Supervised Autonomy: A Framework for Human Robot Systems Development

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ABSTRACT

In this paper we present a paradigm for robot control, Supervised Autonomy. Supervised Autonomy is a framework, which facilitates the development of human robot systems. Each of these components have been devised to augment users in accomplishing their task. Experimental results of this framework in applying to the use of a teleoperation system are presented. Our current progress and planned future work is also presented.

1 INTRODUCTION

In the opening pages of the published book “The Robotics Revolution”, Scott writes, “...at the end of the day, however wonderful the robots, it is the humans who mean the most.”[2]. Very few people would not share this view. Historically, robotic research has been oriented towards the development of systems that can assist people to perform their tasks. Today, little has changed in orienting robotics towards this goal. This, and the large number of domains in which autonomous mobile robots can be applied, has motivated us to investigate a framework that can facilitate the interaction between people and robots. We consider that, any proposed methodology should take into consideration the alleviation of stress on human us while providing suitable level of instructions and feedback. The team “Alleviating stress” means that a human user need not be burdened with the complete control of a system. “Suitable instructions” means that a human user should not need to know the complex instructions required to command a robot to perform a task. “Suitable feedback” means that feedback is given both in appearance and explanation of what have taken place, must also be provided.

With these considerations we propose a methodology of “Supervised Autonomy”, that provides a framework for the construction of human-robot interactive systems. It consists of five interconnecting components: “self-preservation”, “instructive feedback”, “qualitative instructions”, “qualitative explanations”, “user interfaces”.

“Self-preservation” — How should we alleviate the burden placed on the user? The introduction of “self-preservation” shifts the general control of the robot from the user back to the robot itself. “Self-preservation” controls include safety aspects of the robot, such as collision and obstacle avoidance. It removes the need for a tight command loop controlled by the user. For example, if the robot has been instructed to visually servo to a selected target, and unexpected obstacle appears, the robot will move around it or stop to avoid collision, and then attempt to continue serving.

“Instruction feedback” — Do you see what I see? The notion of “instructive feedback” is to provide the same feedback to the user as to the robot. This is based on the intuition that if the user shares the same perception medium as the robot, instructions to the robot will be far more reasonable and sensible. For example, in the case of a visual target to servo to, the User can simply select a target from the same visual data stream that is also shared by the robot.

“Qualitative instructions” — How should the robot be instructed? Commanding a robot can be a difficult and troublesome task. To overcome this problem we prescribe the use of qualitative high-level instructions. These instructions offer or suggest information that are easily understood and are relatively natural to use.

“Qualitative explanations” — How should the representation be provided to an User? There is a need to describe to a User what is happening during the course of a robot mission. This description should include what events and activities took place, in a given period of time. For example, a mission can be described as, “Go forward” until you can’t, “keep
“User interface” — What controls should we provide to the User? To complete the system, consideration must be given to the development of a user-interface. It provides a means for the display of “Instructive feedback” and abilities for the User to give “Qualitative instructions”.

The general concept of our paradigm is to incorporate supervisory control with a qualitative approach for the control of robots. Supervisory control does not rely on human users to perform all the basic functions of perception and action in a system. The approach we have taken shifts all basic functions to the physical robot agent, integrated with a set of qualitative instructions, in combination with a simple graphical user interface, and together with suitable feedback form the complete framework.

As an experimental test-bed for our approach we have chosen the task of teleoperating a mobile robot. This task is well defined problem and an excellent framework for evaluating our ideas (see [3] for an extensive coverage of this topic). A well integrated system should provide an user with the flexibility required to travel in complicated and dynamic environments, without requiring a priori knowledge of the environment.

A description of our experimental setup is provided in Section 2. In Section 3, the implemented components which encompass the consideration taken above are presented. A presentation of the experimental result is given in Section 4. Section 5 present further work that is underway for our system. A conclusion is provided in Section 6.

Figure 1: System configuration

2 OUR SYSTEM

An overview of our system is depicted in Figure 1. The full configuration of our system involved four subsystem: a Yambico robot [4], a vision processor [5], a communication server [6] and an user interface console. The basic operation of our system is that the robot is being controlled over a radio via a SUN workstation, acting as a communication server. Due to computation limitation the vision processing resided off-board, the video perceived by the robot is send to the vision processor over a video transmitter. Aside from these special communication medium, the vision processor, communication server and the console all communicate through a standard ethernet network. This same configuration has been used throughout our research [7, 8].

3 COMPONENTS

We have embraced a behaviour-based architecture and our system has been built with a set of high performance real-time vision-based behaviours [7], integrated with a set of qualitative instructions. High-level feedback is provided by the use of Purposive Maps (PM) [9]. The user console is a touch screen with mouse like inputs, providing a simple user interface. In this section will outline the components that we have developed for our system.

3.1 Basic Behaviours

Our initial focus has centred on the development of a set of behaviours that perform basic mobile robot navigation. Throughout our research, we have progressively built a collection of vision-based behaviours. The sophistication of our system was increased by combining the various behaviours. A set of “Basic behaviours” have been used throughout our system, Collision Avoidance, Free-Space-Move and Goal-Seeking. A full coverage of the implementation of these basic behaviours can be find in [7]. Their function and their usage in this framework are discussed in the subsequent sections. Moreover, they have been designed to allow easy customisation for other purposes. For example, for landmark-based navigation, vision-based vacuum cleaning and soccer playing (See [7, 8, 10], respectively). Due to this flexibility and generality of these basic behaviours, we recognised that they have been chosen to support the development of our framework.

Some of the key attribute of these basic behaviours can be summarised as follow:

- the vision processing supporting those behaviours exhibit real-time performance, at video rate (30 Hz).
- environmental changes has been carefully considered: handle lighting changes, dynamic situations
(environment need not be static, such as moving obstacle is handled).

- goal-based behaviour was also provided: goal-seeking, visual target servoing, pursing and foraging.

### 3.2 Self-preservation

For the self-preservation part of our framework, two behaviours are being utilised, Collision avoidance and Free-space-move. As suggested in the previous section these behaviours have been taken from a set of available basic behaviours. These behaviours have been implemented via two real-time visual detector, collision detector and free-space detector. The key idea behind these detector is the determination of free-space, similar idea have been proposed by [11].

The self-preservation abilities provided are as following:

- Collision Avoidance – the basic prevention of collision, it is used as the general fallback mechanism for the other behaviours.
- Free-space-move – the general ability in avoiding obstacles (static or dynamic) by determining a safe trajectory at each video frame cycle, hence, emerging a behaviour which moves the robot around obstacles.

### 3.3 Instructive feedback

The use of vision endorse the key notion of this component, both the user and the robot are provided with the same visual display, this can be seen in Figure 1 and Figure 3. In our configuration, video is provided to the user via the console (See 3.6 for further detail), and it is duplicated then fed into the vision processor. A feature that we have incorporated into our system to demonstrate the advantage of this aspect, is by allow the robot “Make a suggestion” to the user. This is done by allowing the robot’s own capability in determining a suitable feature in the environment, the robot simply suggest to an User a suitable target for operation, for example for visual servoing.

### 3.4 Qualitative instructions

As suggested earlier, instruction given to a robot should be easily understood and are relatively natural to use. Our motivation, in the context of navigation, has been to provide natural navigational instructions which are used throughout the everyday life of a person. For example, “Going along this wall.”, “Move forward.”, “Go between these two objects.” and “Go to this place”. The experimental results will show the usage of these instructions.

To demonstrate this part of our framework we have implemented the following simple qualitative instructions:

- Go Forward – allows user to instruct the robot to move ahead, the Self-preservation component of the system will prevent collision from occurring.
- Go To – allows user to select a target, in order for the robot to move toward, i.e. visual servoing.
- Go Between – allows a user to instruct the robot to travel between two objects. For example, to move between a doorway.
- Keep To – allows the robot to keep long a boundary, typically it can be used for directing the robot to follow a wall.

![Figure 2: PM of Mission](image)

### 3.5 Qualitative explanation

Explanation which is to be provided to human should not be overly complex, it should be provided so that only the necessary information is presented. This gives rise to a mechanism that can maintain a record of events that occurred during mission execution. We have chosen Purposive Maps (PM) [9] to maintain a log of events. The PM is used to provide a qualitative explanation of the events that occur during the execution of high level qualitative instructions. Thus, also removing a system’s reliance on direct feedback.

Figure 2 show a PM of the experiment which was conducted using our system, further detail of the experiment is provided below, see Section 4. The key idea of incorporating a PM, it can be used to express only the key necessary information. The PM showed a sequence set of behaviours executing in a qualitative manner providing a simple and natural way in which information can be shared with both human and robot. In this example, it is easy to see from this information that, the robot at first spun right, went forward, traveled between a door, then went a long a wall, turned left, went through another door and servoed toward a landmark on the floor.

For implementation purposes, a PM is simply represented as a sequential list data structure, connect
each of the behaviours as an ordered sequence in the list.

Figure 3: User console: demonstrating the Qualitative instructions, “Go Between” and “Keep To”

3.6 User interface

Figure 3 shows the graphical user interface provided to the user as a console, the prime focus of this design was to keep everything to a minimum, thus producing a simple but effective interface. Physically, the interface provide a sample touch screen, acting as a mouse, which the User simply select a target by pointing at the screen. Other functionalities included are: link status between of the sub-system is also provided, indicating their connection; a list of qualitative instructions is provided via a menu, allowing selection to be made easily.

4 EXPERIMENTAL RESULTS

The intention of this experiment is to demonstrate our approach through the development of a system that allow the teleoperation of a mobile robot. To show how a mission can be performed using only a set of simple qualitative instructions. The basic mission of the system is to travel from one room to another. Either the robot or the user was provided with any prior knowledge of the environment. The user was able to perform the task without any difficulty.

Figure 4 shows snapshots of a mission performed using the qualitative instruction developed for our system, described above. The basic mission was performed through only a handful of commands given by the user via a console. Only seven instruction were needed, 1) Turn right, 2) Go Forward, 3) Go Between, 4) Keep To, 5) Spin Left, 6) Go Between and 7) GoTo.

Figure 2 showed a PM produced for this experiment.

Figure 4: Snapshots of a Supervised Autonomy mission: 1) Turn right, 2) Go Forward, 3) Go Between, 4) Keep To, 5) Spin Left, 6) Go Between and 7) GoTo.

5 FURTHER WORK

Currently we are moving on to a Nomad 200 system with on-board vision processing and radio ethernet capabilities. We are also incorporating a panoramic cam-
era system to provide the user with a 360° view of the robot’s environment. Hence, augmenting the visibility for the user. The top portion Figure 5 showed a raw image of the panoramic system, while the bottom image show a unwrapped view of the same image of the environment. A active pan-tile camera has also been added to this new configuration, the basic relation between the panoramic and active camera is that the 360° view provide a general impression of the environment, while the active camera is used for providing detail viewed and used for navigational purposes.

6 CONCLUSION

In this paper we presented a developmental paradigm, Supervised Autonomy, in this framework a system is build in a way which can augment human facilitation. We purposed five key attribute which interconnect into a complete human-robot interface system. The essence of our paradigm is that we emphasis the human aspects, and shifting as much possible of the computational and cognitive load onto the robot, and this alleviating stress on the user.

We believed that the visual behaviours used play a significant role in providing the autonomy to our system, which served as the foundation of the complete system.

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