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STRATEGIC DEVELOPMENT OF INTELLIGENT TRANSPORTATION SYSTEMS FOR DISABLED PEOPLE

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Abstract: This article proposes a research for infrastructure set up of a dedicated embedded software architecture for the control of a personal transportation vehicle helping disabled people in fulfilling daily operations, like moving from one place to another, or executing repetitive tasks that impose specific sequences of movements between certain locations, with desired velocities. Considering the degree of handicap of the owner, such a device might also need to possess some abilities to navigate with certain autonomy, for example to follow a painted path (a series of marked points) or to recognize landmarks and to pilot towards a destination target with obstacle avoidance and continuous spatial localization. In this respect, this paper presents a general framework for increasing accessibility and mobility of personal transporters that naturally integrates methods of artificial intelligence.

Keywords: Service Robots, Personal Transporters, Control, Robot Navigation

1. INTRODUCTION

Transport is an essential factor in improving access to different environments for disabled people. It is inevitable that their special needs will not always be met in the design of any mobile vehicle model for the general population. There is a wide range of control adaptations and access aids which can be fitted in such a way that life would become more convenient for passengers. Adaptations to the vehicle (personal transporter) may be necessary and should be considered in relation to the functional handicap of the individual. However, elderly drivers present a whole new range of challenges related to vehicle and equipment issues and to the physiological and *cognitive aspects* of driving.

Based on the degree of personal handicap, personal transporters should fulfil specific tasks in indoor or outdoor environments, urban or non-urban areas, friendly or not-engineered human environments. As this research work identified, personal transporters for people with disabilities should:

- be simple enough to be operated by a limited mobility / locomotion person;
- be reliable in operation with improved stability;
- be a reliable *information system* that process high amounts of data in real-time;
- be easy to program;
- be easy to modify in order to implement more complex navigational tasks;
- must have improved autonomy in fulfilling the navigational objectives.

Such a hardware / software control structure would eventually allow the user to navigate through a confined environment with less difficulty that would other be possible with a conventional joystick-based wheelchair. Improvement of the driving accuracy, human interface and comfort of a personal transporter could be accomplished by altering the wheels, batteries, motor driver cards, joystick, control software, chassis and suspension system.

This research work intends to draw the guiding lines of design and implementation of an embedded, real-time personal transporter control module integrating a number of assisting functions and procedures

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(orientation, displacement, behavioural adaptation to the environment, locating and reporting) that protect and allow handicapped people to integrate in social life and daily working activities.

The paper is organized as follows. Section 2 briefly presents strategic goals that an Intelligent Transport System (ITS) for disabled people should afford in order assure accessible transportation and mobility. Section 3 describes a framework of defining navigational tasks based on artificial intelligence methods. Such a system would act over longer intervals and especially within broader boundaries, without having to intervene manually into the system. This is closely related to the fact that actions must be taken despite of little *a priori* knowledge and uncertainty. Section 4 presents a solution that provide a user who is visually impaired with mobility independence while section 5 introduces results that could improve handicaps generated by motor system disorders. Section 6 gives some conclusions and directions of further research.

2. STRATEGIC DEVELOPMENT OF ITSs FOR DISABLED PEOPLE

Today, the problems and requirements for people with cognitive, developmental, or mental impairments have yet to be clearly defined. Safety standards, codes of practice, assessment tools, and training, as well as research into **Intelligent Transport Systems** (**ITS**s) that provide independent local mobility are needed. This section refers to and defines a framework of specific navigational tasks that would be eventually included in a software architecture for increased mobility of personal transporters for disabled people.

Navigating a wheelchair through a confined or congested space can be extremely difficult. Conventional wheelchairs require an accurate approach path and a large amount of free space to undertake simple maneuvers such as driving through a doorway. Semi-autonomous control of the wheelchair's motion includes advanced driving methods such as *obstacle avoidance*, *door-driving* and *wall following*. More than that, a higher autonomy eventually requires improved methods for *localization*, *path planning* and *navigation towards target positions*.

Therefore, in order to be able to execute complex tasks in complex environments the personal transporter must be able to autonomously operate at a certain degree, that means to be able to move in its environment, to adapt to the changes in the environment, to "learn" from experience, to modify its behaviour (its way of acting), and eventually build internal representations of the surrounding world that may be used for decision making processes (e.g. for navigation). A mechanical structure that displays such a way of functioning has special abilities that humans usually call "*intelligence*" (Murphy, 2000). Essentially, action schemes, which are thought up by humans, shall be mapped on a computer system, so that the behaviour of the system can be called intelligent.

By integrating special characteristics of "intelligence" and "intelligent control" into a mechanical structure leads to a certain degree of autonomy in fulfilling navigational tasks. *Intelligent control* is directing a complex system to a goal (Dumitrache, 1998)). The word "intelligent" in this definition implies that we expect to achieve some resemblance to the intelligence demonstrated by living creatures, primarily by humans (Dumitrache, 2000). When referring to mobile robotics, these concepts transforms into mechanisms of *perception*, *processing* and *behaviour generation* (Dragoicea *et* al., 2003). Intelligent control techniques with biological insights, as artificial neural networks, fuzzy control, genetic algorithms or synergetic combination of them can be used successfully in building control systems for autonomous operation of autonomous vehicles (Dumitrache and Dragoicea, 2005).

Autonomy can be achieved by transferring principles of natural intelligence into machines (vehicles and personal transporters). Accessible transportation and mobility of disabled people (cognitive, developmental, or mental impairments) could benefit from building more or less complex navigation systems that import fundamental competences from the navigation of animals and humans (*self-localization*, *path planning, map building* and *map interpretation*). As for such a vehicle the navigation within the world is the goal, both proprioceptive-based systems and image-guided systems must anchor the navigation system within the world itself, based on the detection of unique features in the world (landmarks). Provided that the control system of the personal transporter is able to identify landmarks unambiguously, navigation could be further achieved with respect to the *world*, rather than with respect to an *internal* frame of reference.

3. DESIGN FOR ACCESIBILITY AND MOBILITY BASED ON AUTONOMOUS NAVIGATION

The special characteristic of the proposed control architecture for accessibility and mobility is that such a system would act over longer intervals and especially within broader boundaries, without having to intervene manually into the system. This is closely related to the fact that actions must be taken despite of little *a priori* knowledge and uncertainty. This uncertain knowledge is closely connected to the field of artificial and computational intelligence. Intelligent abilities, such as learning from experience, planning of actions or detection and identification of errors, used to be dealt with by the process operator, are integrated more and more into the autonomous system.

The experiments presented in this work specifically describe a framework of defining navigational tasks based on artificial intelligence methods. The research focused specifically on automated learning techniques (artificial neural networks) and process knowledge based techniques (fuzzy systems). Basically the methods used through these researches (Dumitrache and Dragoicea, 2004) specify and parameterize a process non-linear function $\boldsymbol{F}$ with parameters $\boldsymbol{p}$, which maps inputs $\boldsymbol{x}$ to outputs $\boldsymbol{y}$ and represents the knowledge as shown in figure 1.

A propulsion controller acts as the “brain” of the unit by collecting data and replacing the joystick usual control signals. The proposed experiments used mobile robots as a special test bed for emulating the behaviour of such a personal transporter. Automated learning techniques and process knowledge based methods were successfully used in order to test specific autonomous behaviours. Such an artificial “brain” should be able to acquire, process and generate behaviours for navigation. It should eventually replace the joystick control of the vehicle in such a way that the person with a certain degree of handicap would be dispensed from fulfilling certain actions regarding navigation.

Dedicated actions related to navigation could be developed, as *obstacle avoidance* (in a certain area for indoor and outdoor environments), *wall following*, *navigation to a target position* (possible in previously known environments), *map building*, *localization*, etc, depending on the type of perceived sensorial information. The experiments briefly presented here were specifically designed in order to acquire the six requirements previously defined in section 1. This substitute brain could successfully replace the human intervention for indoor or outdoor environments, previously engineered for wheelchair movement.

4. AUTOMATED LEARNING TECHNIQUES FOR AUTONOMOUS NAVIGATION

We consider automated learning techniques a complex method that allows to represent the knowledge obtained as data sets, where an unknown, complex process representation is derived from only input $\boldsymbol{x}$ or input and output data $(\boldsymbol{x},\boldsymbol{y})$. The data based self-organized methods (like ART and SOFM neural networks) are processing and structuring sets of example input data. The main characteristic of this type of architectures is that this unsupervised learning determines clusters or structural characteristics within the input space (Kohonen, 1985). The characteristic of such clusters can be analysed in a second step and be stored related to them. In operation, this method maps incoming data into particular cluster or within the determined structure. The cluster of structure information can be used to evaluate the incoming data.

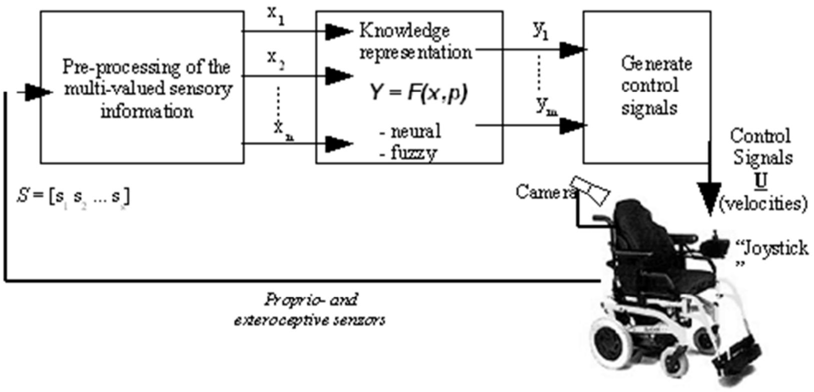

Fig. 1. Intelligent Transport System (ITT) for Accessibility and Mobility

Applications on mobile vehicle's autonomous navigation based on ART2 neural networks model were developed. These neural network models of self-organizing type were used in order to establish and adapt a place representation through a progressive learning process in which fast learning takes place. Such a navigation strategy could be easily used for indoor-localization and accessible mobility of a motorized vehicle for disabled people.

The solution presented here could provide a user who is visually impaired with mobility independence. The sensory information routinely collected through the sensors is instantly forwarded to the propulsion controller that acts as the brain of the vehicle. This information (from sonar sensors, infrared sensors, or video camera) is further used to establish a virtual environment that reflects the environment encountered by the user.

The fundamental principle used here is that of human navigation based on information about landmarks. Map in this context denotes any one-to-one mapping of the world onto an internal representation. This representation does not necessarily look like a map we are used to, in fact in mobile vehicles it often takes the form of artificial neural network excitation pattern.

Landmarks could be defined based only on sensory perception, i.e. location-dependent sensory patterns such as sonar range patterns or images perceived at a particular location. By actively exploring the environment, the mobile robot accumulates evidence through its sensors, making a correspondence between sensory inputs and motor actions.

In this way the further navigation process is governed by simple rules referred to as *behaviours* that would lead quickly to useful patterns of autonomous action and navigation (Dragoicea and Dumitrache, 2003). The exploration phase is completed with a learning process in which an Adaptive Resonance Theory self-organizing neural network (ART2) is used in order to cluster the perceptual space of the mobile vehicle, figure 2.

The results presented further are obtained through a landmark-based method, accumulating evidence over time. The ART2 neural network learns to classify the sensory patterns that the proximity sensors produced during the reactive exploration stage. Suitable perceptual landmarks emerge rather than being defined arbitrarily by a human designer. In the wider context of the map-building and localization competences the ART network is effectively used as a "black box" for classifying sensor patterns.

The learning controller ART2 will guide the robot in the further stages when the vehicle should navigate autonomously (figure 3). Building maps and localization competences could be further implemented as figure 2 proposes, but they are beyond the goals of this work.

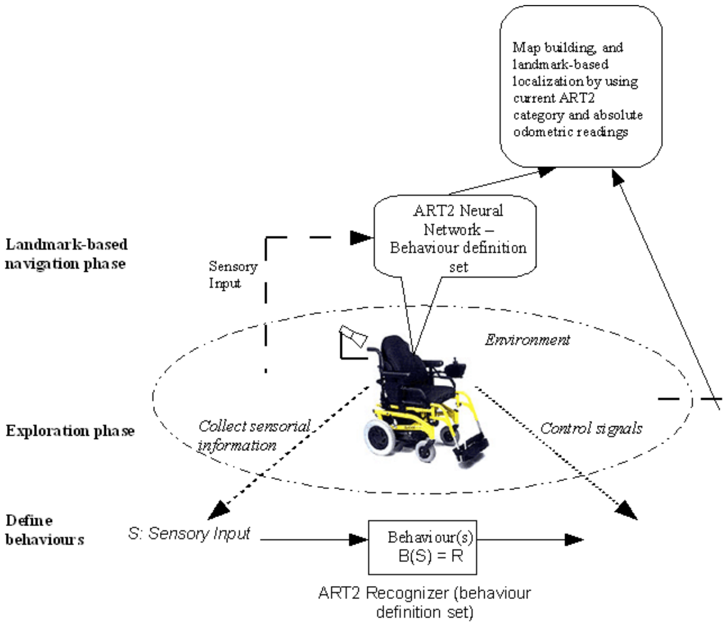

Fig. 2. Behaviour based navigation by using schemas theory

They will be the core of another research. As seen in figure 3, the ART2 controller is able of generalising in order to extract the salient features in a given situation, without being distracted by the finer detail of individual sensor patterns.

5. FUZZY LOGIC APPLIED TO EMBEDDED CONTROL OF PERSONAL TRANSPORTERS

In case of process knowledge based methods like fuzzy systems the information about the process is mapped into a specific representation, the influence of single input values on specific outputs being formulated with quantitative or qualitative statements. In these cases a couple of single input-output relations or relation between inner variables of the process serve to model the complex input-output behaviour called ***F***. The input-output relations are represented by sets of parallel fuzzy rules.

This research integrates some aspects of mobile vehicle control by using fuzzy reactive behaviours in the frame of the so called subsumption architecture. Simple behaviours were previously represented in a fuzzy reactive multi-control system (Dragoicea *et* al., 2003)).

Fuzzy logic can be easily incorporated into a micro-controller platform used for improving navigation abilities of disabled people to a smoother control operation of the system. In particular, based on its simplicity, this solution could be easily downloaded into an embedded board that acts as the brain of the personal transporter. Such a solution for hardware and software integration is under development at the Faculty of Control and Computers in the "Politehnica" University of Bucharest. The goal of such a personal transporter is improve the independent mobility of individuals with multiple disabilities based upon integrated sensory information and human-machine interaction.

In particular, a handicap generated by motor system disorder could be improved by increasing precision of wall- and object- distance navigation (complex navigation abilities based on fuzzy logic, as wall following behaviour, go-to-target behaviour, obstacle avoidance behaviour, etc).

For example, subjects with Parkinson's disease exhibit impairment of grasp or coordination of reach and grasp during a maximal speed prehension task. In order to improve coordination and precision of navigation, automated guiding techniques could be used. The fuzzy logic controller presented here could eventually establish a convenient solution to mask the effects of pathological tremor suffered by users of joystick controlled electric motorized wheelchairs.

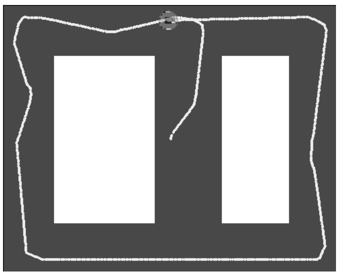

Fig. 3. Landmark navigation based on ART2 neural network controller

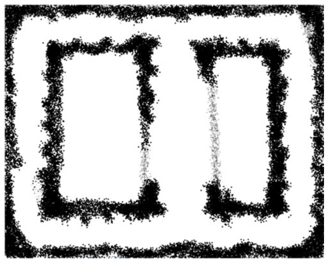

Fig. 4. Robot's perception map

In (Dragoicea *et* al., 2003) a strategy is presented that introduces an improved approach for designing a *fuzzy reactive multi-control system*, in which each behaviour is realized as a separate fuzzy logic controller - FLC. The multiple outputs are merged together by a gating system acting as a supervisory module (under a certain arbitration strategy). In this way, it is possible that simpler behaviours are combined in order to obtain more complex navigation behaviours (figure 5).

There may be several reactions in execution at the same time in such a behaviour-based controller. The action executed in the actuators may contain the overall, or a part of the effect of the actions resulting from behaviour programs. The propulsion controller of the mobile vehicle can retain its relationship to the environment by using a set of behaviours each of which maintains a mapping from sensory information to some control parameters for actuators. Behaviours are formulated using fuzzy "perception–action" rules, which are then periodically applied to control the vehicle, as figure 5 presents. The behaviour coordination problem, i.e. *behaviour arbitration* and *command fusion* was solved here by using a flexible arbitration policies using fuzzy meta-rules. The reactive behaviours in the behavioural set are all implemented as fuzzy logic controllers (FLC). The input and output variables to the controller are identified to be the sensory inputs (in each of the four abstracted directions), respectively, the left and right motor controls (or wheels velocities). The data collected from sensors and used as inputs $\boldsymbol{x}$ for the knowledge representation $\boldsymbol{F}$ function has to be further defined accordingly the set of sensors that the vehicle usually use and depends on the hardware setup.

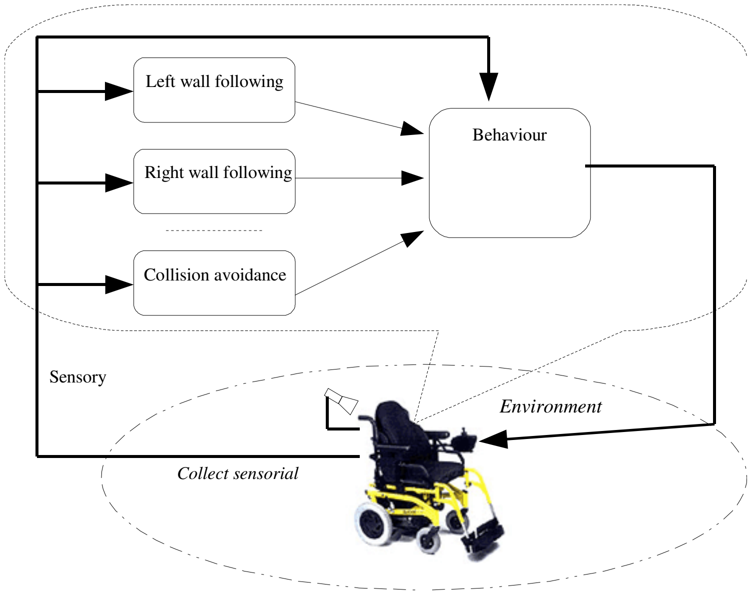

Fig. 5. Fuzzy multi-behaviour based controller for autonomous navigation

The results that are briefly presented here (figure 6) are obtained by using a mobile robot with 8 proximity sensors, but the strategy clearly defines a set of IF-THEN rules that could be further used.

6. CONCLUSIONS

The personal transporter is treated here as a special type of mobile robot that eventually would become autonomous after designing specific methods for navigation. Because these vehicles are performing such important jobs, their functions have to be reliable and accurate. A motorized personal transport vehicle (PTV) could be modified in such a way that robust control algorithms upgrade the functional navigation abilities. A microcontroller module could be designed to run complex algorithms as artificial neural networks and fuzzy logic controllers in order to assist autonomous navigation abilities. Control signals from an input, such as a joystick, are modified by the algorithm in accordance with the prescription for a particular user, according to a personal degree of handicap.

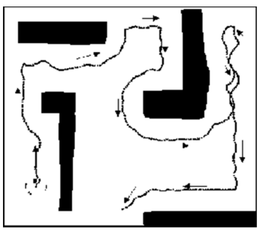

Fig. 6. Fuzzy behaviours in navigation – wall following behaviour

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