

Derivatives of the estimated state vectors (\hat{X}_h, \hat{X}_v) are the fuzzy inputs to a Sugeno detector with an output that will control the transitions of the states machine responsible of generate the commands. The last transition (Spd_tr(n-1)) will be an extra input that controls which rules are used by the detector at each time.

The knowledge-base of the fuzzy system (figure 4(b)) is made up by an initial calibration process that normalises all the input variables to a range (-1,1). Each input variable has three membership functions (Neg, Zero, Pos). Zero is a triangular function while the others are trapezoidal. Said functions were adjusted in an experimental way. At last, fuzzy rules were chosen by direct observation according to the memberships shown in table 1. Positions with no membership are due to the fact that are dependent of the user and so are not generalizable.

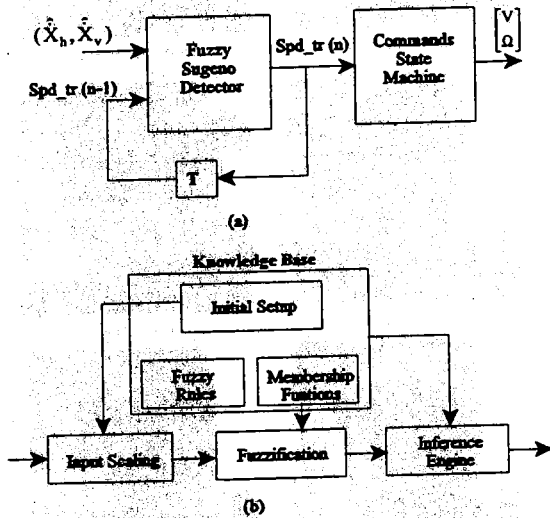


Figure 4. (a) Commands generation schema (b) Knowledge base of the fuzzy detector

As we work with the derivatives of the state vector, the actions speed are taken into account. It is not enough to do one action, but it must be executed with some speed. In this way some unvoluntary facial movements are eliminated.

In figure 5 it is shown a detection sequence of several head movements besides the temporal evolutions of the state variables derivatives used in the fuzzy detector.

The detection of eyes and mouth actions is based on the analysis of the hollows on the skin blobs imposing some geometrical restrictions. Hollows appear in the blob because in the face there are some features like: eyes, mouth, eyebrows, etc, that have different colors related with the skin. When the consecutive number of times that facial features (eyes or mouth) have not been detected is above a certain threshold, it is made a change in the

direction or in the wheelchair state on/off, respectively.

Head Actions [Speed_tr]	Derivatives of the state vectors			
	\dot{h}_s	\dot{x}_{os}	\dot{v}_s	\dot{y}_{os}
Still	Zero	Zero	Zero	Zero
Turn right starting	Pos	Neg		
Turn right ending	Neg	Pos		
Turn left starting	Pos	Pos		
Turn left ending	Neg	Neg		
Rise starting	Zero	Zero	Pos	
Rise ending	Zero	Zero	Neg	
Bow starting	Zero	Zero	Neg	Pos
Bow ending	Zero	Zero	Pos	Neg

Table 1. Fuzzy membership of the derivatives of the state vectors for the different head actions

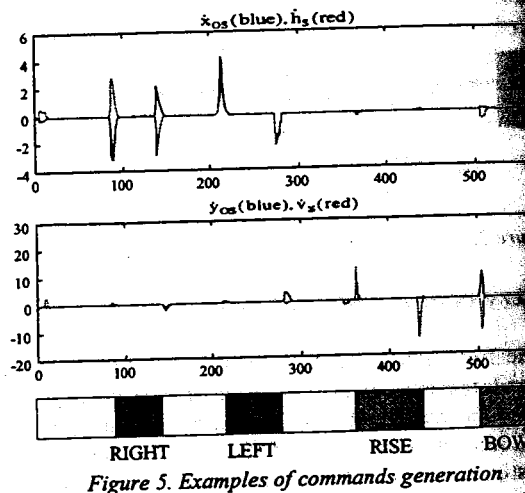


Figure 5. Examples of commands generation

Figure 6 shows the command generator state machine. This implements the high level control generating the linear and angular speed (V_{cmd}, Ω_{cmd}) as a function of the command activated. Turn commands involve angular speed in fix quantities each 100 ms and depending on the direction and on/off states. Acceleration and deceleration commands work of a similar way but with linear speed. Speeds are saturated to a prearranged value in order to improve the security of the guidance. The direction command change the movement between forward and backward and the on/off allows to stop the wheelchair and start the process.