Interfacing Users with Very Severe Mobility Restrictions with a Semi-Automatically Guided Wheelchair

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1. Summary

TetraNauta is an on-going R&D project[1] aimed to develop a controller for standard electric-powered wheelchairs that permits users with very severe mobility restrictions (such as people with tetraplegy) to easily navigate in closed environments (home, hospital, school, etc.). This project intends to design a non-expensive guidance system to help this kind of users to drive the wheelchair with the minimum effort, but maintaining the user as active as possible. For this reason the design of the user interface is a key factor. Some characteristic of this interface can be taken as a workbench for the design of more complex and security critical mobile systems.

2. Introduction

The benefits of autonomous mobility for physical and cognitive rehabilitation have frequently been stated. To advance in this way, diverse auto-guided "intelligent" wheelchairs have been designed for people having serious restrictions to use standard electric-powered wheelchairs. Most of these wheelchairs are able to move around avoiding obstacles and traversing difficult zones (such as narrow doors) (see [Bourhis-96], [Yoder-96], [Cooper-95], [Craig-93]). Nevertheless, from our experience designing an intelligent wheelchair (see [Civit-97], [Díaz-97], [Civit-96]) some problems arise. One of them is that the use of smart wheelchairs may interfere the rehabilitation process, due to the lack of participation of the user, limiting the benefits that can be obtained if the remaining abilities are used. To avoid this problem, the TetraNauta project included this requirement: The interface should adapt to the user capacity, requiring as much participation as he or she can provide.

The project started with a user requirement study carried out by the National Hospital of

1. The partners of TetraNauta are: the National Hospital of Paraplegics [NatHosp-98], an industry, Bioingeniería Aragonesa S. A. [Bioing-98], and two university research teams, the Group of Robotics and Rehabilitation Technology. University of Seville [] and the Laboratory of Human-Computer Interaction for Special Needs, in the Department of Computer Architecture and Technology[LIPNE-98]. The University of the Basque Country.

Paraplegics. As a part of this analysis a specific methodology for the detection and evaluation of the mobility needs of severely motor impaired people was developed [NatHosp-98]. This methodology is mainly based on direct analysis of the actions and movements performed by the users.

3. Features of the TetraNauta prototype

The idea behind TetraNauta is to help users that have very strong difficulties in riding a chair by any of the conventional means. They have just to indicate where they want to go and the navigation is done automatically by the chair controller. The user will be able to recover manual control whenever he or she desires to do so.

Since full automatic guidance results too complex and expensive, the TetraNauta approach uses landmark detection techniques, similar to the ones frequently used by Automated Guided Vehicles. This technique has also some disadvantages: on the one hand wheelchairs can only follow the limited drivepath, so they are bounded to in-door medium. On the other hand, the environment must be adapted using detectable marks [Arkin-90]. Nevertheless, these disadvantages are highly compensated by the low price of the used detectors (a standard black and white video camera). Currently, landmarks are lines painted in the floor, but different alternatives are being under study. The absolute position detection is solved using transponders.

3.1. TetraNauta architecture

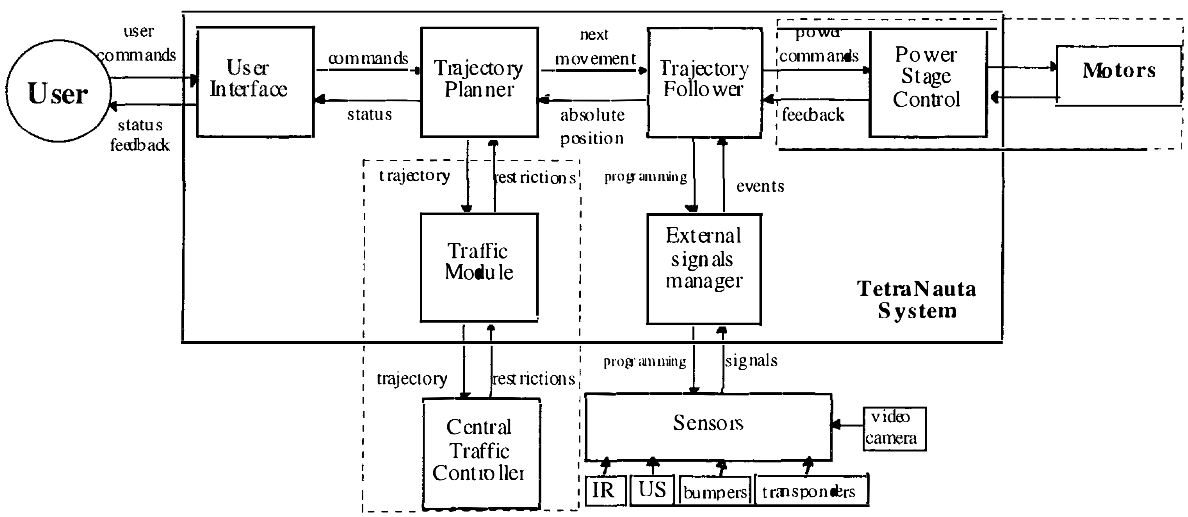

Fig. 1 The TetraNauta architecture

The architecture of TetraNauta reflects the modular structure shown in Fig. 1. Four main intercommunicating modules have been defined to manage external events and communications: User Interface, Manager of External Signals, Traffic Module and Power Stage Control, while other two modules, called Trajectory Planner and Trajectory Follower, manage the general co-ordination and supervision.

As previously mentioned, the trajectory follower uses two types of identification marks to follow the trajectory. In the current prototype these marks are:

- Floor marks: this permit a certain segment of the trajectory to be followed by the chair. This marks are detected with a very low cost parallel port camera.
- Global position marks: these are very low cost batteryless transponders located in specific locations that allow the TetraNauta controller to verify its real world position.

Different scenarios have been foreseen (big hospital, medium school, small day-centre, home), so the functionality of these modules may vary from one scenario to other. Let us concentrate in the parts related to user interface and traffic control.

4. User interface

The user controls the system through a very intuitive graphical interface. The interface translates his or her orders (e.g. the desired destination) into commands for the Trajectory Planner (that calculates an optimised trajectory, in terms of distance and traffic, to the desired final location, using an internal representation of the environment). It also gives feed-back to the user about the current operation. Diverse input/output devices are possible to suit the user physical characteristics: joystick, mouth-stick, touch-screen, one-key scanning, and voice recognition for input purposes, while a display and synthetic voice are used for output. The selection process has been designed to minimise the effort required from the user.

4.1. User participation

User participation is a key aspect in Rehabilitation Technology. For this purpose, two opposite goals have to be balanced. On the one hand, the user must be kept as active as possible to avoid the lost of his/her physical and cognitive abilities. On the other hand, the system should help him/her to drive with the minimum possible effort, to avoid fatigue and danger.

To reach this balance, an adaptable interface is being designed to automatically adapt the system to the user features, trying to demand from him/her all the collaboration he or she can give without fatigue or insecurity.

An important condition is that the user always has the control to pass to manual driving or to stop the wheelchair.

This model of user participation could be an interesting workbench for more complex mobile user interfaces that only require user participation in security critic situations, because long user inactivity can lead to his/her incapacity to face the critical situation.

5. Traffic control

5.1 Traffic module

Each wheelchair control is provided with a traffic module that decides what to do when a traffic problem comes up (mainly in crossings and crowded zones).

If the number of wheelchairs is relatively high, traffic problems can arise, mainly in crossings. Different models have been studied to face diverse traffic situations:

- Distributed with local communications: each wheelchair communicates with the nearest ones and decides about the trajectory when traffic problems arise. That is useful for medium traffic environments.
- Distributed without communication: each wheelchair has its own algorithm to decide what to do in case of traffic problems, which is enough for traffic no dense and low probability of conflicts.
- Centralised: a central computer communicating with every wheelchair via radio, supervises the traffic and informs about the new restrictions to the trajectory to the implicated wheelchairs. This model results adequate for scenarios with dense traffic.

In the first two cases, there are not external restrictions and the traffic decisions are taken by the local Traffic Module [Alami-97], [Brummit-96] using low range media (radio or infrared beams) to communicate with the nearest ones or without communications (as an autonomous entity) [Chaib-Draa-94].

5.2 External Traffic Controller

In the third case, each local traffic module communicates with the central computer to send the desired trajectory and to receive information about the restrictions to this trajectory imposed by the central Traffic Manager. This module, only present in very crowded environments, records from the Traffic Modules all the movements of the active wheelchairs. When traffic jams are detected or drivepaths are blocked or broken, the Traffic Controller sends this information to the active wheelchairs in form of restrictions to the map stored by each wheelchair. Thus, they can recalculate a new trajectory to their final destination.

6. Safety

The signals from the diverse "sensors" (infrared and ultrasonic detectors, transponders, video camera, etc.) and their programming are under the responsibility the External signals Manager, that communicates every event to the Trajectory Follower. When the Trajectory Follower detects a conflict with another chair or a possible collision with any other object, it informs the Trajectory Planner so that a possible solution is found.

Main safety problems are solved in the following mode:

- Both an "stop" command from the user and a signal from the bumpers (that detect collisions) stop the wheelchair immediately.
- For static (objects in the trajectory) and mobile (people) obstacles detection, wheelchairs are equipped with ultrasonic and infrared detectors [Ko-96].
- To avoid that one wheelchair overtakes another one intercommunication via infrared signals is being tested.

7. Conclusions

Some special characteristics of the TetraNauta user interface, make it an interesting workbench to test different approaches for the design of complex user interfaces for mobile systems.

Preliminary results with the diverse modules that demonstrate the technical feasibility of the system have been obtained. Now some prototypes are being built to test the requirements fulfilling. To evaluate the usability, acceptability, safety and adequacy of the system, traffic simulations and user testing are foreseen.

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