasks, plans and execution status that can be presented to non-expert human team members.

2. **The approach should be grounded more explicitly in the reference scenarios and it should be ensured to integrate quickly and often with the TDS.**
We share resources with the Tactical Display System (TDS), and tools such as that of ([30] (Annex Overview 2.9)) are fully integrated with the TRADR core system and accessible to the TDS.

3. **It is recommended to utilize the bw4t tools to generate lessons, and apply them in the robot simulation, and later in experiments with robots, as early as possible in the project.**
BW4T is currently used for an experiment to investigate the effect of failed communication on decision making strategies. Because we cannot rely on WiFi, communication failure will have an impact on the effectiveness of the team, highlighting the need for team resilience. The insights gained by this experiment could be used to design resilient search and rescue teams. This experiment is also motivated by the formal work on minimal coordination in [46] (Annex Overview 2.1). In

this experiment we start from the simplest functional agent design and we systematically add features that enhance teamwork. Using simulations in BW4T we test for each feature if and how communication failure affects this team. BW4T allows us to quickly test communication failure in many and diverse situations. An early experimental result is that knowledge of the location of agents could reduce the need to communicate between actors. For this reason we now keep track of the location of all actors (robots and humans alike) in the TDS system and database.

4. **Tools (persistence for human commanders) and other issues need to be carefully aligned and coordinated with WP3. Integration with other WPs should be clearly planned.**
   This was done, as explained above.

5. **Make clear how WP5 contributes to endowing robots with social sentience**
   This issue is addressed in Section 1.3.5. Main obstacles for an implementation within TRADR are the low degree of autonomy in the robots and their very limited situation awareness but also the lack of experience and knowledge of users about the robots' capabilities. As a result, users are reluctant to pass control to the robots.

1.3 Actual work performed

Work in Year 1 had focused on exploring and modeling tasks and teamwork in USAR teams. In Year 2 we started to develop tools that can actually support teamwork during long-term missions. The TRADR Joint Exercise (TJex) and the TRADR End User Evaluation (TEval) events in 2015 provided rich opportunities to refine the concepts as well as to gather data for empirical grounding and evaluation of the concepts.

The work WP5 performed in Year 2 therefore comprised the following:

- development of tools for monitoring team activities and providing reports to build common ground among team members on long-term missions (Sections 1.3.1 and 1.3.6)
- theoretical studies of coordination requirements in multi-agent systems (Section 1.3.2)
- development of an approach to task coordination in robot-assisted USAR operations (Section 1.3.3)
- knowledge representation and reasoning for agents (Section 1.3.4)

- development of a framework for mixed-initiative adaptive user interfaces to support human-robot collaboration (Section 1.3.5)
- adaptation of tools for decision support in USAR teams (Section 1.3.7)
- empirical studies of team relationships and performance based on TRADR experiments (Section 1.3.8)

Below we provide a summary on these subtasks. Section 2 contains abstracts of the papers and reports where this work is presented in more detail and which constitute the annexes of this report.

1.3.1 Mission Monitoring and Reports for Shared Situation Awareness

In Year 1 we had analyzed the communication structure and requirements in USAR teams (c.f. [31]). We discussed how tools could be devised that support USAR teams during sorties by providing the members synchronously with reports about important events occurring during a robot deployment, supporting them in the briefing and debriefing phases in preparing and reviewing sorties as well as allowing new team members to get an overview of the situation and happenings during the mission. Such, the reports are supporting the human team members in establishing common ground. Though specifically designed for team leaders across missions, they can have other uses too.

In [30] (Annex Overview 2.9) a team support tool developed in Year 2 is described that provides such functionalities as a report system. An important consideration for the design and setup of the system was that in actual situations TRADR robot teams usually will be part of larger teams that involve members not directly involved in working with robots but performing other tasks. Nevertheless, they should also be able to access information from the teams directly working with the robots assuming

- Information from the robot teams should be available *anytime anywhere.*
- Customizable Views: users should be able to select what information they are mostly interested in.

Therefore, the report system is set up as a web application that can be used with any web enabled device (PC, laptop, tablet, smartphone, etc.) with access to the TRADR network. [39] (Annex Overview 2.10) shows what types of information are involved in actual missions. It demonstrates especially that the local teams who are actually working in a disaster area are in continuous contact especially with their (remote) command center which also creates and maintains extremely detailed mission logs and reports from

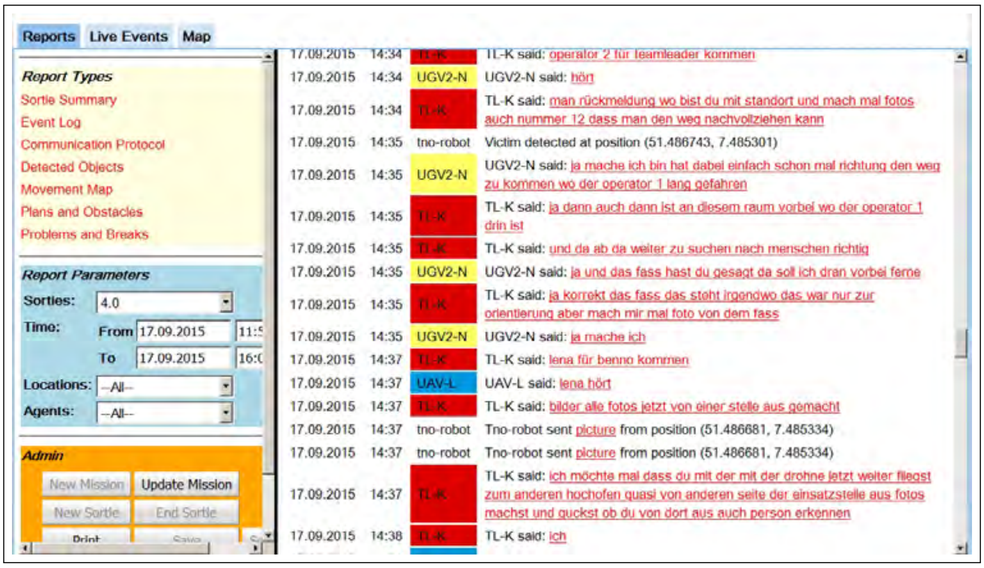

Figure 1: Event log of a sortie with human communication and robot events

the communication with the local teams. Event protocols similar to those created by the command center can be generated by the report system as illustrated by Figure 1 that also shows the user interface. The possibility to capture and interpret also human communication by speech recognition as described in [25] (Annex Overview 2.7) is important in detecting misunderstandings or failures in team cooperation, e.g. when the team leader requests a picture from a robot (operator) and it does not arrive subsequently.

The reporting system supports both a "synchronous" reporting mode which pushes concise textual descriptions of captured events immediately and automatically to the users and an "asynchronous" mode where various types of reports get generated only when users issue a request from the user interface. In difference to other text based reporting systems, the TRADR application uses also visualizations e.g. of robot movements on a map and provides fast access to pictures and recordings taken during a sortie. Also, users can augment the data set interactively in providing annotations and marking points of interest.

The reporting system is integrated into the TRADR core system.

1.3.2 On Minimal Coordination Requirements for Multi-Agent Temporal Resource Distribution Tasks

The work presented in [46] (Annex Overview 2.1) establishes the ground for investigating how agents can reason about cooperative teamwork in a search and rescue task.

In this work we investigate three questions for what we call *resource dis-*

tribution problems in the presence of multiple *homogeneous agents*: When do agents in a *cooperative team* need to communicate in order to guarantee task completion? What are the *minimal coordination requirements* to guarantee task completion in such a team? And how do these requirements for coordination depend on the complexity of the tasks? Resource redistribution tasks, as defined in this work, represent many of the challenges that make coordination in search and rescue a problem: The initial state of the environment is unknown, agents are distributed and must make online decisions based on their findings, and actions can have irreversible consequences. We focus on the requirements for *temporal goals* that require agents to (re)distribute resources over time.

We propose a formal model of resource distribution tasks and introduce two basic approaches for coordination: *ranking-based mechanisms* and *communication*. We show that rankings can be used as a coordination mechanism sometimes instead of communication. Only in those cases where rankings are insufficient to anticipate the behaviour of other agents, some form of communication is needed to prove that a team of agents can guarantee task completion. We also show that the main problem in our setting is how to coordinate agents when tasks require the simultaneous execution of actions and when decision making of multiple agents needs to be synchronized.

1.3.3 Towards Resilient Task Coordination Support in Robot-Assisted Search and Rescue

To allow robots to be actively engaged in task coordination, a computational representation of tasks and processes in robot-assisted search and rescue is needed. Using this representation, members of the human-robot team should be able to take tasks upon themselves, allocate tasks to other team members (either human or robot), and obtain insight on which tasks others are performing, have been performing and will be performing.

In [54] (Annex Overview 2.2), we present a formal approach to task representation within the larger task-context of a functional purpose (specifying the demand), the resources (specifying the available means), and the physical environment. In a resilient system, the tasks continuously adapt to any changes of these three contextual factors. By adopting a formal, computer-readable task-model, both robots and humans can contribute to resilience and be continuously aware and in control of all relevant aspects of tasks, resources, functions and environment.

In this work, three novel contributions are presented to this larger ambitious goal. Firstly, we present a user requirements engineering framework containing twenty high level functionalities that are relevant for resilient task coordination support. Secondly, we present a number of ontologies which can be used to computationally represent the information that is needed to provide that type of support. Thirdly, we present three prototype function-

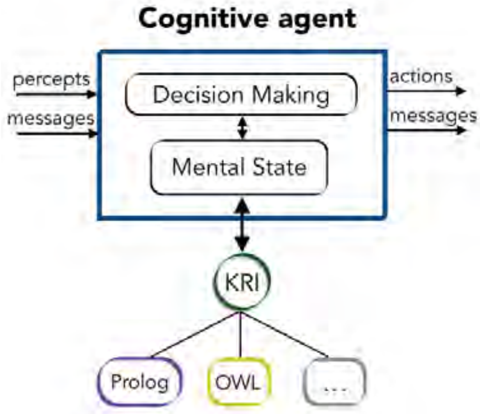

Figure 2: A GOAL cognitive agent with the Knowledge Representation Interface (KRI)

alities that implement a few of the proposed user requirements, and build on the ontologies we have developed. The prototypes are demonstrated in a field experiment (the TRADR exercises) where UGVs and UAVs are applied to help firemen in a disaster response scenario.

1.3.4 Designing a Knowledge Representation Interface for Cognitive Agents

Agents are needed for creating the team aspect of the human-robot mission, and treating the robots as equal teammates. Agents manage the commonly gathered knowledge by the team, and create role-based display profiles for the firefighters.

In the TRADR project, we have chosen to represent semantic high-level knowledge of the team using ontology technology. In order to use ontology technologies in agent frameworks, a generic solution to the problem was found. Our work described in [3] (Annex Overview 2.3) addresses this issue by creating a generic interface to allow a flexible choice for knowledge representation (KR), and making use of existing technology. Even though these systems accept OWL (the *Web Ontology Language*) in the agent framework, in our work we propose a KR interface aimed at providing a practical solution to the more general problem, to facilitate the choice among a range of KR languages for representing and storing agents' knowledge.

Taking into account some generic design principles, an analysis of the agent systems' requirements, and matching them with the available features of KR languages resulted in the proposed KR interface. In the paper we also present two implementations (Prolog and OWL) for GOAL [22] agents, to show the practicality and usability of the interface. As shown in Figure 2, a cognitive agent is on the one hand part of the environment by receiving percepts and sending out actions, and on the other hand part of a multi-agent system by communicating to other agents through messages. An agent's internal components provide a form of decision making over a mental state consisting of the collection of beliefs, knowledge, and goals. The language in which these are represented can be flexibly chosen through the KR Interface.

In the future, a more extensive analysis on the applicability of this interface to KR languages is planned, specifically investigating the case for probabilistic (Bayesian) or fuzzy logic-based languages. A comparative performance testing is planned to be included in the follow-up journal paper on this topic.

1.3.5 Mixed-Initiative Adaptive User Interface

To share collaborative and transferred responsibilities between two actors, a mixed-initiative adaptive user interface seems very useful. The Value of Information (VoI) can be used as a Mixed-Initiative mechanism to decide whether or not a user should be consulted. Depending on how the problem is modeled, the use of a decision-theoretic framework provides sufficient freedom to choose from any of the Levels of Autonomy (LoA), reaching from manual control to full automation.

In an ideal scenario, robots would be able to explore the disaster area autonomously as part of a team. However the current level of autonomy of the robots is not sufficient to accomplish these tasks autonomously and therefore the robots are manually teleoperated during missions by specialized operators who are part of a team [49]. It is also important to highlight that autonomous capabilities of robots will not be useful if they are not accepted by their human team members [35].

Although autonomous behavior of robots in USAR missions is desired, current missions require the integration of teleoperated robots with different levels of autonomy as team members and often require more than one operator. Situation Awareness during teleoperation is related to the operator's mental model of the location, of the robot, and its surroundings along with what they mean. This is essential for the success of the mission.

Interface design is critical in order to maintain and acquire SA, however, there is no standard set of rules or guidelines to develop them. In most cases the UI is designed according to the criteria of the developer and the specific application. Even when the guidelines established by a project have a human-centric design, the interface still has open potential capabilities. Static interfaces are not able to take advantage of the context of a specific task and impose additional cognitive load on the operator by making him do additional adjustments or interpretation of parameters.

Experienced users often exploit the advantages of different views and manually choose the most applicable to the current task. Non-experienced users often stick with the views that were presented by default. Interfaces also play an important role in user acceptance of such systems. Even when autonomy modes are available, users don't make use of them and might feel as if they are not in control when the robot is in autonomous mode.

In [43] (Annex Overview 2.4), we describe a prototype of a Mixed-initiative Adaptive User Interface, which supports displaying information that is considered most useful. Applying decision theory to model beliefs about the operator, robot and interface, the proposed Adaptive User Interface bases the Mixed-Initiative interaction on a Hierarchical Influence Diagram that mirrors the GUI's hierarchical structure. The main result of this work is the integration of many approaches applied on different domains to create an adaptive mechanism that integrates the interface as an active player in the interaction. This could provide substantial benefits in the Search and Rescue domain.

The use of Hierarchical Influence Diagrams to model a user and adapt the contents of a User Interface provides several benefits. Each decision can be broken into smaller problems making them simpler to model and understand and simplifying the addition of new sensors and updates to the model itself. Each influence diagram can be modeled by taking into account only the information required for this particular decision. It is possible to construct the diagrams as Multi-Agent Influence Diagrams, a variation of influence diagrams that are used in game environments to model the interaction of different agents with possible different goals. This would account for the uncertainty in the beliefs of every participant in the system. It would also benefit from the integration with other communication patterns such as the ones described by [32], such as human-pull, human-push and robot-push.

1.3.6 A Hybrid Approach to Activity Recognition of Humans in a Human-Robot Rescue Team

The work described in this paragraph aims to allow the robot/ system to understand what taks the human team members are performing. In this way, the robot/ system can follow what is going on without the human having to tell the system. In [4] (Annex Overview 2.5), we describe a hybrid approach to activity recognition of humans in a human-robot rescue team. The hybrid approach combines data-driven and knowledge-driven techniques into a single framework (similar to [45]). The data driven techniques provide various sources of information, while the knowledge-driven techniques integrate that information into a coherent structure and provide reasoning capabilities. The sources of information include three human behaviours, namely physical motion, communication, and interface actions, and additional information related to the hierarchical structure of a human-robot rescue team. The activity recognition system is evaluated during a high fidelity exercise with actual fire fighters, of which the results are compared with two other approaches, namely the most common activity, and random activities. The most common activity approach predicts the most common activity, defined as the most occurring activity with the longest duration, at any time. The random activities approach predicts one or multiple random activities at any time. The activity recognition system should at a minimum outperform those approaches.

1.3.7 Decision support for allocation of unmanned vehicles

In the USAR domain, a lot of information needs to be gathered with the resources available in a dangerous environment. The allocation of the unmanned vehicles must be done as smoothly as possible. A decision support for the allocation of unmanned vehicles can support the commander in his task, lowering his workload and increasing his effectiveness and efficiency. In [51] (Annex Overview 2.6) we present an existing algorithm to allocate unmanned systems, tailored to the USAR domain with input from end-users, cognitive work analysis and workflow models.

1.3.8 Supporting long-term human-robot teams

The presence of robots in a team has an influence on the team relation dynamics; however, (almost) no research is available that addresses how the team relation dynamics are influcenced. The influence of team relation dynamics is meant here on several levels, e.g., for sharing situation awareness, team forming and building, and team roles.

In [37] (Annex Overview 2.8), we describe how we approach this topic by first looking at modelling relationships within a team, to suggest a way to influence these relations to increase long-term human-human and human-robot cooperation. We do this by analyzing team communication during TEval 2015, and by forming hypotheses regarding different relevant factors that influence team performance.

1.4 Relation to the state-of-the-art

Mission Monitoring and Reports for Shared Situation Awareness There is hardly any work on monitoring missions with the goal of creating reports on joint human-robot team activity for non-specialist end-users for shared situation awareness. The use of natural language descriptions for single AUV events similar to those the TRADR report system generates in synchronous mode have been proposed in [27]. Extended natural language reports for single sorties are envisioned for AUV missions in [28].The TRADR reporting system goes beyond these proposals in integrating multiple data sources, in its options for selecting information, and in combining visual, textual and aural modes of presentation.

On Minimal Coordination Requirements for Multi-Agent Temporal Resource Distribution Tasks Many studies have shown [44] advantages of multi-robot systems over single robot systems because of: e.g. robustness, inherently distributed tasks, task complexity, efficiency or simpler robots. There are also many formal approaches based on logic that provide coordination mechanisms for teams that guarantee task completion in foraging settings. For example, in [15] TeamLog was applied to guarantee effective teamwork in a rescue robot case. Most of these works, however, do not prove whether coordination mechanisms are needed nor do they show that a particular coordination mechanism is sufficient to ensure task completion. In the present work we consider more complex tasks and show that communication can be necessary for specific tasks. Work on strategic logic like ATL [2] is also concerned with teams of agents pursing a joint gaols in an adversarial setting. However, the focus is on finding *joint* winning strategies, ignoring aspects related to (limited) communication and coordination. Also in resource bounded extensions of ATL such as [6, 1] where agents have to coordinate, in principle, on resource production and consumption to achieve a temporal task, questions related to coordination are avoided by focussing on the existence of joint winning strategies. In epistemic extensions of strategic logic different types of communication and knowledge sharing [2, 14] and capabilities of agents [7, 8] have been investigated with respect to agents' ability to guarantee temporal tasks. In particular, [33] investigates the interplay between communication and coordination in the presence of imperfect information and argue that multi-agency implies limited coordination. In comparison to our present work all the analysis is on a very high-level and no specific coordination nor communication mechanisms are discussed. Another distinguishing feature of our formal model, e.g. also to robotics setting such as [47, 48, 42], is that agents can alter the environment, by picking up, carrying, and dropping resources. As a consequence, our framework is much more grounded in real-world settings. A lot of work has also established empirically that more or less limited coordination mechanisms are sufficient and effective to achieve a foraging task, see e.g. Farinelli et al. [16] for a survey. Our work aims to complement this empirical work with a formal analysis of the need for a coordination mechanism.

Towards Resilient Task Coordination Support in Robot-Assisted Search and Rescue Many approaches to task modelling in complex domains are either not formalized and thus not useful for computers (s.a. Cognitive Work Analysis [26]), or they are limited in scope and focus on only one aspect of the task-concept (s.a. [50], [53]). Relevant work from the multi-agent systems community is agent organization modelling (e.g. [13], [24]), where the goal is to balance agent autonomy against central control.

Central control is implemented using the organization model, in which computational task modelling plays an important role.

Designing a Knowledge Representation Interface for Cognitive Agents Currently a few agent programming frameworks exist, that allow the use of ontologies, and they have their shortcomings. Other systems come with a predetermined language for representing knowledge, and the programmer or user does not have the possibility of choosing another.

Most agent programming frameworks (e.g. 2APL [11], 3APL [12], GOAL [22], Jason [5]) are built on top of logic programming or a slightly different version of it. Alternatively, approaches towards integrating semantic web technologies (e.g. OWL [40]) into agent-based frameworks exist. JASDL [34] is an extension of Jason, which allows for integration with OWL, and as such lets agents incorporate OWL knowledge into their belief base. JIAC [23] is a Java-based agent framework, that also uses OWL for representing agent knowledge. A version of the BDI agent-oriented programming language AgentSpeak based on description logic is defined in [41]. A first step towards the use of ontologies in the multi-agent framework JaCaMo exists in [17]. The authors propose the use of a semantic web language as a unifying framework for representing and reasoning about agents, their environment, and the organizations they take part in. The particulars to achieve this are not discussed.

Approaches to Human Activity Recognition in a Human-Robot Rescue Team Due to the various challenges within urban search and rescue, robots can provide a useful contribution. Robots are able to enter voids too narrow for rescue workers, or explore structurally or environmentally unsafe surroundings (e.g., danger of collapse, fire, etc.) [9]. While robots are able to provide many benefits to rescue workers, various challenges remain in perception, mobility, but also in human-robot interaction. Robot operators have difficulties maintaining awareness of the environment, for example, problems detecting victims, or inability to estimate whether rubble is crossable. Also, as robot autonomy improves, it is important for the operator to understand the decision-making process of the robot. Various approaches to support human-robot rescue teams exist, for example, adaptive automation (e.g., [29]), dynamic task allocation (e.g., [36]), and shared mental models (e.g., [18]). However, all these approaches rely on knowing what is going on, which includes knowledge about the task, the environment, and the agents. Also, in most cases assumptions about various aspects of knowledge are made in order to reduce the dependency on information. Human activity recognition in a human-robot rescue team tries to provide part of that knowledge and lessen the need for some assumptions.

A good approach for activity recognition is an ontology-based approach, that defines activities using an explicit representation in an ontology. An ontology is a data structure in which entities and relations between the entities are captured. There are several ontologies on activity recognition, for instance recognizing social interaction in nursing homes [10], in meetings [20] or in smart environments such as homes and offices [55]. All these approaches use ontologies to capture the relations and different features as input for the recognition of activities. Features used are for instance, speed, distance, relative direction of entities, video images (annotated manually), body movements (hands and head). As can be seen in the overview of features, there is a difference in use of real-time features and features that have to be processed afterwards. In our research we use the ontology based approach and used the reserach of [10], [20], [55] as input to choosing features that we can measure in USAR environments (such as a mobile phone for walking, sitting, location etc.).

Mixed-Initiative Adaptive User Interface Mixed-initiative interactions are distributed in a scale according to the level of control of the user by Goodrich and Schultz [19], in which teleoperation is classified as direct control and consequently the biggest issue is designing user interfaces that reduce the cognitive load of the operator. Dynamic Interaction is a research direction that encompasses many HRI efforts, includes time- and task varying changes in autonomy, information exchange, team organization and authority, and training. In this regard, by including the dimension of information exchange the scope of adaptive and adaptable interfaces is incorporated. Team organization and authority incorporates mixed-initiative interaction. A comparison between the control of a large group of robots simulated with different control levels is presented by Hardin and Goodrich [21]. The results show that a Mixed-Initiative approach outperforms the other two methods by complementing the abilities of the operator. In terms of social robotics, as suggested by Looije et al. [38], an adaptive interface could predict from its observations how stress affects the user and as a result provide shorter responses to them. They also point out that robots with adaptive interfaces are more easily perceived as a social actor and could therefore have more influence on the stress level of the user. The need for Adaptive User Interfaces for Search and Rescue is presented by [52]. They differentiate between adaptive interfaces and the adaptable interfaces, which both have their pros and contras: Adaptive interfaces have the potential to improve overall human-machine system performance if properly designed. Adaptable interfaces leave the user in control, but adapting takes time and the user may not have enough time and may prefer to change to a more optimal user interface.

2 Annexes

2.1 Rozemuller, Chris, Bulling, Nils and Hindriks, Koen (2015), "On Minimal Coordination Requirements for Multi-Agent Temporal Resource Distribution Tasks"

Bibliography Chris Rozemuller, Nils Bulling, Koen V. Hindriks(2015), "On Minimal Coordination Requirements for Multi-Agent Temporal Resource Distribution Tasks". Submitted paper. Delft University of Technology, Delft, the Netherlands.

Abstract When do agents in a *cooperative team* need to communicate in order to guarantee task completion, and what are the *minimal coordination requirements*? We investigate these questions for what we call *resource distribution problems* in the presence of multiple *homogeneous agents*, and simple temporal tasks. We propose a formal model of resource distribution tasks and introduce two basic approaches for coordination: *ranking-based mechanisms* and *communication*. We show that rankings can be used as a coordination mechanism sometimes instead of communication. Only in those cases where rankings are insufficient to anticipate the behaviour of other agents, some form of communication is needed to prove that an agent team can guarantee task completion. We also show that the main problem is how to coordinate agents when tasks require the simultaneous execution of actions and when decisions need to be synchronized.

Relation to WP This paper contributes directly to T5.2 by describing a theoretical framework for the modeling of coordination requirements of cooperative teams.

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Availability Restricted. Not included in the public version of this deliverable.

2.2 J. van Diggelen, J. de Greeff, W. van Staal and M.A. Neerincx (2015), "Towards Resilient Task Coordination Support in Robot-Assisted Search and Rescue"

Bibliography J. van Diggelen, J. de Greeff, W. van Staal and M.A. Neerincx (2015), "Towards Resilient Task Coordination Support in Robot-Assisted Search and Rescue". To be submitted to IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN) 2016.

Abstract This paper describes a novel approach for computational task modelling aimed at providing task coordination support for Robot-assisted

Search and Rescue (RaSaR). To enable effective human-robot teaming in a search and rescue scenario, it is of particular importance to have a shared understanding of the mission, environment, stakes, and circumstances, to achieve optimal human-robot collaboration. As search and rescue missions can be quite chaotic, complex, dynamic and time pressured, the coordination of various tasks needed to be performed by various actors constitutes a major challenge. To facilitate resilient task coordination, we present ontologies, a user-requirements framework, and an implemented prototype which has been tested during a field test with end-users. We describe how the use of this framework can help supporting task coordination in the RaSaR domain.

Relation to WP This report describes approaches for task-coordination support functions for RaSaR missions. Because task-coordination is at the heart of human robot teaming (WP5), this is a relevant contribution.

Availability Restricted. Not included in the public version of this deliverable.

2.3 Bagosi, Timea, de Greeff, Joachim, Hindriks, Koen, and Neerincx, Mark (2015), "Designing a Knowledge Representation Interface for Cognitive Agents"

Bibliography Bagosi, Timea, de Greeff, Joachim, Hindriks, Koen, and Neerincx, Mark (2015), "Designing a Knowledge Representation Interface for Cognitive Agents". Submitted paper EMAS 2015 (AAMAS). Delft University of Technology, Delft, the Netherlands.

Abstract The design of cognitive agents involves a knowledge representation (KR) to formally represent and manipulate information relevant for that agent. In practice, agent programming frameworks are dedicated to a specific KR, limiting the use of other possible ones. In this paper we address the issue of creating a flexible choice for agent programmers regarding the technology they want to use. We propose a generic interface, that provides an easy choice of KR for cognitive agents. Our proposal is governed by a number of design principles, an analysis of functional requirements that cognitive agents pose towards a KR, and the identification of various features provided by KR technologies that the interface should capture. We provide two use-cases of the interface by describing its implementation for Prolog and OWL with rules.

Relation to WP This paper describes a flexible interface for multi-agent systems to choose between different knowledge representation technologies. It contributes to WP5 by creating an interface that allows agents to represent human-robot teaming with ontology technology.

Availability Restricted. Not included in the public version of this deliverable.

2.4 Ortega (2015), "A Mixed-Initiative AUI for Rescue Robotics"

Bibliography Argentina Ortega Sáinz. "A Mixed-Initiative AUI for Rescue Robotics." Research and Development Project Report, August 2015.

Abstract Human-Robot Interaction remains one of the biggest challenges in Search and Rescue Robotics, where many issues are directly related to the User Interface Design. Operators require the correct information presented at the right time and form without increasing their cognitive load in order to acquire and maintain Situation Awareness. An Adaptive User Interface could exploit the advantages of context relevant information as well as considering the operators state of mind to present the information more adequately and make tasks more manageable but could affect the operators acceptance and control of the system. A Mixed-Initiative Adaptive approach presents a balance between user control and adaptive behavior. Applying decision theory to model beliefs about the operator, robot and interface, the proposed Adaptive User Interface bases the Mixed-Initiative interaction on a Hierarchical Influence Diagram that mirrors the GUIs hierarchical structure. The Value of Information is used to determine if the operator should be queried or not.

Relation to WP This paper contributes to T5.2 by describing an approach to balance automatically between the user control and the adaptive behavior of the controlled system.

Availability Restricted. Not included in the public version of this deliverable.

2.5 B. Bootsma (2015), "A Hybrid Approach to Activity Recognition of Humans in a Human-Robot Rescue Team"

Link to thesis: `http://theses-test.ubn.ru.nl/bitstream/handle/123456789/263/Bootsma,%20B.,_MA_Thesis_2015.pdf?sequence=1`

Bibliography Bas Bootsma (2015), "A Hybrid Approach to Activity Recognition of Humans in a Human-Robot Rescue Team" Thesis, August 2015.

Abstract Due to the various challenges within urban search and rescue robots can provide a useful contribution. Robots are able to enter voids too narrow for rescue workers, or explore structurally or environmentally unsafe surroundings (e.g., danger of collapse, fire, etc.). While robots are able to provide many benefits to rescue workers, various challenges remain in perception, mobility, but also in human-robot interaction. Robot operators have difficulties being aware of the environment, for example, problems detecting victims, or unable to estimate whether rubble is crossable. Also, due to improvements in robot autonomy it is important to understand the decision-making process of the robot. Various approaches to support human-robot rescue teams exist, for example, adaptive automation, dynamic task allocation, and shared mental models. However, all these approaches rely on knowing what is going on, which includes knowledge about the task, the environment, and the agents. Also, in most cases assumptions about various aspects of knowledge are made in order to reduce the dependency on information. Human activity recognition in a human-robot rescue team tries to provides part of that knowledge and lessen the need for some assumptions. Human activity recognition is the process of recognizing human activities based on observations about a human, and the environment using an automated system. First steps are taken in recognizing activities of the human team-members in real-time by development of a Activity Recognition System (ARES).

Relation to WP This report describes background and a first development of an activity recognition system to recognize activities of human team-members. It contributes to T5.2 because mutual understanding between human and robots, it is important to know who is doing what.

Availability Restricted. Not included in the public version of this deliverable.

2.6 N.J.J.M. Smets, T. Mioch and M. Duinkerken (2015), "Decision support for allocation of unmanned vehicles"

Bibliography Nanja Smets, Tina Mioch and Marco Duinkerken (2015), "Decision support for allocation of unmanned vehicles" Report, December 2015.

Abstract In this report we looked at decision support for the commander to allocate his unmanned vehicles for the tasks and locations needed. To be able to perform such a complex task, the decision support needs to be able to reason and compute what the best allocation is for the tasks and advice the commander in a possible planning. In the military domain, this kind of decision support is also under research. Within the EDA project "Autonomous Decision Making (ADM)" and the four year research programme Unmanned Systems, both carried out by TNO, an optimization algorithm for the deployment of assets is developed and tested in the military domain.

In this report this algorithm is going to be adapted for use in an Urban Search and Rescue (USAR) environment.

Relation to WP This report describes background and a first development of an planning tool for unmanned systems. It contributes to T5.2, because for mutual understanding between human and robots, it is important to know who is doing what.

Availability Restricted. Not included in the public version of this deliverable.

2.7 M. Janíček and B. Kiefer (2015), "TEval 2015 Team Communication Analysis"

Bibliography Miroslav Janíček and Bernd Kiefer (2015), "TEval 2015 Team Communication Analysis", Report, December 2015.

Abstract This report describes our analysis of the team communication data gathered at the TRADR End-User Evaluation (TEval) in September 2015. The data set comprises 4 sorties, each of approx. 1 hour length. We show the breakdown of times the users spent occupying the audio channel, present preliminary results for speech recognition-based transcription, an annotation of the discourse segmentation based, and show that the annotation is consistent enough to mandate an automatic annotation process.

Relation to WP This report presents an analysis of spoken communication among human team members during multiple USAR missions at the TEVAL event and discusses the potential of automated methods. This is a relevant contribution to T5.2 because spoken language is the most important means to create common ground among human team members.

Availability Restricted. Not included in the public version of this deliverable.

2.8 R. Looije, T. Mioch, J. van Erp, M. A. Neerincx (2015), "Supporting long-term human-robot teams: identifying observable relationship factors"

Bibliography Rosemarijn Looije, Tina Mioch, Jan van Erp, Mark A. Neerincx (2015), "Supporting long-term human-robot teams: identifying observable relationship factors", To be submitted, 2015.

Abstract Human-robot teams are getting more prevalent in different domains (e.g. industry, search and rescue, military). A robot in the team will have influence on the team relation dynamics, but in what way we dont know yet. We suspect that the interaction manner of the robot can influence the team dynamics, but to understand this we first need a model of the relationships within a team. After that we can suggest ways to influence these relations with as goal to increase long term team performance. In this paper we first look at literature on human-human and human-ICT/robot teams, after which we focus on observable relationship factors and how these can be observed from real human-robot teams in action. We finish with a set of hypotheses that can be evaluated in future work.

Relation to WP This paper describes possible influences of relationship factors in human-robot teams.

Availability Restricted. Not included in the public version of this deliverable.

2.9 W. Kasper (2015), "Mission Monitoring and Reports for Shared Situation Awareness"

Bibliography Walter Kasper (2015), "Mission Monitoring and Reports for Shared Situation Awareness", Report, December 2015.

Abstract This report describes a monitoring and reporting system for TRADR. It is able to monitor robot activities and human verbal communication persistently and to make the information available to users in a structured multimodal interface integrating textual event descriptions, visualizations and audio playback as reports for briefing and debriefing activities as well as for creating situation awareness for new or outside participants. It is realized as a web application allowing it to be used anytime anywhere on any web enabled device. We also present results from an end-user evaluation at TEval on a first prototype of the system.

Relation to WP This reports presents a first implementation of a reporting system to establish common ground and knowledge in teams based on the team communication analysis of [31] presented in TRADR Deliverable D5.1 and thus directly contributes to T5.2.

Availability Restricted. Not included in the public version of this deliverable.

2.10 R. Maul and N. Pahlke (2015), "Framework of an information pool used in disaster response to create situation awareness"

Bibliography Robert Maul and Norbert Pahlke (2015), "Framework of an information pool used in disaster response to create situation awareness", Report, December 2015.

Abstract This report presents the framework of information that is actually used at FDDo during real disaster response. It represents all information that are given to the responding units and all information that are gathered and filed. The table grounds on a number of mission reports, expert interviews and own experience. development as well as the TDS development in terms of design review.

Relation to WP This report lists the information that is available, created and shared among teams during disaster missions and thus it directly contributes to T5.2.

Availability Restricted. Not included in the public version of this deliverable.

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