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SIRIUS: IMPROVING THE MANEUVERABILITY OF POWERED WHEELCHAIRS

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[*]*Abstract*— **The indoor maneuverability of powered wheelchairs may be difficult or bothersome in several circumstances. In this paper, we describe an experimental powered wheelchair named *SIRIUS*, developed at the University of Seville, which introduces some simple but effective navigation aids. Special emphasis is placed on the implementation of recorded trajectory playback and in the shared control modes, i.e. the chair's guiding where both the user and the computer collaborate. Furthermore, SIRIUS is an open platform to essay another kinds of functional or navigational aids, because its hardware architecture is based on a commercial PC. This would permit many devices that are frequently needed by the chair driver to be integrated smoothly into the chair controller.**

I. INTRODUCTION.

Powered wheelchairs are one the most important elements in the field of rehabilitation. Indeed powered wheelchairs are not a luxury for most users but their only way to live independently. Much R&D work in the field of rehabilitation engineering is being focused on the improvement of power wheelchairs [1], [2], [3], [4], [5]. In this context, automation, robotics and telematics should play a very important role in the field of rehabilitation engineering. During the last decade advanced wheelchairs have experienced a spectacular improvement from the technical point of view, and many prototypes have been built to overcome the limitations of current wheelchairs. Some of them are: difficult adaptability, high cost, outdated designs, imprecise battery gauges, difficult handling and lack of portability [4].

Besides, a wide range of off-the-shelf electronic devices and sensors can be found today at very low cost. While, for example, most of these devices are being incorporated to automobiles as luxury components, they can play a crucial role in advanced wheelchair aids. Thus, we belief that researchers should do a special effort to incorporate these devices to powered wheelchairs. An important effort is also required to bring these development to the market as, otherwise, they will not benefit the final users.

During the last years in the Robotics and Computer for Rehabilitation Lab at the University of Seville we have developed a system named SIRIUS that embeds many mobile robotics features [6], [7]. It is based on a conventional wheelchair but adding sensors and a controller; so it can be teleoperated or navigate in an autonomous way. Moreover SIRIUS can be used as a research platform to test new advanced features: GPS navigation systems, telecommunication devices, artificial vision-based navigation, etc. In fact, we are working nowadays in a research project in order to incorporate telecommunication systems to standard wheelchairs, and the possibility of interacting with adaptive environments.

In this paper, and using SIRIUS as a platform, we discuss how the advanced navigation system (usually found in mobile robots) can help a wheelchair user and, also, how the user can aid an advanced navigation feature. In section II we briefly describe the main subsystems incorporated to SIRIUS for improving navigability. We discuss in section III the navigation aids experimented until now and finally the conclusions are found in section IV.

II. THE SIRIUS PROTOTYPE.

SIRIUS is a wheelchair prototype that has been built based on a conventional wheelchair, and that remains open as a platform for testing different innovations. The prototype is intended to be a low cost personal domestic chair that should incorporate advanced navigation features.

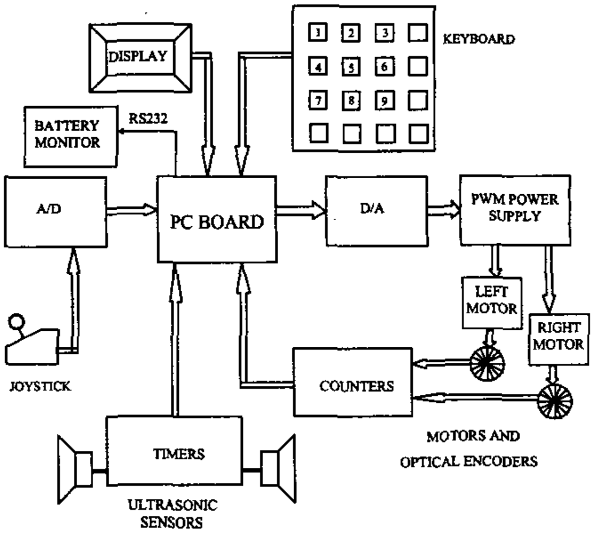

Fig. 1: Subsystems of SIRIUS

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Besides we can not forget that a personal wheelchair can never be a fully autonomous system (like AGV, Automated Guided Vehicles), but a "semiautonomous-teleoperation" system. We mean that we cannot eliminate the user operation mainly because: *a)* complex navigation systems are prohibitive due to the intended low cost of the commercial wheelchairs, *b)* fully automatic systems usually are refused by users and *c)* In houses, there are small intricate spaces where the chair must navigate in. So the user will sometimes have to guide it (or show the trajectory to the chair the first time), and we are developing a mixed or "shared control" system: control processing is shared between the user and the automatic sensor-based control system [1].

The new hardware that the SIRIUS prototype includes has been incorporated into a conventional power wheelchair. The wheelchair has two independently rear driver wheels, which cause turning by their differential speeds, and two front castors or "free-wheels". Below we describe the main components that have been added, and in Fig. 1 we show a schematic of SIRIUS.

PC-based architecture. We have also reached the wheelchair prototype on the basis of a low cost high performance system. So we have "adapted" all subsystems to go around a common CPU board and have simplified the electronic devices needed. Our CPU alternative is a PC board based chair. If a x86 based main board is used, control circuitry can be incorporated as PCI or ISA based cards. This would also permit many devices that are frequently needed by the chair driver to be integrated smoothly into the chair controller (for example, voice recognition systems, movement sensors, graphic user interfaces, etc.). Besides, as the computing requirements have increased, the main board has been easily updated with more powerful x86 processors. The only limitation is that low power versions should be used. On the other hand, PC architecture eases software development, and in fact, the PC solution for embedded systems is being more and more common [8].

For PC adaptation we have used our previous experience in the conversion of robot control units, and have maintained SIRIUS as an open platform to improve multisensor coordination and navigation algorithms. In this sense the first purpose of SIRIUS was to determine what navigation features might incorporate a conventional wheelchair in order to facilitate the maneuvering in small areas. This will be discussed in next section.

Power motor drivers. The former chair had a pair of relays in order to change the direction of turn. This makes impossible to build a high performance control because the switching delays introduce non-linearity when crossing the zero. We incorporated a new power driver that ensures linearity in both directions and increases efficiency. The driver is based in an H-bridge of MOS transistors, with a pair of BJT transistors as the driver stage, that are commanded by PWM waves.

Optical encoders and counters. SIRIUS gets the position feedback through two optical encoders at each wheel, and saves this information in two 16-bits counters. That permits us a high precision determination of the chair position and an accurate recovering of trajectories in this research prototype (as we show in next section). Although these feedback sensors give high precision, we are considering a simpler feedback, that would avoid the encoders assembly in a prospective commercial chair. A possibility is detecting the intensity changes in the motors brushes, which precision will be accurate enough to allow the recovering of trajectories.

User Interface. Designing a complete user interface needs a multi-disciplinary approach, including rehabilitation engineering, robotics, ergonomics, psychology, computer science, etc. For our prototype we did not consider all these aspects. We are using the original joystick and have included a 16 keys keyboard to select the different parameters and actions. We have added a LCD display to inform about the state of the wheelchair. Finally, a special button (the former horn) is used to play back trajectories. Of course all the input information is digitized to be supervised by the CPU.

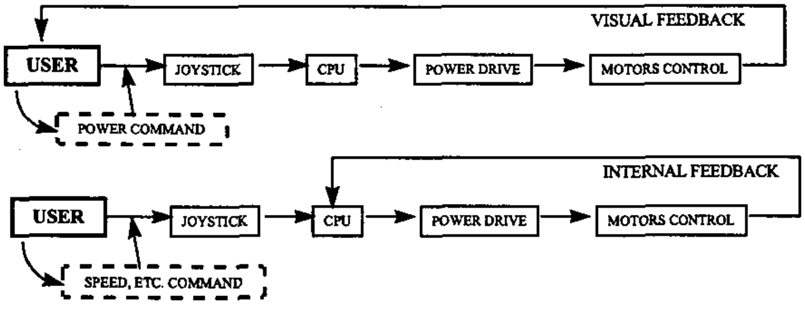

Fig. 2: Possibilities for low-level feedback.

External simple sensoring information. Ultrasound transducers are the cheapest way of measuring distance and calculating the world position in a changeable environment. Although sonar information is not complete, their distance measures can be interestingly exploited as explained in the following section.

III. NAVIGATION MODES AND EXPERIMENTAL RESULTS.

After working with SIRIUS prototype and discussing them with many users and educators we have identified some of the navigation aids to be included in order to improve the maneuverability of powered wheelchairs.

We deliberately have avoided beacons, fixed paths or any other way of guiding the chair. Most of bibliography focuses on autonomous robots that follow fixed paths or are guided by beacons or artificial vision. The last is non-viable in this moment because of its cost and computational requirements. On the other hand, we think that adjusting beacons or fixed paths in a domestic environment that may frequently change is not a good idea. This way of navigation only can fit in places where changes of the scene can be restricted and that have more open spaces like hospitals or industrial environments; this is not the case for a personal indoor wheelchair.

The final prototype can be considered like a teleoperated mobile robot with some amount of autonomy. The complexity of the interaction human-computer in the navigation has implied the organization of the functionality in layers of control. We have followed the classical layers proposed in [9], but adding the user action as a new agent that can interfere with them. That is, from the most "intelligent" or highest to the lowest we find:

- *Task planner*. Obviously the user always must do this in wheelchairs.
- *Trajectory planner*. This can be done by the user (e.g. selecting a fixed trajectory like a straight line). But the computer for example can do it if the user had selected a task like "play back a trajectory". In this case, this planner will retrieve the last memorized trajectory and it will send it to the lower level.
- *Trajectory generator*. It generates the next point in the trajectory sent by the immediate upper level. Although the CPU (like in mobile robots) usually does this generation, if the user moves the wheelchair through the joystick, then he/she is constructing his/her own trajectory.
- *Controller*. This level tries to converge real posture to the desired posture given by latest level.

From the preceding organization we can distinguish two kinds of feedback, which can be alternatively done by the user or the computer: 1) The low-level feedback, done at the controller level. 2) The high-level feedback, done at the trajectory planner level (in SIRIUS the task level feedback is always done by the user).

In the first trials we show the difference when activating or not the controller feedback, i.e., when the low-level control was done by the user or by the CPU (see Fig. 2). When automatic feedback is not activated the only adjustable "parameter" is the power given to each wheel through the joystick or any other user interface (see Fig. 2, upper drawing). This makes the user the controller, continuously adjusting the joystick depending on the external conditions of inertia, floor slope, etc. For example, in the presence of slopes the control system automatically changes the power given to the wheels in order to maintain the desired speed, and to avoid the chair's turns (more probable when rising a slope). This "open-loop manual control" increases the difficulty of handling the chair. In fact, with the usual open loop control the user "closes" the feedback path [Cooper95].

Otherwise, when a computer is used to control the wheelchair (see Fig. 2, lower drawing), the joystick command can be the linear and turning velocity (other possibilities include converting joystick commands into distance). This computer based feedback control makes the chair motion more intuitive and independent of external conditions. Here the speed of the drive wheels is sensed in order to obtain feedback information. Furthermore, the existence of an automatic low-level feedback can serve to tune system parameters to the user's needs. This improves the adaptability of the chair making possible a "tunable control". For future work even the input signals from the user interface could also be pre-conditioned, for example to neutralize intention tremor.

The second group of essays was based in the need to relieve the user. We mean to say that in several situations, the difficult or bothersome guiding of the joystick (or any other interface) can be substituted for prefixed trajectories.

We have concluded that three trajectories were especially interesting for the users: straight ahead or back, slight changes of path's curvature, and 90 degrees turns. These trajectories are selected in SIRIUS through the keys 1 to 9 ('2' forward, '8' backwards, '4' 90 degrees left turn and '6' 90 degrees right turn, as shown in Fig. 3). When moving in a corridor, the selection of a straight path can be very comfortable. In this case it is necessary to add some mechanism to neutralize the little orientation's deviations of the wheelchair. We have found two simple mechanisms, which implantation will not increase the wheelchair's cost: slight changes of path's curvature that can be chosen by the user (for example in keys 1,3,7 and 9 for SIRIUS), or continuous lateral distance measures with an ultrasonic sensor. Changes of lateral distance will mean changes of orientation. The last mechanism has been fully tested in AGV's, where the sonars are frequently the only sensor device to follow a wall [10]. Sometimes they incorporate a full array of sonars around the robot (furthermore they are intended for other reasons like maps building). Although some works like [11] have considered this possibility, we think that this option is not obligatory in wheelchairs because of its complexity and due to the problems associated with sonars multiple reflections and detection faults (e.g. if the object is as narrow as some table legs). Moreover building a map may not be a good idea in environments like some users' homes, which may frequently change.

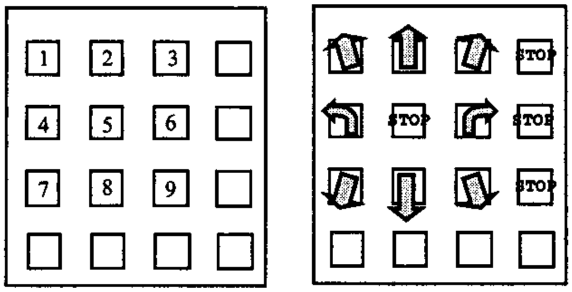

Fig. 3: Correspondence between keys and prefixed trajectories.

The third group of tests was done with sensors for obtaining external feedback information. Due to the high precision of odometric internal sensors (optical encoders at each wheel), we do not consider complicated sensoring to get complete information, but the simplest ones, which are sufficient to help the internal sensors' guiding. We finally decided to incorporate four ultrasonic sensors: two frontal (at left and right sides) with high reach distance and two lateral. The lateral ones were intended for guiding SIRIUS through a corridor as explained before. The frontal ones can be inactive or programmed in two main ways:

- Obstacle detection and progressive speed reduction used to approach an object facing it. We mix two different effects: velocity reduction and turn. The speed is reduced as we approach the obstacle, and each wheel's speed reduction is proportional to the inverse of the distance to the object detected by each sonar. The different speed reductions translate in small turns that faces the chair to the object.
- Obstacle avoiding without changing the main wheelchair orientation (very useful to cross a door) saving the user from bothersome guiding. Here we also mix the velocity reduction and the turning, but in a different way. The speed is reduced as we approach the obstacle, and at the same time when one of the sonar detects a wall but the other does not, a small turn is performed to avoid the door walls (for example, the automatic right turn in Fig. 4). The small turns are recorded; when the obstacle are lost the old orientation is resumed (the final left turn in Fig. 4). This is done without user intervention. However if the user is guiding the joystick, the automatic correction of orientation helps the user to cross the door. This is simply done by adding the joystick command to the automatic command (with a scale factor). The result is that is almost impossible to collide with the door walls (supposing the initial wheelchair orientation is facing the door under 30°, the maximum detection angle of sonars). In addition the user that guides the joystick has the impression that "someone" is helping him/her.

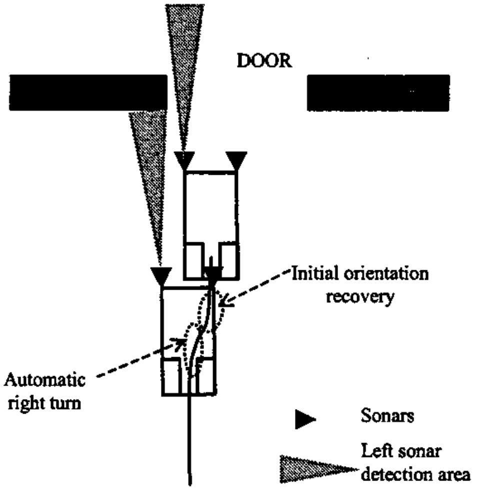

Fig. 4: Obstacle avoiding helps to cross a door.

However ultrasonic sensors suffer from several drawbacks: they do not work properly in very noisy environments, they have a limited sensing range with significant minimum distance, etc. For these difficulties it is easy desirable that the sonars information will be combined with other sensors.

The last group of navigation aids is the most automated: playing back recorded trajectories. The main intention of this is to avoid the user the difficult maneuvering of reverse driving, and may be very useful in small areas like bathrooms. Therefore the CPU is always memorizing the trajectory done by the chair (no matter which agent has done it). For example, in Fig. 5 the CPU will have memorized the path from point 1 (initial position) to 2 (final position in the bathroom).

When the user wants to play back the trajectory (e.g. when he wants to go out the bathroom), he/she pushes a button and the wheelchair began to automatically move in the reverse direction and recovering the last movements. For example, in Fig. 5 SIRIUS recovers the trajectory from point 2 to 3 (position after first recovery). When the user decides that the path recovery was enough (e.g. if the chair is out of the bathroom at point 3), he/she can press one of the stop buttons, and the chair leaves this automatic mode and stops. From here the CPU continues again to record the trajectory and the recovered path was lost (fragment 2 to 3 in Fig. 5). Therefore if in some meters the trajectory recover button was pressed again, the recovery will be done forgetting the previously recovered path. Then if the button were pressed in point 4 of Fig. 5, the recovery will pass through points 4, 3 and 1, forgetting the previously recovered trajectory (inside the bathroom). This permits to "nest" the repetition of trajectories.

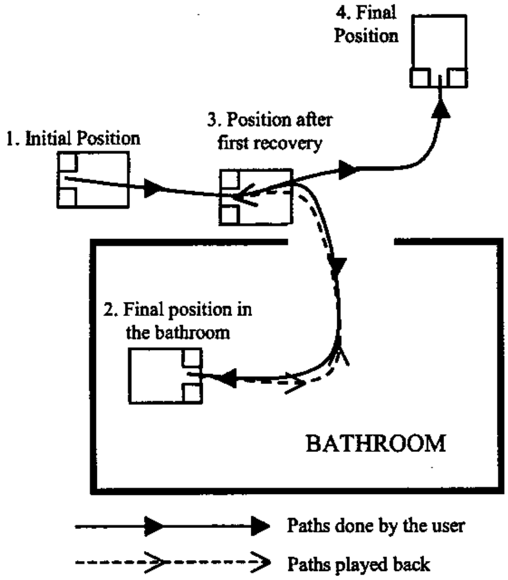

Fig. 5: Playing back paths in SIRIUS: the possibility of nested recoveries

In order to play again a previously recorded trajectory we must choose a control law for the two driven wheels, considering SIRIUS as a mobile robot. This is a classical problem in non-holonomic systems like mobile robots [12] and several solutions have been proposed. We have preferred to use the "path following" approach which ignores the time to follow the trajectory [12]. In our system this time is of no concern, and this way we avoid the drawbacks of considering desired time evolution ("trajectory tracking" approach) such as discontinuities in transient responses. The whole procedure for selecting a good control law for unicycle robots (like SIRIUS) is explained in [13] and it is far from the scope of this paper.

The experimental results of paths recoveries are good enough when these paths does not have many rotations. But we have observed that the orientation errors due to slippage have to be considered. Although the control law ensures that robot follow the internal memorized path with little errors, slippage errors could accumulate and the deviation from the original path may be 4 or 5cm for each 10m of path. Note that the controller tracks the path using internal odometric feedback, i.e. it can not estimate slippage errors. Therefore we must introduce some mechanism of external feedback to correct this problem. In this field there is lots of research in fully autonomous AGV's, but all of them implies a complicated sensoring information and processing, as one can imagine. Although there have some trials of this kind in advanced wheelchairs (ultrasonic array in [11], stereovision in [3], etc.) we have incorporated a very simple solution: the user him/herself can introduce little corrections to the automatic recovery. That is, if the user sees that the chair is deviated some centimeters for example to the right, he/she can push the joystick to the left to inform the computer of the deviation. The more he/she pushes the joystick, bigger will be the correction introduced in the trajectory. It is a fact that the user usually overestimates the deviation and then in a few meters he/she acts again (in the opposite direction) until the chair recuperates approximately the original path. This human-computer cooperation can be considered as another kind of shared control [1].

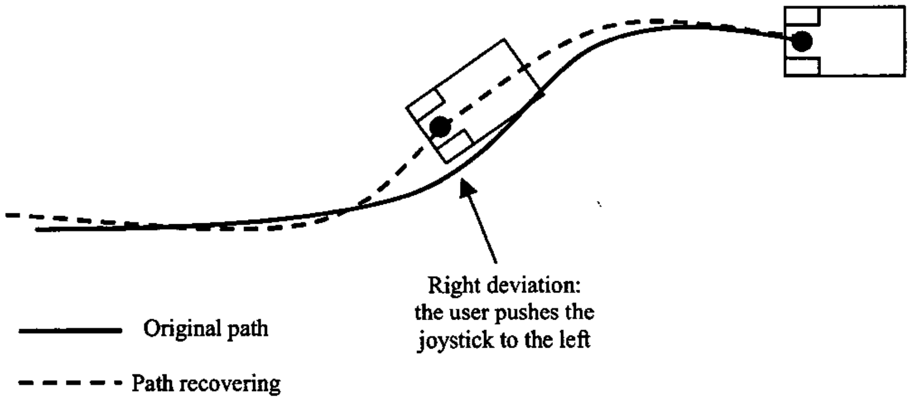

Fig. 6: Shared control in a path recovery.

IV. CONCLUSIONS.

After the work done in the navigation aids for SIRIUS prototype, we came to several conclusions for improving the maneuverability of powered wheelchairs. All these features have been included without eliminating the user participation in wheelchair control. We part from this consideration because of: a) the high cost of complex navigation systems, b) the user's rejection to fully autonomous systems, and c) the difficulty small spaces where the chair must navigate. The main conclusions are centered in *a)* The advantages of closed loop control (via internal odometric feedback) that reduces bothersome guiding in many cases; b*)* The benefits obtained when mixing computer and human control. Here we present two cases: computer correction of the user guiding via simple sonar information (very efficient to cross doors) and user correction of automatic path recovery (correction of slippage deviations, very difficult to detect via external feedback).

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