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# „Gaze-based Wheelchair Control using Hidden Markov Models“

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# Gaze-based Wheelchair Control using Hidden Markov Models

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## INTRODUCTION

For disabled or elderly persons with heavily reduced physical and/or mental abilities, steering a wheelchair with a standard joystick is hardly possible. For these persons special control devices (e.g. button pads or sip-puff devices) have been developed. Due to the reduced command set such input devices provide, their use is time-consuming and tiring, leading to significantly reduced acceptance among the user group.

To reduce the workload put on the disabled user, an assistance system is proposed, which estimates the currently intended direction of movement of the user by evaluating his/her gaze behavior.

Physiological trials document strong correlations between humans' gaze and locomotion. Prior to changing movement direction anticipatory eye and head movements occur, indicating where the person intends to go [Hollands2002]. Though, not every change in gaze direction during motion is induced by an intended directional change. This is for instance the case, when being distracted by environmental cues or while searching in the environment.

Existing approaches utilizing gaze direction for controlling wheelchairs apply the basic assumption that the user wants to go where he/she is looking at for a while [Kuno2003]. Such a direct coupling neglects the existence of gaze direction changes not relevant for the intended movement direction. This can lead to inappropriate or even dangerous wheelchair motion.

Summarizing, to enable convenient and dependable gaze-based wheelchair control, a method to distinguish if a user really wants to go where he/she is looking at is needed.

## MATERIALS AND METHODS

For realizing the gaze-based assistance system a commercial electrically powered wheelchair of *Otto Bock Healthcare GmbH* has been equipped with a head-mounted eye tracking device of *SensoMotoric Instruments GmbH* (see Fig. 1). In combination with magnetic head-tracking, it provides the user's current gaze direction relative to the wheelchair. To prevent collisions with obstacles the prototype is equipped with ultrasonic and infrared sensors. A detailed description of the assistive wheelchair is given in [Bartolein2007].

Fig. 1: Wheelchair prototype with head-mounted eye tracking device and collision avoidance sensors

To be able to distinguish motion-relevant from motion-irrelevant gaze portions, distinctive gaze patterns have been identified based on physiological findings and self-recorded gaze data. Motion-relevant patterns comprise looking to the front while driving straight and three phases occurring during directional change (preparing turn, turning, realigning). Being distracted and searching the environment have been identified as important motion-irrelevant phases.

To estimate about the currently active gaze state, these gaze patterns have been modeled using Hidden Markov Models (HMM) [Rabiner1989] for looking to the left and right. As shown in Fig. 2, the observation sequence $O=O_1O_2...O_K$ serves as input to the HMMs and is provided by the eye tracker at $10Hz$. It consists of elements $O_k=(\alpha_k, \Delta\alpha_k)$, where the angle $\alpha \in (-\pi, \pi]$ represents the horizontal gaze deviation, and

$$\Delta\alpha_k = \alpha_k - \alpha_{k-1}, \qquad 1 \le k \le K \qquad (1)$$

describes the horizontal gaze deviation change.

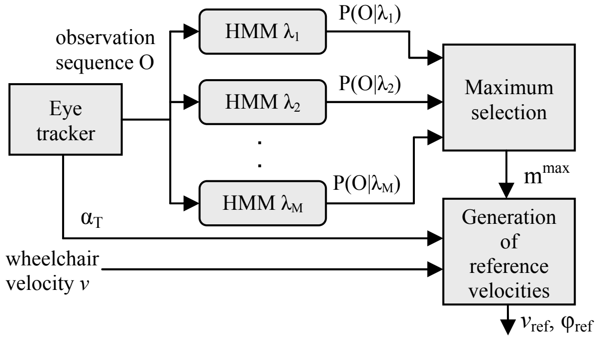

Fig. 2: Estimation of the current gaze state using HMMs and generation of appropriate wheelchair motion.

Every HMM $\lambda = (A, B, \pi)$ possesses $N$ internal states and is defined by its state transition probabilities $A$, the observation probabilities $B$, and the initial state probabilities $\pi$. As the observations $\alpha$ and $\Delta\alpha$ are of continuous nature, the observation probability for model state $n$ is calculated via the two-dimensional Gaussian probability distribution

$$b_n(O_k) = \frac{1}{\sqrt{(2\pi)^2 \det(\Sigma_n)}} e^{-\frac{1}{2}(O_k-\mu_n)^T \Sigma_n^{-1}(O_k-\mu_n)}, \quad (2)$$

where $\Sigma_n$ is the covariance matrix and $\mu_n$ the mean vector. In every time step the likelihood $P(O \mid \lambda_m)$ for producing the sequence of the last K gaze observations is calculated for all $M$ HMMs via the forward algorithm. The most probable gaze state of the user is given by

$$m^{\max} = \underset{1 \le m \le M}{\arg\max} \left[ P(O \mid \lambda_m) \right], \quad (3)$$

the HMM providing the highest likelihood.

After now knowing about the motion relevance of the user's gaze, appropriate translational and rotational reference velocities $v_{ref}$ and $\varphi_{ref}$ for moving the wheelchair can be generated, according to the current gaze deviation $\alpha$ and wheelchair velocity $v$.

## RESULTS

To test the described gaze state estimation gaze data was recorded while driving the wheelchair. Fig. 3(a) shows the horizontal gaze deviation while driving a left turn. At second one gaze starts to deviate from straight to the left (negative values) for about two seconds, remains at around -60° (-1 rad) for a short time and then slowly returns to the front direction until second six. Afterwards gaze deviates to the left, right and again to the left in fast succession. The deviations during the last four seconds were caused by the user looking at different objects in the closer surroundings after turning.

The estimated gaze states for all time steps of the given gaze recording are depicted in Fig. 3(b). During the turn, the modeled gaze states for turning left are recognized correctly with 93%. The motion-irrelevant gaze portions starting between second six and seven are identified properly with an accuracy of 85%. Adapting model parameters to individual persons (via Baum-Welch algorithm [Rabiner1989]) might further improve recognition quality.

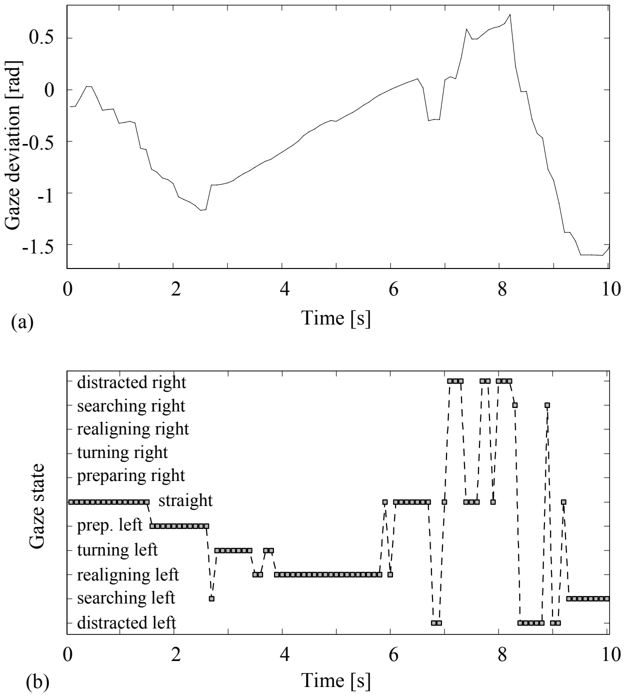

Fig. 3: Horizontal gaze deviation (a) and according recognized gaze states (b) while turning left and looking around afterwards.

## CONCLUSION

An approach for estimating a wheelchair user's intended movement direction by interpreting its gaze behavior is presented. Modeling distinctive gaze patterns using HMMs the person's most probable gaze state can be determined and appropriate wheelchair movement be produced. This leads to a considerably reduced handling effort and therefore might substantially increase acceptance of powered wheelchairs for severely disabled.

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