

Teleoperation of Unmanned Vehicles: The Human Factor

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ABSTRACT

Unmanned vehicles or robots promise to increase the operational range of the armed forces while reducing the exposition of personnel to hazardous conditions. They have traditionally been in use for aerial surveillance and ground based explosive ordnance disposal. Following the ongoing progress in research and technology, unmanned vehicles have the potential to play a much more versatile role in future conflicts. The use of such systems is already expanding into reconnaissance, surveillance and target acquisition scenarios. Virtual and Augmented Reality technologies are utilized across a wide range of relevant areas concerning the development, evaluation and operation of unmanned vehicles. Virtual Reality interfaces are of high value for the development process ranging from the technical design phase to the simulation-based evaluation of the human-machine system. A particularly relevant aspect concerning unmanned vehicles represents the operational performance of the human-machine-team. This performance however, is primarily dependant on how effectively a human operator can supervise and control the unmanned system using a given human-machine interface. In this paper we present a task-centric approach to the command and control of unmanned vehicles that differs significantly from the traditional vehicle-centric teleoperation method as used in todays available systems. We believe that this approach can support the acceptance and use of unmanned vehicles by dismounted soldiers. Our interface implementation features both 2D and virtual scene representation components to allow the task specification by the user.

1.0 INTRODUCTION

Unmanned vehicles or mobile robots promise to increase the operational range of the armed forces while reducing the exposition of personnel to location-bound hazardous conditions and risks. Mobile robots have been in development for decades and have improved their performance and fitness to operate in indoor and outdoor environments ever since [9]. While most commercially available military unmanned vehicles are either aerial vehicles (UAV) used for reconnaissance, surveillance and target acquisition (RSTA) or ground-based explosive ordnance disposal robots (EOD), mobile robots addressing the problem of RSTA in urban scenarios have become a main interest of military forces involved in urban conflicts. In this paper the focus is on the operation of unmanned ground vehicles (UGV) in short range non-line-of-sight conditions. In this paper we present a task centric approach to the command and control of unmanned vehicles that differs significantly from the traditional vehicle centric teleoperation method as used in todays available systems. We believe that this approach can support the acceptance and use of unmanned vehicles by dismounted soldiers.

From the perspective of an operator of an unmanned ground vehicle, controlling a mobile robot can in general be regarded as a dual-task problem: The first, being the pilot task covers the aspects of the unmanned platform, e.g. maintaining operational effectiveness, obstacle avoidance etc. The second, being the payload task covers all aspects regarding the task objectives the unmanned vehicle is used to

Trouvain, B. (2006) Teleoperation of Unmanned Vehicles: The Human Factor. In *Virtual Media for Military Applications* (pp. 11-1 – 11-8). Meeting Proceedings RTO-MP-HFM-136, Paper 11. Neuilly-sur-Seine, France: RTO. Available from: <http://www.rto.nato.int/abstracts.asp>.

accomplish, e.g. applying sensors for surveillance or searching. In today's available robotic systems such as for example UAVs, this leads to control stations with at least two operators being exclusively assigned for piloting the robotic platform and applying the payload. Figure 1 shows a simplified model of a computer-based human-machine-interface as used for controlling unmanned vehicles.

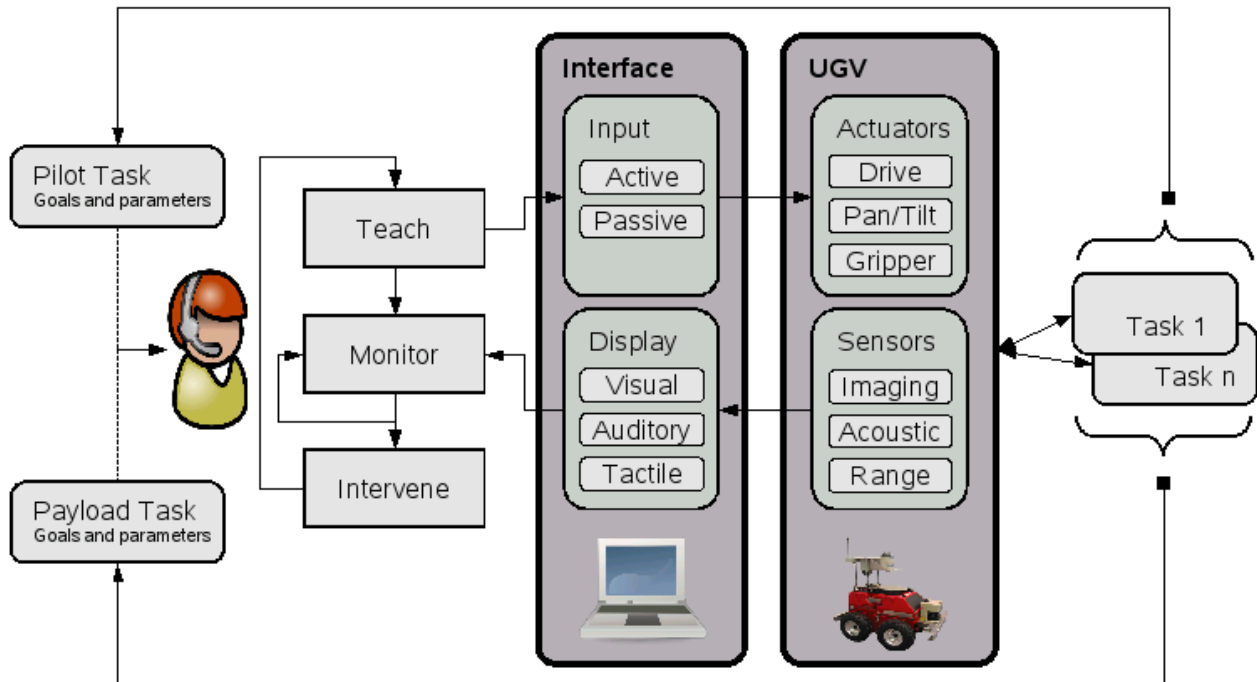


Figure 1: General Model of a Human-Machine-Interface for Teleoperation or Supervisory Control of Unmanned Vehicles. The operator is given the goals and parameters of the pilot and the payload task and executes a standard control loop. The interface receives the operator input and translates it into robot commands to address the given tasks. The feedback information from the robots' sensors is rendered by the display of the interface which is monitored by the operator.

The model depicted in figure 1 outlines the scope of the task of using an unmanned ground-based vehicle from the operators' perspective. The human-machine-interface and the vehicle represent the key components in this model. Based on the capabilities of the unmanned vehicle various tasks in different operational environments can be addressed. However, in non-line-of-sight conditions the interface represents the only link between the operator and the vehicle. All operator input must be translated into vehicle commands by the input components of the interface. The display component of the interface must render all feedback information necessary to provide the operator with a sufficient picture of the robots context. The operator must monitor all incoming information about the state of the vehicle, the environment, and the state of the tasks to effectively supervise and control the unmanned system.

This model of teleoperation for unmanned ground vehicles has some disadvantages concerning the integration into military operations based on the use of such vehicles by dismounted soldiers:

- Even under the assumption that the pilot and the payload task can be interleaved or serialized the effective utilization of an unmanned ground vehicle using this interaction model will bind at least one operator full time. Further the operators' visual attention is bound heavily to the interface when supervising the operation of the vehicle platform or when executing some payload specific operation, e.g. manoeuvring in difficult places or the continuous adjustment of sensors in dynamic situations.

- Unmanned ground vehicles are in general highly complex systems. Realizing ergonomic input and output components generates various constraints on the human-machine-interface. Foremost the physical display size is relevant if the unmanned vehicle provides high resolution visual information. A physically large interface is in general considered difficult to be used by dismounted soldiers.
- The performance of the unmanned ground vehicle is highly dependant on the operational environment. For effective operation, static and dynamic obstacles must be classified by the operator to identify what risk they pose to the vehicle. Dynamic obstacles such as debris, foliage or left over barbed wire to name a few are difficult to judge in their effect on the mobility and can easily immobilize the unmanned vehicle. Further, operational environments may vary from open terrain to urban settings as well as the utilized vehicle may vary in type and payload. This leads to the point that the effective utilization of unmanned ground vehicles requires well and continuously trained specialists rather than on-demand users.
- The presented model of teleoperation does not scale well between the number of operators and the number of unmanned vehicles as well as the type of the vehicle (ground and air). Multiple operators or multiple unmanned vehicles are of interest here. As well as the use of heterogeneous type vehicles such as unmanned aerial and unmanned ground vehicles. A classification of possible operator and unmanned vehicle teams can be found in [8].

The above named disadvantages for the model of teleoperation as outlined in figure 1 can be partially addressed on three levels: first the vehicles' capabilities and robustness can be improved to reduce the risks based on the operational environment, further increasing the level of vehicle automation can reduce the amount of supervision and interaction required by the operator. [4]. Second, the training of the operator can be improved and extended to prepare the operator for a wider variety of situations. Third, the human-machine-interface provides a range of opportunities to generate either positive or negative impact on the overall human-machine-team performance.

In non-line-of-sight conditions, when the operator must completely rely on the data transmitted from the vehicles' sensors the human-machine-interface becomes essentially the performance limiting factor. To address the above mentioned disadvantages of the outlined teleoperation model, we developed a user-centric human-machine-interface concept using a declarative approach to teleoperation.

2.0 CONCEPT OF A DECLARATIVE INTERFACE FOR UNMANNED GROUND VEHICLES

2.1 Declarative Control of an Unmanned Ground Vehicle

The attribute declarative and imperative have been translated from the computer science domain where they are used to classify programming paradigms. Traditional programming languages such as C, Pascal and Ada are termed imperative programming languages as they require the programmer to explicitly describe the computation in terms of a program state and statements that change the program state [1]. Declarative programming on the other side describes "what" a result is like, rather than "how" to create it. This is a different approach from the traditional imperative paradigm [2].

In our concept the traditional imperative paradigm is analogous to the model of teleoperation as shown in figure 1. An operator imperatively or explicitly commands an unmanned vehicle to perform a sequence of actions to resolve a particular task. This method leads to the disadvantages as stated above. Translating the declarative paradigm to the operation of unmanned vehicles means that the operators' task will be to specify the desired result the unmanned vehicle should deliver rather than executing the command sequence to achieve this result. A simple example of declarative interaction is already widely used when

specifying way- or goal points and delegating the explicit command generation to an automated subsystem. An important aspect, when considering declarative interaction with unmanned vehicles is that the explicit command generation for the vehicle itself is still required as in the teleoperation model. This will be done by either a specialist operator or by an automated subsystem translating the declarative interaction into a command sequence. Figure 2 depicts this concept schematically.

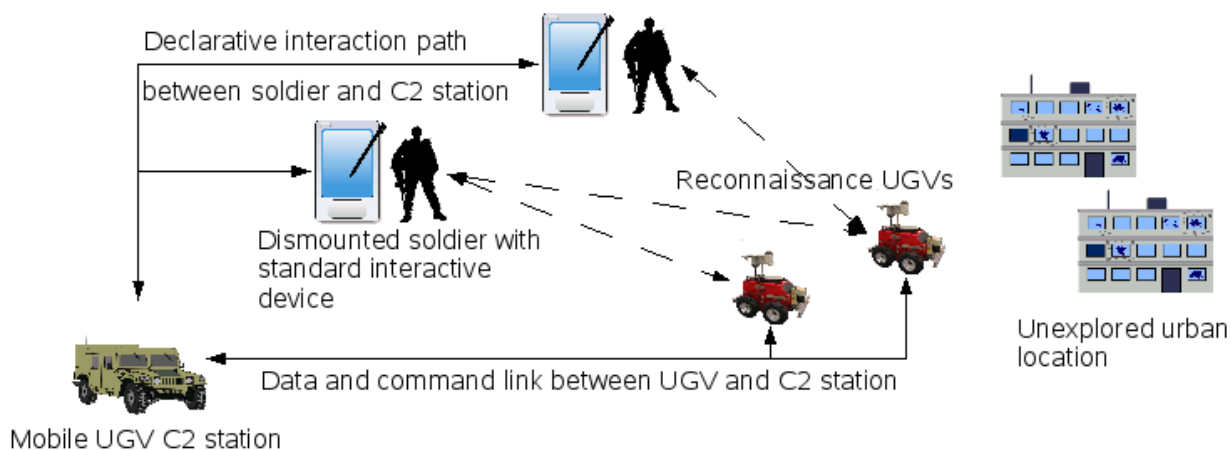


Figure 2: Declarative Human-Machine-Interaction Model. The dismounted soldier interacts with the unmanned ground vehicle using a standard interactive device as for example a PDA. The soldier does not control the vehicle itself but declaratively specifies, for example map-based, the task the vehicle should resolve. The commands are relayed to a mobile UGV command and control station where a specialist operator uses the standard model of teleoperation (see figure 1) to resolve the specified tasks.

The central difference and advantage of the declarative teleoperation approach is that the interaction with the unmanned vehicle is transformed from vehicle-centric to task- and user-centric. Vehicle specific aspects of the teleoperation are no longer relevant for the dismounted soldier as the soldier can interact with the UGV by stating “what” it should do and the specialist operator in the mobile UGV command and control station is responsible for the realization or the response that the given task can not be executed. This approach leads to the possibility that the dismounted soldier just needs an interface to specify the tasks to be resolve by the unmanned ground vehicles. This type of interaction with unmanned vehicles provides several advantages:

- The declarative human-machine-interaction scales well with physically small and lightweight user interfaces. Without the need to display information associated with the pilot task, since this is only relevant to the operator in the command and control station, the interface for the dismounted soldier can be reduced to render only task specific information. Starting with speech-based command input to be interpreted by the operator in the command and control station, or other small graphical user interface devices like personal digital assistants (PDA, as presently used in some Special Forces units) can already be used effectively.
- As stated above the declarative approach to the use of unmanned vehicles by dismounted soldiers can be realized on small and lightweight interfaces. Declaring tasks for mobile systems essentially requires georeferenciation as well as action description. A task description could for example be stated like the following: “Observe the eastern side of building X and report any activity”. This task can be well described by text or if available by a graphical map-based input method. The required input and output modalities for this type of interaction are already available in today’s PDAs, tablet PCs or other portable computers and should therefore be well integrateable into existing computing equipment.

- As the declarative approach of interaction with unmanned vehicles is user- and task-centric instead of vehicle-focused, it scales well with multi-operator and multi-vehicle scenarios. Developing effective means and interfaces for the simultaneous teleoperation of multiple unmanned vehicles is a difficult problem and presently a research activity [5][6]. With this approach a dismounted soldier is capable of utilizing multiple vehicles simultaneously by specifying a task that requires the use of multiple vehicles. For example the specification of a task to observe a building from multiple angles to identify possible risks. This task would be resolved by multiple vehicles each under the supervision of a single remote operator. Concerning the multi-operator capability, a declarative task specification can be well visualized by standard graphical user interfaces. This supports the co-operative work of multiple operators as they can collectively work on a given task description as well as identifying the motivation of a visualized task.
- The declarative interaction approach results in an abstraction from a specific unmanned vehicles by moving the vehicle specific command and control aspect from the dismounted soldier to the specialist operator in the UGV C2 station. This allows the abstraction from a specific unmanned vehicle type. Whether the vehicle is wheel- or track-driven, or even a legged device has no impact on the way the dismounted soldier interacts with it. The soldier just needs to describe the “what is to be done” and the “how” is resolved by the remote specialist operator. A dismounted soldier without any training in controlling unmanned aerial vehicles could for example specify a task where the roof of a specific building is to be inspected for any hostile activity.
- We believe that the declarative interaction method should require a lower learning and training effort than the standard teleoperation method as depicted in figure 1. Our believe is based on the following assumptions: First the declarative approach can be realized using standard user interfaces, which are in most cases well known to many users. Second the inherent abstraction of the specifics of the unmanned vehicle of this approach relieves the dismounted soldier to acquire any in-depth knowledge about various unmanned vehicles. Third, the declarative task specification methods can be grounded on common military types of georeferenciation and action description. This should relieve the dismounted soldier of the need to learn special and most probably vehicle-specific protocols to effectively utilize an unmanned vehicle. However, this is only valid for the dismounted soldier. The UGV specialist operator in the command and control station responsible for executing the tasks as described by the dismounted soldiers must of course have in-depth knowledge about the controlled unmanned vehicle.
- Scaling with increasing levels of vehicle automation. Given the present pace and progress in research and development of unmanned vehicles one can assume that the degree of automation, or autonomy [4] will increase to either reduce the operators’ workload and increase the capabilities of the vehicle. From a dismounted soldier’s point of view using a declarative approach to human-machine-interaction as presented in this paper, improvements in automation based capabilities do not change the way of interaction. Changes induced by modified capabilities of the vehicle affect the specialist operator but are transparent to the declarative method of interaction as used by the dismounted soldier.

2.2 Interface Realization

Traditionally, human-machine-interfaces for the command and control of unmanned vehicles have been vehicle-centric [3]. In these interfaces a lot of emphasis is put on the visualization of the status of the vehicle platform and the payload components such as sensors and manipulators. For the dismounted soldier using an unmanned vehicle in the sense of using a resource most if not all of this status information is irrelevant.

Following the declarative approach to the command and control of unmanned vehicles the design of the interface can be task oriented. The task for the dismounted soldier as the user of an unmanned vehicle is

no longer the manual control of the vehicle but the specification of what task the vehicle should accomplish in the present situation. Designing an interface for declarative human-machine-interaction is therefore more focused on task specific input and output methods. In our first version of the declarative interface we chose therefore a standard tablet PC as input and output device for the dismounted soldier.

The input modality used in our example is pen-based interaction as this is a likely form to be used when requirements for physical dimension, mobility and speed of input do not permit keyboard input methods. The output modality is primarily visual with supplemental auditory elements. An interface for declarative interaction requires primarily the referenciation of both locations and objects to define tasks and task constraints such as directions, distances and timing. To enable the declarative task specification we used an interface based on the sketchboard metaphor. Sketchboards are already widely used as rapid prototyping interfaces. We use the sketchboard to allow the use the specification of tasks by drawing the task parameters into a map from a top down two dimensional perspective. A secondary input and output component is realized by the visualization of a virtual environment of the task scene from either a vehicle based perspective or an arbitrary virtual location to allow the user further means of specifying task constraints. Figure 3 shows a sample screenshot of the interface as seen by the user.

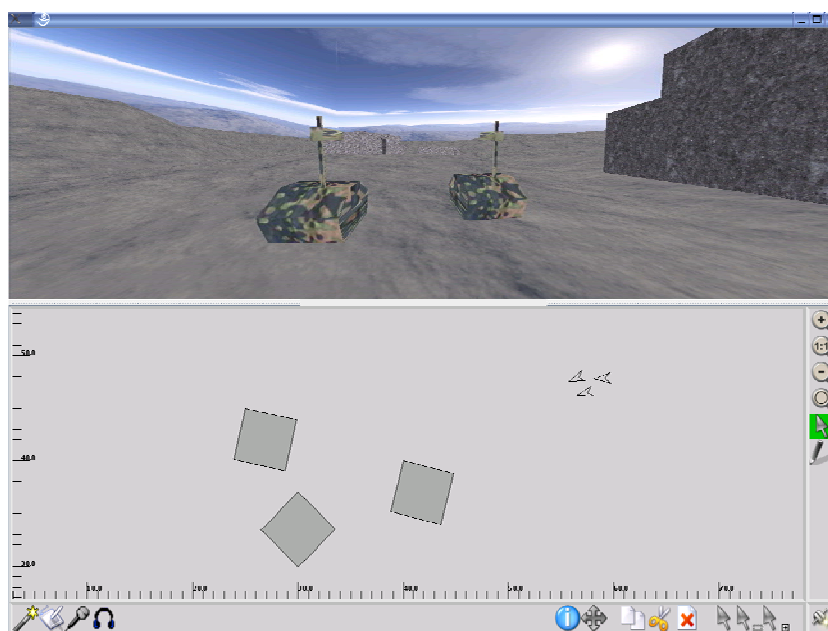


Figure 3: Screenshot of the Tablet PC Based Interface. The lower section contains the sketchboard interface showing three unmanned ground vehicles as arrow-head shaped elements. Three simplified buildings are present. The sketchboard contains some icon-based mode buttons to enable standard create/edit/delete operations by the user. The top section of the interface contains the rendering of the virtual environment which is generated out of the map data as present on the sketchboard. The perspective in this example is based on the camera of the rightmost vehicle showing the other two vehicles in front.

2.3 Declarative Task Specification

An important benefit of the declarative interaction with unmanned vehicles is that it can be realized using standard computing equipment using well-known interactive methods such as the pen-based sketchboard approach we use in our example. The same is valid for the process of the declarative task specification which has to be done by the dismounted soldier. Standard procedures known from graphical user interfaces such as point and click, component dragging, undo and redo, or opening a context menu can be used for the specification of a task for the unmanned vehicle. Figure 4 depicts a sample task specification

following the situation as present in figure 3. The interaction in this example is conducted using only pen-based input.

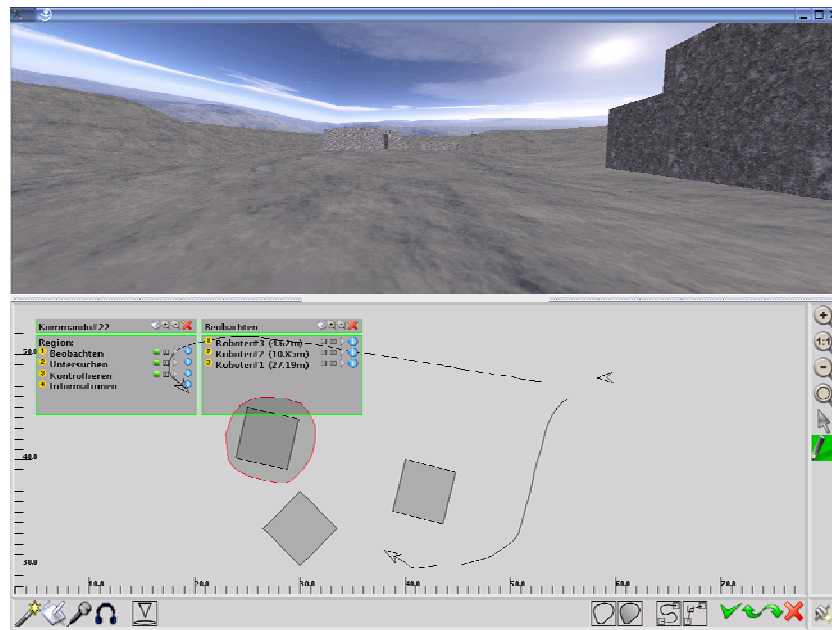


Figure 4: Sample Task Specification Using the Sketchboard Interface. In this example the user (dismounted soldier) wants to observe the leftmost building. To move two vehicles into the desired observation position a path is drawn on the sketchboard to be following by the vehicles. The relevant building is marked on the map and using the context menus for building-based operations the user specifies the task to be resolved. In this example the user can choose between “Observe”, “Examine”, “Investigate”.

3.0 CONCLUSION

In this paper we stated that the standard model of teleoperation as shown in figure 1 has several drawbacks when concerning the use of unmanned vehicles by dismounted soldiers. These drawbacks are in general founded in the requirement that operating an unmanned vehicle is a high workload task which binds a single person full time to a complex human-machine-interface. To improve the possibility of the integration and use of unmanned vehicles with teams of dismounted soldiers we developed the concept of a declarative human-machine-interface. This concept differs from the traditional vehicle centric paradigm of the command and control of unmanned vehicles as it focuses on task descriptions. We believe that this approach has several advantages compared to the traditional approach:

- It allows for simple and lightweight user interfaces based on standard hard- and software.
- It scales well with multi-operator and multi-vehicle scenarios as the task declaration is based on the desired result and therefore invariant to the number of vehicles used to achieve this result. Even mixed type vehicles such as UGVs and UAVs can be used this way.
- Possibly lower training requirements since the interface can be built around standard input and output components as used in todays portable computing equipment. Also the vehicle abstraction should reduce the required amount of specific knowledge about particular models of unmanned ground vehicles.
- It scales well with different levels of vehicle based automation. Due to the vehicle abstraction of the interface different levels of automation should be transparent to the user.

These advantages should support the acceptance and use of unmanned vehicles by dismounted soldiers in missions where such vehicles can take over hazardous activities. The next step in our development process is the actual testing and evaluation of our interface with novice subjects. The results of this evaluation will guide the next development cycle. At this stage the three dimensional scene representation is extended to enable the creation and modification of tasks from multiple perspectives.

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