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A robust navigation system for robotic wheelchairs

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ABSTRACT

A landmark based navigation system for robotic wheelchairs is developed. The proposed navigation system is robust in the localization procedure which is the major problem in robotic navigation systems. Every landmark is composed of a segment of metallic path and a radio-frequency identification (RFID) tag. The odometry information is used for localization, which is corrected on-line every time the robotic wheelchair is over a landmark. A topological map is generated using such landmarks to compute the shortest path. A technique to generate the topological map for this navigation system and an obstacle avoidance strategy are also developed.

1. Introduction

There are many people with both lower and upper extremity impairments or severe motor dysfunctions. For them, it is difficult or impossible to drive a conventional wheelchair. A robotic wheelchair is developed to let these people with physical disabilities overcome the difficulties in driving a wheelchair. The robotic wheelchair system integrates a sensory subsystem, a navigation and control module and a user-machine interface to guide the wheelchair in automatic or semi-automatic mode (Bourhis, Horn, Habert, & Pruski, 2001; Mazo, 2001; Parikh, Grassi, Kumar, & Okamoto, 2007; Zeng, Teo, Rebsamen, & Burdet, 2008). In automatic mode, the handicapped people only have to choose on a monitor onboard the wheelchair the destination using any of the following alternatives: hand or chin controlled joysticks, breath-expulsion device, vocal commands, eye movements, or head movements. Other alternatives for the human–machine interface can be used such as electrical potentials due to brain activity (Ferreira et al., 2008). After the choice of the destination, the robotic wheelchair goes to the destination without any participation of the user in the control. On the other hand, in the semi-automatic mode the user shares the control with the robotic wheelchair. In this case, only some motor skills are needed from the user. In the present work, only the automatic mode of the navigation system is considered. The necessity of an automatic mode on a robotic wheelchair arises when the user has severe neuromotor injuries that cause loss of muscle mobility and, thus, only a human–machine interface based on brain signal can be used. Generally, such interface has delays in the command generation which can make the wheelchair driving difficult.

The research of Parikh et al. (2007) provides an integrated solution for robotic wheelchairs to motion planning and control with human inputs from three sources: at the highest level, the human operator selects the destination; at the intermediate level, the user interacts with the controller to avoid obstacles; and at the lowest level, the human operator can directly provide velocity commands using a joystick.

In the work (Mazo, 2001), driving by breath-expulsion, voice-command guidance, and guidance by head movements and electro-oculographic signals (EOG) have been tested on a robotic wheelchair. Other contributions of Mazo (2001) are on the sensory system and the control system. The sensory system uses ultrasonic and infrared sensors, as well as laser emitter and CCD camera detector to obtain environment information which allows to localize the wheelchair. The control system uses an optimal-adaptive control law along with an optimal-fuzzy trajectory tracking.

The work (Bourhis et al., 2001) describes a prototype of a robotic wheelchair. This prototype has manual, semi-autonomous and autonomous mode. The choice of the mode usually depends on parameters such as: single-switch or proportional man–machine interface sensors, modeled or non-modeled environment, etc.

In the works (Courbon, Mezouar, Guénard, & Martinet, 2010; Yu, Beard, & Byrne, 2010) vision-based navigation systems of unmanned aerial vehicles were proposed. A navigation system based on natural landmarks is proposed in Courbon et al. (2010), and a mapping based on an extended Kalman filter and path planning technique for collision avoidance for miniature air vehicles were proposed in Yu et al. (2010).

The previous works present complete solutions for the navigation system of robotic wheelchairs and other mobile robots. However, they have lack in the robustness of the sensors or need many sensor devices to give more robustness that implies high

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complexity. Recent works uses a RFID reader and barcode scanner to globally localize the vehicle. In Tao, Wang, Wei, and Chen (2009) a RFID reader detecting the RFID tags on the floor or furniture for location is used. However, observations with uncertainty are obtained from the sensors. Partially observable decision processes (POMDPs) are used to deal with this uncertainty. POMDPs are techniques for calculating optimal control actions under uncertainty. In Zeng et al. (2008), the estimation of the wheelchair's posture (i.e., position and orientation) is made using the odometry complemented by absolute positioning provided by the observation of barcode patterns from a barcode scanner mounted below the seat of the wheelchair. These unique barcode patterns serve as the artificial landmarks corresponding to global positions that have been saved into the memory in advance. However, if the barcode is covered with dirt, the barcode reading may be wrong.

In the present work, a landmark based navigation system which is robust in the localization procedure is developed. Partially known static environments are considered in the design of the navigation system. Every landmark is composed of a segment of metallic path and a RFID (radio-frequency identification) tag. These landmarks are placed in several locations specially in doorways, passageways and target positions. Every segment of metallic path and RFID tag defines a node of a directed graph. This graph defines a topological map. The initial posture (position and orientation) and final posture of the wheelchair do not need being over a segment of metallic path, nevertheless these postures are also considered as nodes of the graph. After generating the topological map, a shortest path from the initial to the final node on the graph is computed using Dijkstra's algorithm. A metric map is also used in the navigation system, specifically, it is used in the path planning between pairs of landmarks. A novel localization procedure for this navigation system based on encoders, inductive sensors and RFID reader is developed. This localization procedure is the major contribution of the present article. The odometry information is used for localization, which is corrected on-line every time the robotic wheelchair is over a landmark. To make this localization procedure functional, it is guaranteed that the robotic wheelchair attains a specific posture over the landmark. An entire metallic path connecting the initial and final points is not required but only segments of metallic paths. Other good techniques for localization called Simultaneous Localization and Mapping (SLAM) algorithm can be found in literature (Asadi & Bozorg, 2009; Doh, Lee, Chung, & Cho, 2009; Temeltas & Kayak, 2008). However, generally, the SLAM algorithm is high computational complex and need a data association, which are not characteristics of the technique proposed in the present work.

Others contributions of the present work are the development of a technique to generate the topological map and an obstacle avoidance strategy. The aim of the topological map generation technique is to avoid great odometry errors disabling connections of too away nodes or disabling connections which would imply a navigation through unsafe passages. The obstacle avoidance strategy is proposed for a safe navigation. An adaptive dynamic trajectory tracking controller (De La Cruz, Carelli, & Bastos, 2008) is implemented to guarantee the asymptotic stability in the tracking control under heavy loads that is the case of the combined user and wheelchair. In the literature of robotic wheelchairs control, path following controllers based on kinematic model (Rebsamen et al., 2007; Zeng et al., 2008) and optimal-fuzzy trajectory tracking controller (Mazo, 2001) were applied. The first controller has the disadvantage that the asymptotic stability is not guarantee under heavy loads. The second controller is based on heuristic knowledge.

Finally, experimental results obtained under many conditions are presented. The robotic wheelchair navigates without colliding through a very narrow doorway in one of the experiments. The experimental results show that the proposed solution, presented in this work, is efficient and effective.

2. Navigation system

The navigation system developed in the present work considers only the automatic mode, i.e. the wheelchair navigates to the destination without any participation of the user in the control. The navigation system is intended for people who have difficulties to guide a conventional wheelchair. Those difficulties are caused by extremity impairments or severe motor dysfunctions. In the case of severe neuromotor injuries that cause loss of muscle mobility, only brain signals can be used in the human–machine interface. Generally, this human–machine interface has a great time delay in the command generation that limit the drive skills. The necessity of using an automatic mode increases for this case.

The architecture of the wheelchair navigation system is illustrated in Fig. 1. The user interface allows the user to choose on a monitor onboard the wheelchair the destination using any of the following alternatives: hand or chin controlled joysticks, breath-expulsion device, vocal commands, eye movements, head movements, or brain signals. This user interface were extensively studied in literature as Mazo (2001) and Ferreira, Celeste et al. (2008). The localization is estimated using the information provided by inductive sensors, encoders and a RFID (radio-frequency identification) reader. The path

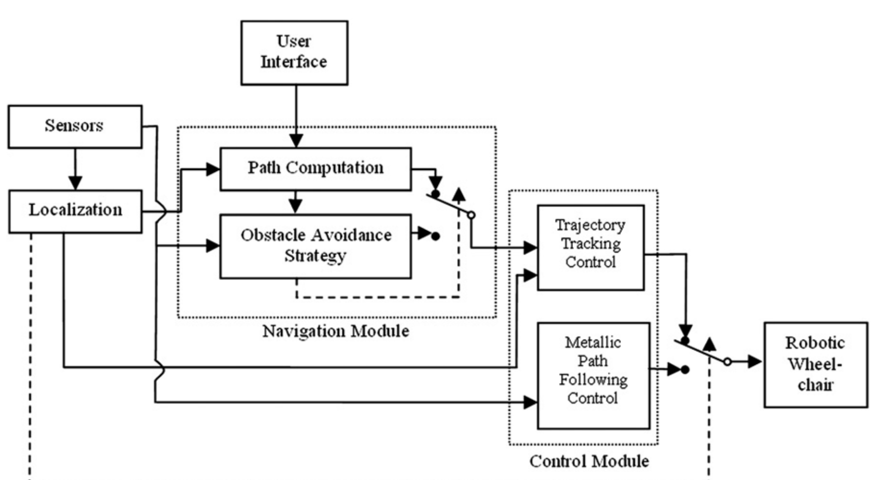

Fig. 1. Wheelchair navigation system architecture.