Human-Human Inspired Task and Object Definition for Astronaut-Robot Cooperation

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Abstract

This paper presents a comparison of three different speech based task communication methods using a simulated astronaut-robot geological exploration mission as a test case. The conventional task communication method, in which the astronaut needs to communicate both the action and target, is compared against communication methods where object affordances, i.e. object action possibilities, are used to complete the task definition. The idea of this object affordances based approach is to transfer the cognitive object-action association process from the astronaut to the robot. The user test campaign described in this paper, performed with a fully autonomous centauroid robot, shows that the use of only the action name or action target name in the task communication can be successfully used to lower the workload of the test persons. The robot's capability to understand object-action associations introduces also a viable mechanism to add error tolerance to the communication as the astronaut has always alternative ways to make the required tasks communicated.

1 Introduction

Task communication to a robot is cumbersome, especially when compared with the efficient communication between humans. The way we naturally communicate with people in the real world could thus provide useful insights for better communication with robots in the future. Natural human-robot interaction, defined often simply as a human-human type of interaction in the real world [1], has already been mentioned often as a desired key element for future manned planetary surface missions to the Moon and Mars [2, 3].

This paper examines the problem of how definition and communication of tasks between astronaut and robot could be made more intuitive and error tolerant. Intuitiveness means that the communication should feel self evident to the human, or is at least very easy to learn. Error tolerance means that the communication can cope, at least to some extent, with the user errors by providing, for instance, alternative ways to communicate.

The approach to ease the communication is based in this paper on a concept called object affordances. The idea of the concept is that the task is communicated only by using the task associated target name or action, and by letting the robot associate the possible action to the object, or vice versa, the possible object to the action.

This human-human inspired human-robot communication approach is demonstrated in this paper for the first time on a full robot-astronaut cooperation scenario where the robot and astronaut are both working together in order to achieve a common goal. The common goal in this case is a successful geological exploration mission which has been previously identified as a potential future application where astronaut-robot cooperation could be useful [4].

The paper is structured as follows. Section 2 presents the concept of object affordances and how it has been used previously in user interface and robotics research. The research problem examined in this paper is presented and elaborated in Section 3. The test setup, obtained results, and analysis of these results are presented in Section 4, Section 5 and Section 6, respectively. Finally, Section 7 concludes the paper with suggestions for future work.

2 Related work

2.1 Concept of object affordances

The underlying idea researched in this paper is the usage of known object properties to limit the possible tasks that can be performed with the objects. This approach is based on so called "theory of affordances" [5], which postulates that all objects can be seen having a property called affordance that defines which action are possible in relation to the actors. Formally the affordance is defined in the theory of affordances as "action possibilities in the environment in relation to the action capabilities of an actor".

The concept of affordances has been initiated and elaborated mostly by the researchers in the discipline of psychology. The affordance concept can be seen to be derived from the way perceptual systems of animals are being considered to evolve from the need to control and guide actions [6]. It is not thus only that we are able to perceive actions but it is in fact the initial reason for us having the perception capabilities.

Perception of objects has been shown to create in humans direct mental associations to the possible actions that can be performed with the objects [7, 8]. Furthermore, the form of perception can be other than the visual type in order to still create the object-action association [7], also when the objects are not directly present but for example out of sight [8].

Thus, perception of objects alone can convey the information about the object associated actions. For example, when a person indicates an exit door to somebody they you also convey implicitly the possible actions, such as go out or open the door. Object reference alone thus is enough to communicate the whole task consisting of action and target object. Especially when the actor action possibilities are quite limited, as it is the case with an average service robot, the object-action associations can unambiguously define the desired tasks.

2.2 Affordance in user interface research

The idea that objects and actions are linked has been successfully adopted into use in the field of human action recognition. First of all, the observed human actions have been used to identify objects in the environment [9]. The idea is that certain actions, for instance typing, can be performed with certain objects, such as a keyboard. Thus if we have an a priori list of object affordances, we can automatically classify objects just by observing the user actions.

This object action link has been also used in the other direction, i.e. to recognise actions based on the observed objects [10]. The underlying idea is however the same, certain actions can be performed only with certain objects. Also in this case we need the a priori list of object affordances that we can then use to link the observed objects with the possible actions.

The difficulty of this type object-action association is proportional to the complexity of the environment, i.e. to the number of possible actions and objects in the environment [10]. Especially actions that can be related to several objects, such as picking up, require additional information, for example from the work context, to make the association unambiguous. This complexity constraint is also applicable when we communicate using object affordances. The greater the amount of different objects and actions we need to consider, the more likely the communication is ambiguous. The two above described applications show, however, with functional implementations in everyday environments, that the concept of object affordances has been successfully utilised in the user interface research.

2.3 Affordance in robotics research

Performing given actions to specified objects has been consider to be in the centre of Human Robot Interaction (HRI) [11]. The main goal of human-robot communication is then to transfer these two coupled parameters between the human and robot actors. The concept of object affordances has thus been long, in one form or another, in the core of robotics research.

One recent robotic application, which explicitly utilises the concept of affordances, introduces a robotic subsystem that can automatically detect object affordances from the robot's environment [12]. The idea of this robotic subsystem is to scan for spatial relationships from the environment that meets the requirements of certain actions. For example, "chair" is an object that affords the action of sitting. A chair has for this functional purpose a flat area on a height of few tens of centimetres from the ground. The chair is in this way defined through the actions that it affords. This type of automatic affordance perception subsystem could be a valuable counter part of the human-robot communication system described in this paper.

3 Research Problem

The overall goal of this research is to make the communication between the astronaut and the astronaut's assisting robot more easier. Especially, the astronaut-robot communication should be made more intuitive, i.e. self evident to use and easy to learn, and more tolerant to the user errors. The research focus is on scenarios where the astronaut and robot are located in a shared work space on a planetary surfaces, such as on the Moon or Mars.

The question examined in this paper is whether object affordances, inspired by human cognitive capabilities, can be used to improve the human-robot task communication. The possible improvements could be in the sense of decreased astronaut workload, increased tolerance towards communication mistakes, or decreased communication times. The tasks examined here are defined to be consisting only of two coupled parameters of action and target of the action, which can be considered to be the minimal parameters to define a proper task [12].

The concept of affordances is examined here by defining an a priori database of action-object relationships to the robot. The robot can then use this database to link objects to actions, and vice versa. The idea is to provide this way the robot a human-like capability to understand object-action relationships in the task communication. This should enable that only the target or action names can be, in some cases, used to communicate the whole task. The robot's task interpretation architecture schema, with this new object-action relationship database subsystem, is shown in Figure 1.

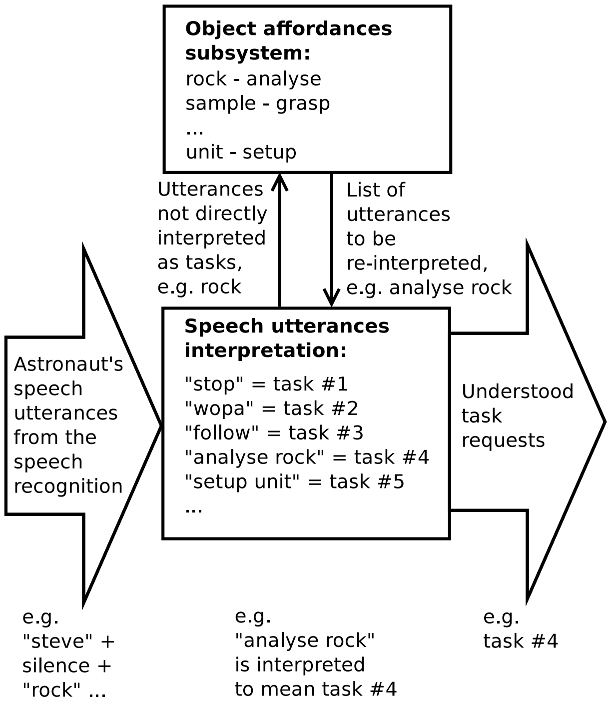

Figure 1. The architecture schema of the robot's task communication interpretation system with the new examined object affordance subsystem.

For example, lets examine task communication where the target name is "rock" and the action name is "analyse". When the human states "rock", the robot can understand that there is only certain actions that it can perform with rocks. In case the action is unambiguous, the task is immediately properly defined. In an ambiguous case, the robot might need to ask for the desired action or utilise the work history or current context of the work. Similarly, when the human states "analyse", the robot can check which targets it can analyse and thus potentially unambiguously define the complete task.

The target application of astronaut-robot task communication is taken into account by constraining the examined communication interfaces to the ones that are applicable for Extra Vehicular Activity (EVA) suited astronauts. The communication from astronaut to robot is done using only speech and the astronaut's body location. The communication from robot to human is done instead using speech, head orientation, mouth expressions, and robot's platform location and orientation. These are all communication interfaces that can be made relatively easily available for any astronaut and robot working together in a shared workspace.

The answer to the question of object affordances usefulness in the task communication, is sought by comparing the three previously described task communication methods, i.e. direct action with target, target name and action name methods, during their use on a simulated astronaut-robot geological exploration mission. These user tests are described in detail in the next Section.

4 Test Setup

The overall context of the performed test is astronaut-robot geological exploration done on the surface of Mars. In the test, the test person is an astronaut working with a robot. The robot is following the test person and performing two different tasks based on the astronaut's requests. The first task is to make measurements from interesting rock samples, when the astronaut points them to the robot, and report the measurement results to the astronaut. The second task is to setup field experiment units based on the decisions of the astronaut.

As stated in the previous section, the goal of the test is to evaluate three different methods of task communication. The first task communication method being evaluated is always communicating all of the task parameters. In this test the task parameters are the action and the target of action. Thus, the speech utterances used with the first examined communication method are in this test "analyse rock" and"setup unit".

The second and third communication methods being evaluated are based on the object affordance concept presented earlier. With the object affordances based approach the object associated action possibilities are utilised to complete the requested task. For example, based on a rock-analyse object-action association we can derive the task to be "analyse rock" by just communicating the object name "rock" or the action "analyse". The second communication method speed utterances are then in this test "rock" and "unit", and with the third "analyse" and "setup".

4.1 Test configuration

The astronaut space suit is simulated in this test using restraining clothing, shown in Figure 2. The simulated space suit consisted of a heavy backpack, high heel sandals, and a helmet. The purpose of the suit is to constrain the test person movement so that, for example, picking items from the ground is a very difficult if not impossible task. The test person is also given a wireless microphone for the speech communication.

The Aalto University's WorkPartner robot [13], shown in Figure 2 and Figure 3, is used as a fully autonomous astronaut assistant robot in this test. The robot moves in this test using its wheels and middle joint. It has a SICK LMS291 laser rangefinder on its chest which is used to track the test person and to enhance the wheel odometry based localisation. The robot upper body has two (Degrees of Freedom) DOF, enabling the upper body to tilt and rotate, and five DOF both in the left and right

Figure 2. The restraining outfit used by the test persons consisted of high heel sandals, backpack and helmet.

arms. The head is mounted on top of a two DOF pan-tilt unit and a LED array is used to imitate the mouth movements while speaking.

The WorkPartner robot is able to understand five different speech requests. First, and probably the most important one, is “stop” which stops all the robot movement, both the wheel and manipulator. Another similar speech request is “wopa”, the name of the robot. It will stop the wheel movement and drives the manipulators to the zero position, as shown in Figure 3. The robot head is tracking the test person in all situations except when the “stop” is requested. The third basic speech request is “follow” which will cause the WorkPartner to try to maintain a safe distance of two metres to the test person.

The two actual speech requests that enable the test person to perform useful tasks are “analyse rock” and “setup unit”. When the “analyse rock” is requested, the WorkPartner robot will drive to analyse the rock in the the location where the test person was standing at the moment when the request was given. The “setup unit” speech request instead causes the robot to setup a measurement unit in the current location of the robot.

The tests are performed in the Aalto University TUAS building main hall, shown in Figure 4. The usable test area is approximately eight metres wide and 30 metres long. The used rock samples and the measurement unit mockup are shown in the Figure 5.

4.2 Test protocol

The flow of the test for each of the test persons is the following. After describing the test idea, the test person is first taught to communicate with the robot using a wireless microphone. The speech recognition software, in this case CMU Sphinx II [14], is trained separately for all the test persons in order to guarantee as high a speech recognition rate as possible. The test persons are told to practise the

Figure 3. The WorkPartner robot is operating in this test as an astronaut assistant robot.

Figure 4. The scenario test area. The white papers on the ground are used to cover the rock samples.

speech communication first with a laptop computer and later with the robot until they are confident that they are able to communicate without problems.

As stated earlier, the possible speech utterances are “stop”, “wopa”, “follow”, “analyse rock”/“rock”/“analyse”, and “setup unit”/“unit”/“setup”. The robot acknowledges the requests by describing through speech what it is going to start doing next. The pointing is done using the test persons centre of mass, which is calculated from the laser scanner ranging measurements. The human body is a very minimalist pointing interface which is, however, always available to any astronaut that is physically present in the same space with the robot.

The actual test starts when the test person starts to move in the previously unexplored area. The test person

Figure 5. Measurement unit mockup (above) and few interesting (lower left) and non-interesting (lower right) rock samples used in the test scenario.

is told to look for interesting samples described with red coloured rocks, as shown in Figure 5. All the rocks are covered with white papers set in a paired line, as shown in Figure 4. The idea in covering the rocks with paper is to detect exactly the moment when the test person detects a new interesting rock by pushing the covering paper away with his leg.

After the test person has found an interesting rock, he requests the robot to analyse the rock. The robot drives to the location indicated by the human body, bends down and reaches towards the pointed sample. The robot moves the arm with simulated sensors over the sample and then returns to an upward position. The robot selects next if the sample was interesting and communicates the result to the test person through speech. If the sample is interesting, the test person is supposed to request a measurement unit to be inserted next to the rock. As requested, the robot then takes a measurement unit from the top of its chassis and inserts it next to the interesting rock.

The goal of the test person is to first setup two measurements units next to interesting rock samples using each of the three communication methods and, then finally, two more measurement units using freely any of the three tested communication methods. This means that in total eight measurement units have to be installed. It is important to note that because we are exploring a previously unknown area, the robot does not understand the objects just by pointing but some utterance is required to define if we are targeting “rock” or “unit”.

4.3 Evaluation metrics

The workloads induced by the three examined communication methods are compared using NASA (Task Load Index) TLX [15]. The NASA TLX, and few other similar methods, are introduced and discussed in [16]. The test persons’ communication method preferences are examined by calculating the number of times the test persons chose to utilise each of the compared communication methods. The needed variables are recorded during the experiment but also video and log files are saved to enable double checking of the results.

The NASA TLX questionnaire will be filled in immediately after the communication method tests for each of the three communication methods. In addition, in the end of the tests, the test person will fill in a free form questionnaire. The idea of this free form questionnaire is to collect all the possible comments from the test persons and make them to answer into few direct questions related to the test.

In order to make the test results counterbalanced, i.e. to eliminate the effect of starting order and learning, only every sixth person does the test in the same order. For this reason the number of test persons have to be also a factor of six, for example 12 or 18.

5 Results

In total 12 test persons participated in the test. Nine of the participants were male and three were female. The average age of the participants was 28.0 ± 3.3 years. All participants, excluding one law student, were Aalto University students. All of the test persons can be considered as novices as they did not have any previous experience with the tested system.

The statistical significance of the obtained results are evaluated using the one way within-subjects ANOVA. The analysis method’s input data sphericity assumption is checked with Mauchly’s sphericity test.

The NASA-TLX test results were collected from each test person for each of the three communication methods. The test persons were asked to evaluate the task communication from the point when they notice that a task needs to be done to the point when they start their speech utterance. This means that, for instance, speech recognition accuracy is neglected in the evaluation. The collected results are shown in Figure 6.

The one way within-subjects ANOVA showed that there is significant difference between the NASA TLX results of the compared three communication methods, $F(2,22)=8.01$, $p=0.002$. Mauchly’s test indicated that the assumption of sphericity is not violated (chi-square = 4.70, $p=0.095$). Bonferroni adjusted pairwise t-test comparison showed that the difference between the full action with target based communication and target based communication is significant ($p=0.030$). Similarly, the difference is significant between the full action with target based communication and action based communication methods ($p=0.041$). There is, however, no significant difference between target name or action name based communication methods in this test.

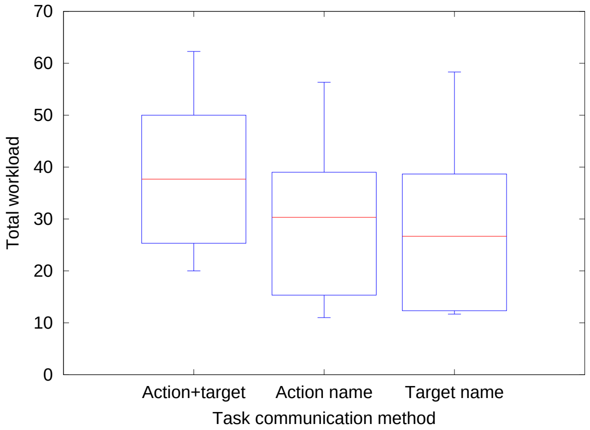

Figure 6. The NASA-TLX workload box plot for the three compared task communication methods.

At the end of the test the participants were also given the possibility to choose freely the communication method that they would prefer to use. The test persons were told to request two times the rock analysis and two times the measurement unit setup. The choices done by the test persons are shown in Figure 7. The full action with target based communication was used in total 11 times, the action name only communication 21 times and the target name only communication 16 times.

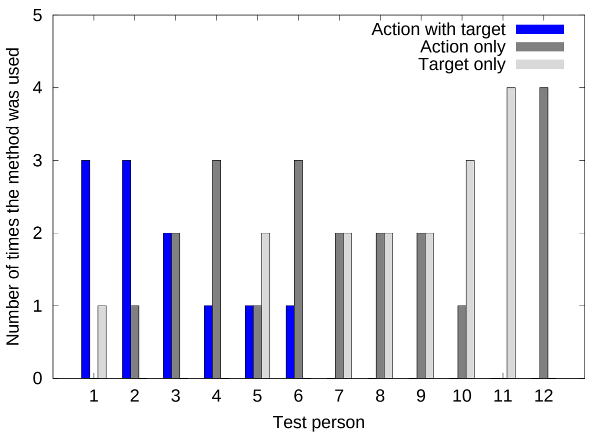

Figure 7. The freely chosen communication methods selected by the test persons.

The test persons made hardly any communication mistakes during the tests. Only one person stated “analyse rock” when he was supposed to say “setup unit”. He, however, noticed the mistake immediately, stopped the robot and communicated the correct request.

The test persons’ task communication times were also recorded and analysed from the video recordings. These analysis did not however reveal any significant differences. This is probably because there were numerous random variables that affected the timing process, even though efforts made to eliminate them, for example, through the use of white papers to detect the exact moment when the interesting rock was detected. These random variables were for example caused by the user and robot movements after finding the interesting rock samples. Some users also waited for instance for the robot head to be stationary before addressing the robot.

The findings from the free form questionnaire results are summarised in Table 1. In addition, the test persons were asked to choose between the three examined communication methods. These selection results are show in Table 2.

Table 1. Free form questionnaire results. The user evaluated the items from 1 (bad) - 5 (good).

Question	Action+target	Action	Target
Easy to recall	3.75	4.08	4.42
Easy to learn	4.25	4.50	4.67
Obvious to use	4.00	3.92	3.75
Overall rating	4.00	4.42	4.25

Table 2. Communication method preference selection results. The number indicates how many test persons selected that answer. For example, five persons answered to prefer probably action over action with target based communication. One arrow means that the user probably prefers and two arrows mean that the user definitely prefers the option.

Question	>>	>	equal	<	<<
Action+target or Target	1	2	4	4	1
Action+target or Action	1	3	2	5	1
Action or Target	3	1	4	1	3

One noteworthy observation during the test was that in the few cases when the robot failed to receive the speech requests, during the choose freely communication method part, the test persons switched relatively quickly to use some other communication method.

6 Discussion

The NASA TLX results, summarised in Figure 6, showed that the workloads observed by the test persons were lower with action and target name based communication methods than with the full action with target based communication method. No significant difference was, however, detected between action and target based communication methods. The selections from the freely chosen communication method part of the test showed that action based communication was most popular, then target name based communication.

The user questionnaire answers offer few possible explanations for these findings. The rationale given for using actions based communication was that action name is a natural way to ask somebody to do something because it is a verb. Two test persons, nevertheless, stated that the use of action for communication was more natural for them only for other of the tasks. For the other task they preferred to use the target name based communication. This indicates that the test persons might not have any clear preferences towards any certain communication method but in the ideal case they would be free to use all of the communication methods simultaneously.

The test persons using target name based communication commented as their rationale that the target is the most obvious way to constrain the task to only one place. In addition, two stated that the communication is also easy to remember because the required speech utterance is the name of the target that they are usually already looking at.

The test persons who chose to use the full action with target based communication answered as rationale that it defines the request always unambiguously. Without the full task communication the robot would not perhaps know in all the situations what to do exactly. It is interesting to note that the test persons did this even though in the performed tests there was no possibilities for false object-action associations.

Both the NASA TLX and communication method choice results point out, however, that the new affordance based communication methods compared were not only good alternative communication methods to use, but actually the ones inducing less workload and being more popular in use.

The questionnaire results shown in Table 1 and Table 2 supported also these findings. Although all of the communication methods received good grades, action and target based communications were slightly easier to remember and to learn. The action with target name communication was however consider to be slightly more obvious to use. This is probably because we are more used to communicate with full action with target type of communication with other people. It is important to note, however, that the other communication methods received also high ratings which means that they were also considered obvious to use.

We can see from these findings that the use of object associated actions can provide a powerful secondary way to communicate tasks to the robot. As observed during the user tests, the communication method can be changed seamlessly if the communication fails in the first attempted way, for example, due to speech recognition failure or due to remembering problems. This can be directly seen to make the communication more error tolerant as there is an alternative way to perform the communication.

6.1 Results applicability

As always, it is important to discuss to what type of situations the results can be applied to. This is especially important in this case because the applied approach is new and the test was constrained primarily to provide answer if the object affordances based communication can be used in practise with robots.

The main constraint in the test was that there were no ambiguous object-action associations involved. This seemingly severe constraint does not, however, apply to most of the current service robots because their functionality is very limited. Nevertheless, a robot with human-like capabilities would definitely need additional methods to solve ambiguous object-action associations. The results presented in this paper do not provide any indication of how this ambiguity solving could be done. The results only show that the affordance based communication was usable in the unambiguous situation.

The geological exploration scenario simulated in this paper should be however otherwise very applicable in many other types of situations. The assistant robot was mobile and fully autonomous, and the test persons were required to both make request and react accordingly to the robot's responses. There is not any reason to assume that the examined task communication methods would not work, for example, equally well with direct teleoperation as well as with peer-to-peer type of interaction.

7 Conclusions and Future Work

7.1 Conclusions

In this paper a comparison of three speech based astronaut-robot communication methods was presented using a fully autonomous centaur-type astronaut assistant robot as a test platform. A full task specification speech utterance, consisting of action and target of action, was compared against only action name and target name based task communication methods. These new methods were made possible by implementing in the assistant robot a subsystem to mimic the human-like capability to understand object affordances, i.e. link objects with their possible actions.

The system evaluation showed that both of the action and target based communication methods were usable in practise to communicate tasks to the robot. Both of these communication methods decreased the overall workload observed by the test persons compared to the full task parameters based communication. The possible explanation offered for this is that the somewhat laborious object-action association in the task communication is transfered for the robot.

The affordance based task communication methods were also concluded to introduce a viable mechanism to provide error tolerance as the astronaut has always alternative ways to make the required tasks communicated. The test persons' communication method preference selections also supported this claim by displaying a wide range of different communication method preferences.

7.2 Future work

The presented test scenario had two primary tasks which were performed towards two different objects. The next logical step would be to test the object affordances usability when several actions are associated with the same objects. The approach could be, for instance, to let the robot propose possible options when the object-action association is ambiguous. Another approach could be to add a possibility to change the working context. For example, in a geological exploration context the robot would only perform analysis for rocks while in a storage operations context it would just move rocks from one place to another. It is not, however, evident that this type of context switching would be advantageous compared, for example, to the full task definition option.

The affordance based task communication approach might be especially useful when using, for example, gestures instead of speech. It is easy to point an object for the robot but to tell the action with pointing or gestures is instead close to impossible. In this case, the use of object affordance would become a vital key component of the communication system as it would make the otherwise seemingly impossible task communication possible.

8 Acknowledgements

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