# Omnidirectional photometric visual path following for wheelchair autonomous driving

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***Abstract*—In this paper we address the issue of autonomous wheelchair navigation. Using an omnidirectional camera, we propose a system that allows wheelchair driving using a visual path following technique. First, a visual path composed of target images is acquired. Second, successive visual servoings are performed by minimizing the error between the current and a target image. Experiments were conducted on a variety of paths: straight line, curved line and forward/backward movements. The ground truth is obtained using a Vicon system that records wheelchair trajectories during the learning and the path following steps.**


## I. INTRODUCTION

Since the last few years, European and North-American public policies are facing major issues related to people with disabilities. Several studies highlight the increasing demand for social care and a steadily growing number of wheelchair users [1]. The cost of caring for people with disabilities in European countries has been recently estimated to 795 billion Euros [2]. Within this framework, the national authorities are moving towards innovative solutions based on robotics and ICT for caring for the user, enhancing his independence and his quality of life.

Within this framework, the European project INTERREG IVA COALAS (Cognitive Assisted Living Ambient System) started in November 2012 and finishing in 2015 aims to bring solutions to these issues. This project is focusing on designing and developing an autonomous cognitive platform combining an intelligent wheelchair (equipped with a set of heterogeneous sensors) and assistive capabilities of a humanoid robot. The project is structured in a user-centred co-creation process aiming to give responses to new needs and uses. Three milestones are defining the project framework:

- expectations and recommendations
- design and development
- evaluation

The work presented in this paper addresses the ”design and development” action, particularly the vision-based wheelchair (Figure 1) autonomous navigation. Several studies related to this research topic have recently been carried out: assistive semi-autonomous or autonomous navigation of powered wheelchair. These works handle mainly the problems of obstacle avoidance and doorway passing [3], [4] based on ultrasound sensor dataset. Other studies are related to assistive autonomous navigation based on LIDAR or Kinect sensors [5], [6], [7], [8], [9]. Indeed, while range sensors almost directly bring a distance from a measure, these active sensors spend more energy than passive ones. In some medical contexts, the emission of ultrasounds, laser or IR light is not allowed. A passive camera easily avoids theses issues and is not range limited as range sensors are. Furthermore, using a passive camera can be used for another vision-based tasks such as person recognition. However, computing distances from images may be tedious if reliable measures are expected, and this is the core issue tackled by many computer vision works. For this reason, we propose to implement a photometric based wheelchair navigation.

The rest of the paper is organized as follows. Studies related to vision-based wheelchair navigation are first presented. Then, the implementation method is described and experiments are presented before the conclusion.

Figure 1: The wheelchair equipped with the omnidirectional camera, on top of it surrounded by the red ellipse.

## II. RELATED WORKS

Vision-based wheelchair autonomous or semi-autonomous navigation has recently received attention from researchers.

Semi-autonomous navigation has been tackled using a camera, oriented forward, to assist the wheelchair driving in order to constrain its lateral position in a corridor [10]. In this work, straight line image features are extracted in order to compute a vanishing point that is used in a control loop of which the task is to have the latter vanishing point at the center of the image.

The latter kind of navigation, even interactive, is reactive and is not sufficient to implement the navigation from a known point A to a known point B. In order to implement such functionality, we can use visual paths. A visual path is defined as a set of images acquired by a camera embedded on a mobile unit during its motion. Indeed, in a general way, the goal of a mobile robot or a wheelchair is not visible from its initial or current position. That is why a set of waypoints is necessary to ensure a guidance to the goal. Once the visual path is known, the autonomous navigation must move the wheelchair to reach every image of the path, successively. While some works deal with 3D reconstruction and mapping along the visual path to increase the amount of available information needed during navigation [11], [12], others directly deal with image intensities [13]. In the latter work, the mutual information shared by the current and the desired images is exploited to build the autonomous vehicle control law that maximizes the mutual information. Thus, waypoints are implicitly defined by images only, composing a photometric visual path. Each waypoint is only linked to the previous and next images along the path so [13] is not a metric navigation but a topological one [14]. The advantage is that this method needs a lighter memory and a lower processing cost when planning the path. Actually, only the links between known places are considered. These latter works were developed for autonomous vehicles context in which a wheelchair may be seen as an instance.

Generally speaking, a perspective camera is used for the vision-based wheelchair control. The perceived field may be limited such that its occlusions are a big issue when comparing the current image to the visual memory. Despite installing additional cameras on the wheelchair is a theoretically valid solution, it increases costs, takes room and introduces synchronization and photometric inconsistency issues between cameras that have to be tackled. The omnidirectional vision brings an elegant answer to these issues, allowing to acquire a panoramic image with a single camera and a catadioptric optics made of a convex mirror and a set of lenses. Even if an extension of 3D reconstruction based visual path following was proposed for wide field of view cameras [15], it needs precise camera calibration and a lot of preprocessing (feature detection, matching or tracking, 3D reconstruction) before producing a control to drive the robot. By making perception and action a bit closer, [16] proposes to address the wheelchair visual path following as a set of successive visual homing, only exploiting 2D features that are based on SIFT features and 2D camera motion estimation. Based on the same idea of executing successive visual homing on each image of the visual path, [17] introduces the omnidirectional photometric visual servoing to control a mobile robot over a visual path. The latter work avoids any feature detection and matching issues (e.g. motion estimation) in order to compute the robot control inputs. The control inputs are obtained from the difference between the current image and the image to be reached. We therefore propose to adapt this work to the autonomous wheelchair navigation issue.

## III. THE PROPOSED OMNIDIRECTIONAL PHOTOMETRIC VISUAL PATH FOLLOWING

The omnidirectional photometric visual path following is implemented as a set of visual servoings successively applied on the list of waypoint images defining the visual path. Image-based visual servoing is the closed-loop control of a robotic system of which the task is defined in the image [18].

In the more precise case of wheelchair control, since the one considered in the experiments of this paper has two independently motorized wheels (back left and right of the wheelchair) and two free wheels, we consider it follows a unicycle model. Such a model only involves two degrees of freedom, that are longitudinal and rotational velocities. Furthermore, in order to have a panoramic visual perception around the wheelchair, the camera axis must be vertical, and by installing the omnidirectional camera at well chosen position, its optical axis and the wheelchair rotation axis are aligned, as well as the X-axis of the camera and the longitudinal axis of the wheelchair. Thus, we can consider the extrinsic calibration between the wheelchair and the camera as being the identity matrix. Experiments shown in Section IV validate the robustness of the visual servoing to this approximation.

In this paragraph, the proposed software architecture is presented. We use ROS (Robot Opœerating System [19]) for our software development methodology. One of the major advantages of using ROS, is the ability to develop algorithms regardless of the used hardware. Figure 2 illustrates this feature. The visual servoing node subscribes to the uEye camera topic `/camera/image_color` which delivers the captured images. Using these images, the visual servoing node generates velocity messages and publishes them to different kinds of hardware platforms (i.e. pioneer 3AT robot, electrical powered wheelchair, etc.). Thanks to this ROS-based software architecture, one can only change the robot topic name (`/RosAria/cmd_vel` or `/Wheelchair/cmd_vel`) to get the algorithms to work.

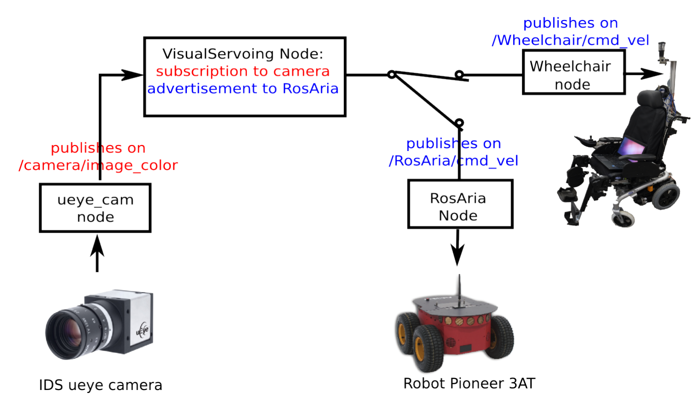
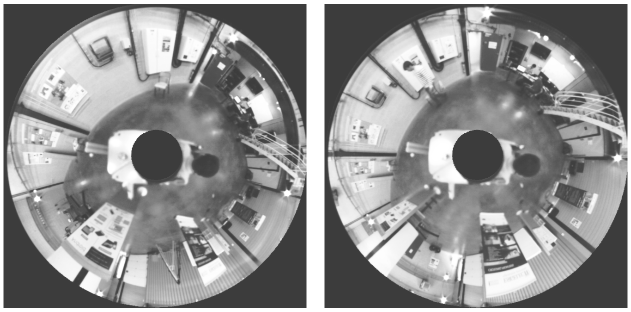



Figure 2: ROS based software architecture.

## IV. EXPERIMENTS

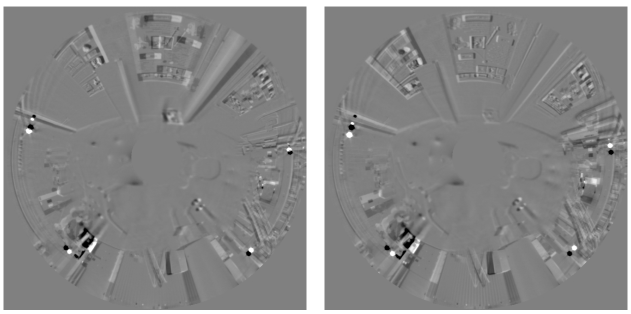
We performed our experiments on three kinds of paths: straight line path, curved line path, and forward-backward movements.

The first step of each experiment is the acquisition of the visual path. For all the experiments presented in this article, 1 frame every 50 is captured for making the so-called visual path.



(a) (b)

Figure 3: Some images of the learned path.



(a) (b)

Figure 4: Difference images during visual servoing.

This number is chosen so that the initial and target images overlap. The camera frame-rate is about 15 FPS. The motion of the wheelchair is controlled using the wheelchair's joystick provided by the wheelchair manufacturer or by a remote one. The set of captured frames are stored in the hard drive, each of these images is considered as a target image.

In the second step, these captured images are loaded and the visual path is followed using successive visual servoings. Starting from an initial position, the wheelchair moves until the photometric error between the current and the target image is below a certain threshold. This threshold is set empirically and may vary depending on the texture richness of the surrounding environment. Once the photometric error is below this threshold, the following target image is considered and the error is minimized. Figure 3 shows some images of a visual path for the curved trajectory presented in section IV-A. Figure 4 shows the image difference between the current and the target image.

Camera calibration was performed using the approach developped by [20]. The time needed to process each frame is about 60ms.

Experiments were carried out in a dedicated room equipped with a 20-camera VICON system (precision less than the millimeter) to record the learned and followed trajectories. Once trajectories are recorded, error between the followed and the learned paths is computed: for each point $(x_f, y_f)$ in the followed path, we find the nearest point $(x_{nl}, y_{nl})$ in the learned path and compute the error between the two points as the following:

$$\text{error}_{(x_f,y_f)} = \sqrt{(x_f - x_{nl})^2 + (y_f - y_{nl})^2} \qquad (1)$$

Note that Vicon points and images captured by the omnidirectional camera are not synchronized. Thus points generated by the Vicon do not correspond necessarily to the acquired images.

### A. Curved line trajectory

In this section we present results regarding a curved line trajectory. Results are shown in Figure 5 and in Figure 6. In this experiment, 16 images are considered to form the learning path. As in the straight line trajectory case, the error between the two paths is minimal as far as the wheelchair approaches to a target image.

However, in the case of curved line trajectory, the error in getting to be large as far as the wheelchair approaches the final target position.

The Video of the learned trajectory can be found in http://home.mis.u-picardie.fr/~youssef/Videos/curved_path/curved_learned_path.mpg. The video showing the followed trajectory can be found here: http://home.mis.u-picardie.fr/~youssef/Videos/curved_path/curved_path_visual_servo.mpg

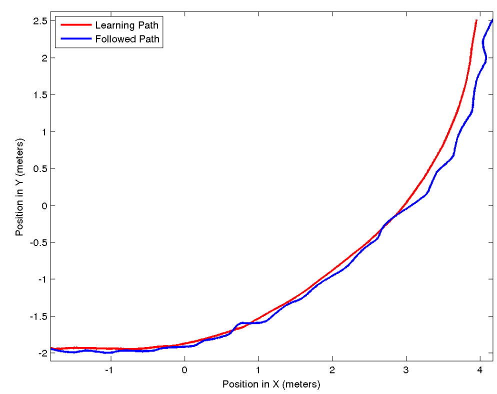



Figure 5: Followed and learned paths for a curved line trajectory.

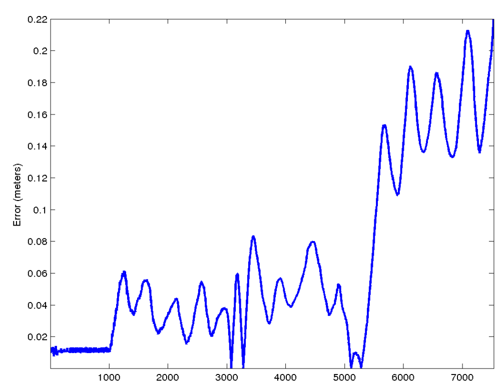



Figure 6: Error between learned and followed paths for a curved line trajectory.

## B. Results synthesis and discussion

Table I summarizes the results presented above. According to this table, the error between the followed and the learned path in the case of a straight line trajectory is smaller than in the other scenarios: the mean error between the two paths in the case of a straight line is only 2 centimetres while it reaches 17 centimetres in the case of forward/backward movements.

When the threshold error is too large, the wheelchair performs several rotations during its trajectory and our system is not able to correct such rotation in order to reach the target position. On the contrary, if the threshold error is too small, several iterations are needed in order to reach the minimum error.

It turns out that our approach is best suited for straight line paths. We plan to investigate how to improve the proposed solution in order to correct rotation during visual servoing.

In order to avoid manual threshold setting, we also plan to study how we can model the photometric error evolution with a 2-degree polynomial. This allows us to move to the next target image once the error stops decreasing

| Trajectories | Straight | Curved | Forward/Backward |
|---|---|---|---|
| min (meters) | 1.96e-04 | 1.75e-04 | 4.15e-09 |
| max (meters) | 0.07 | 0.22 | 0.51 |
| mean (meters) | 0.02 | 0.06 | 0.17 |
| standard deviation (meters) | 0.01 | 0.05 | 0.12 |

Table I: Error statistics (in meters) between the followed and learned path for different trajectories.

# V. CONCLUSION

In this paper we presented a powered wheelchair navigation algorithm based on an omnidirectional camera and visual servoing technique. We proposed several trajectories to validate our experiments. These experiments have shown that our approach is best suited for straight paths and for slightly curved paths. In the future work, we will focus on how to improve the proposed approach to handle paths with higher curvature. We also plan to investigate how to model the error using a 2-degree polynomial which avoids manual tuning of the error threshold. Finally, as in the approach proposed by [21] we want to address the issue of merging manual and robot control for determining the appropriate blending for wheelchair navigation.

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