Behavior Planning for Driver Assistance using Neural Field Dynamics

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Abstract

The behavior planning of a vehicle in real world traffic is a difficult problem to be solved. If different hierarchies of tasks and purposes are built to structure the behavior of a driver, complex systems can be designed. But finally behavior planning in vehicles can only influence the controlled variables: steering angle and velocity. In this paper a behavior planning for a driver assistance system aiming on cruise control is proposed. In this system the controlled variables are determined by an evaluation of the dynamics of two one-dimensional neural fields. The stimuli of the field are determined according to sensor information produced by a simulation environment.

1 Introduction

Driver assistance systems have to assist the driver of a vehicle in his actions. For this purpose the generated behavior-advice or action is determined by the actual task, safety- and comfort-considerations. Those constraints combined with the information about the environment build the basis of the behavior planning part of the driver assistance system. The information about the environment is obtained from sensor data, knowledge and integration over time, as shown in [7, 5].

The interpretation of the information needed by the behavior planning is a problem which has been dealt with in several publications. A flexible architecture for a driver assistance system was presented in [6]. In that paper a modularization of the architecture was proposed which enables the incorporation of the presented behavior planning. A proposal for behavior planning based on scene information using an expert system was presented in [8]. A fuzzy-control-system controlling the velocity of a vehicle using radar-data was presented in [9]

Behavior planning is a complex task, as the proposed action (e.g. overtaking, lane-change) has to be made up of a set of basic behaviors (e.g. tracking of a leader, driving backwards) or, if no adequate basic behavior is known in advance, by calculating a dynamic transition of the controlled values for the behavior planning.

In the presented driver assistance system the dynamics for behavior planning are formulated in the coordinates of the vehicle's controlled variables which are the steering angle and the velocity (as integral over the acceleration). This is done because every action of the vehicle can be decomposed into a change of these two controlled variables. An example describing an intelligent vision system using these controlled variables was published in [4]. In that paper a traffic analysis system for autonomous driving in urban environment was presented.

We describe a behavior planning for cruise control. It is the task to achieve a smooth trajectory in order to follow a leading vehicle. This behavior is based on the results generated by "neural field dynamics". Neural fields have not been applied to the problem of driver assistance before, but papers on controlling an autonomous robot in office environments have been published [3].

The paper is structured into a section motivating the usage of neural fields for behavior planning, followed by a section presenting the field theory of a neural field proposed in [2]. One-dimensional neural fields designed by Amari build the basis of the field dynamics controlling steering angle and velocity of the vehicle. Then, the generation of input data is shown. The definition of input data in terms of field variables, the field dynamics and the extraction of information out of the field excitation are described in the consequent section. Afterwards results for a driving situation is presented before the paper ends with conclusions.

2 Behavior Planning

The term behavior planning comprises a variety of actions to be performed in dependence on the considered time scale. E.g. the action of driving from point A to point B is defined on a larger time scale than the action of changing the actual steering angle by a fraction of a degree. To be able to perform an effective behavior planning according to the actual task the correct time scale has to be chosen or a hierarchy of time scales representing different levels of behavior has to be taken into regard (E.g. driving from point A to point B, driving in urban traffic, overtaking, or stopping the vehicle).

In our paper we consider the shortest time-scale for effective control of a vehicle: The time-scale on which the steering angle and the velocity are controlled. This control is influenced by the task of cruise control changing on a longer time-scale. Cruise control is an behavior based on the task of following a leading vehicle regarding security and comfort considerations. The control of the steering angle results in a smooth trajectory, which does not coincide completely with the trajectory of the leader, because that could lead to cutting curves. Also the steering angle may differ completely from the leading vehicle's steering angle in case of acute danger like a car cutting into the actual lane. For the velocity similar considerations hold: The velocity is supposed to change smoothly according to the velocity of the leader. Only dangerous situations are supposed to result in an abrupt reduction of velocity.

The choice of neural fields for the dynamics of the controlled variables was based on several reasons.

1. The activity of proper designed fields can result in a single-peak solution which results in the decision for only one value of velocity and steering angle.
2. The tendency to produce a multi-peak solution can be taken as reliability-value of the actual decision (which might result in a switch-off of the driver assistance system).
3. Different kinds of information can be coded as preactivation or stimulus to influence the field variable. E.g. object- and lane-information, traffic-rules and other knowledge can be coded additively into the stimulus-signal.
4. In any case, the dynamic system can only vary on its time scale, so a smooth change of the field-variable is achieved.
5. The smoothness of the solution can be controlled by the field input, so information affording an abrupt change can be directly coded into the action to be taken.

In the following section the applied field type is described.

3 Neural Field Theory

Neural fields are nonlinear dynamic systems. Originally they were introduced as models of the neurophysiology of cortical processes [2]. The chosen realization of a neural field was introduced in [2] and extended to multi-dimensional fields in [1]. The dynamic properties of this approach have been examined extensively, so the approach applied in our paper is described shortly. Further information can be found in [2].

The field equation of a one-dimensional neural field is given by

$$\begin{aligned}\tau\dot{u}(z,t) &= -u(z,t) + h + S(z,t) \\ &\quad + \int_\Gamma w(z,z')\varphi(u(z',t))dz' \quad , \quad (1)\end{aligned}$$

where $u(z,t)$ is the field excitation at time $t (t \geq 0)$ at the position $z \epsilon \mathbb{R}$. The position z characterizes the position of the field-site relative to a reference position $z = 0$. The temporal derivative of the excitation is defined by

$$\dot{u}(z,t) = \frac{\partial u(z,t)}{\partial t}.$$

The excitation $u(z,t)$ of the field varies with the time constant τ with $\tau \epsilon \mathbb{R}^+$. By means of the parameter h a constant preactivation of the field is achieved. The stimulus $S(z,t) \epsilon \mathbb{R}$ represents the input of the field which is dependent on the field position and varies with time. A nonlinear interaction between the excitation $u(z)$ of one field-site at position z and the excitation of its neighboring field-sites at positions z' is achieved by the convolution of an interaction kernel $w(z,z') = w(z - z')$ and a nonlinear activation function $\varphi(u(z',t))$. The integration is performed over the set Γ of all field-sites. To guarantee the stability of the solution the activation function is supposed to have a continuous derivative and the properties

$$\begin{aligned}\lim_{u\to-\infty} \varphi(u) &= 0 \qquad \text{and} \\ \lim_{u\to\infty} \varphi(u) &= 1 \qquad .\end{aligned}$$

The interaction kernel is chosen adequately to the intention of diffusion or concentration of the actual field activation. Mostly Gaussian functions (diffusion) or Mexican Hat functions[1] (concentration) are applied. The strength of interaction is determined by the energy W of the interaction kernel

$$W(\Gamma) = \int_\Gamma w(z)dz \qquad .$$

The equilibrium solutions

$$\lim_{t\to\infty} u(z) \qquad \text{with} \qquad \frac{\partial S(z,t)}{\partial t} = const. \quad \forall t > t_0$$

[1] Mexican Hat function(one-dimensional):

$$f_{MH}(x) = c_0 \cdot e^{-\frac{x^2}{2\sigma_0^2}} - c_1 \cdot e^{-\frac{x^2}{2\sigma_1^2}}$$

for the applied fields are divided into three categories [2].

1. $\emptyset$-solution, if $u(z,t) \leq 0 \quad \forall z \epsilon \Gamma$
2. ∞-solution, if $u(z,t) > 0 \quad \forall z \epsilon \Gamma$
3. a-solutions, if local restricted excitations $R(u) = (z_1, z_2)$ of the length $a = z_2 - z_1$ occur.

The excitation $R(u)$ is defined by

$$R(u) = \{z | u(z) > 0 \quad \forall z \epsilon]z_1, z_2[\wedge u(z_1) = u(z_2) = 0\}$$

If only one a-solution exists the solution is called a single-peak or mono-modal solution, if several a-solutions exist a multi-peak or multi-modal solution is given.

The desired type of solutions for the field-equation are single- or multi-peak solutions as they enable the interpretation of the actual state of the field. In case of a driver assistance task a single-peak solution is favorable as only one steering angle or one change in velocity can be set at one time step.

The type of solution is dependent on the stimulus, the preactivation h and the interaction-kernel $w(z)$. According to [2] the correct choice of the parameters of the preactivation and the interaction enables the existence of single-peak and multi-peak solutions. Therefore it must be fulfilled, that

$$W(a) + h = 0 \tag{2}$$

with

$$h < 0$$

and

$$W(a) = \int_{z_1}^{z_2} w(z) dz \quad .$$

The main advantage of the Amari-field is the additive composition of the stimulus. The field can be stimulated starting with less information which can be additively broadened as more relevant information is obtained and is formulated in terms of the field-variable.

The data for the field stimulus have to be coded adequately with respect to the effect they are supposed to have on the field activation (e.g. negative values for inhibition of regions, positive values for excitation). The next section deals with environmental data sensed by the observing vehicle which determine the input stimulus.

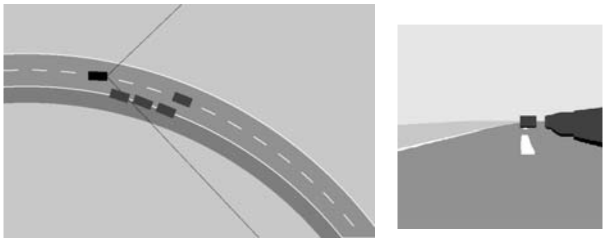
4 Input Data

The behavior of a vehicle can only be controlled according to the information obtained from the environment by sensors and according to knowledge (e.g. the state of the vehicle like steering angle and velocity) and global information (e.g. evaluated GPS-data). Those data have to be interpreted according to position, movement direction and relative velocity of relevant objects in the environment. Relevant objects are characterized by the grade of influence they have on the vehicle and by the actual task. Relevant objects can be other road users as well as traffic signs, elements of the landscape or the lane itself.

. For a good behavior planning several sceneries containing different constellations of objects in position and time have to be tested. Especially critical situations with high efforts on the system are of interest. Those critical situations typically might endanger other road users or the vehicle itself. For safety reasons those situations cannot be tested on real roads without extensively examining the system before. For this purpose a simulation environment has been developed. In this environment the performance of the driver assistance system can be evaluated in critical situations without any danger to the environment. The simulation environment (e.g. fig. 1) produces sensor data for different sensors based on the defined situation. The behavior of objects is defined in world coordinates for the simulated scenery. The actions of the observing vehicle are determined by its initial condition and the controlled variables determined by the driver assistance system. A bird's-eye view can be provided for a better overview (e.g. fig. 1(a)). In this scene the observing vehicle (black) drives with high speed on a two lane road with parking vehicles on the right. It follows the initially slower vehicle moving in front in the same lane. One of several simulated sensor results of the scene is shown in fig. 1(b). A visual sensor is assumed to be fixed at the rear view mirror of the vehicle[2] being directed in driving direction (forward view).

The generated simulation data are interpreted according to the information needed for behavior planning. The information has to be formulated in terms of "position"-information, at which the input of the field is generated, of an stimulus-amplitude coding the grade of influence on the field activation and of the variance determining the influence over a group of neighboring field elements. For the behavior planning two one-dimensional neural fields which are loosely coupled are applied. The "position"-information of the first field is the relative steering angle Ψ (relative to the actual vehicle direction,

[2]Technical data: chip area: $6mm^2$, installation height: $1.2m$, opening angle: $90°$, pitch angle: $4°$



(a) (b)

Figure 1: Simulated sensor data for a traffic-scene of a right curved road with parking vehicles on the right. Driving direction of the observing (black) and of the leading vehicle is from left to right. (a) bird's-eye view of the scene (b) visual sensor with an opening angle of 90.0°

fig. 2), for the second field it is the relative velocity Δv (relative to the actual observer velocity). The grade of influence of the sensor information is related to the relevance of the object which is dependent on the Euclidean distance

$$d_{obj} = \sqrt{x_{obj}^2 + y_{obj}^2}$$

to the object, the angle Ψ_{obj} towards the object and its relative speed Δv_{obj}.

An example for the extracted information accord-

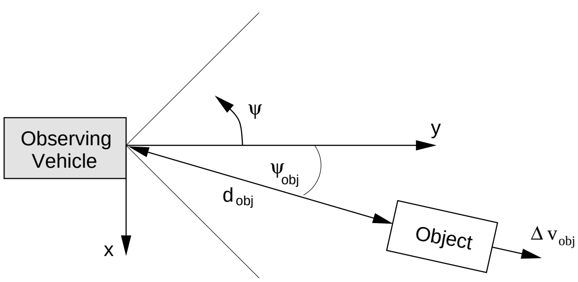
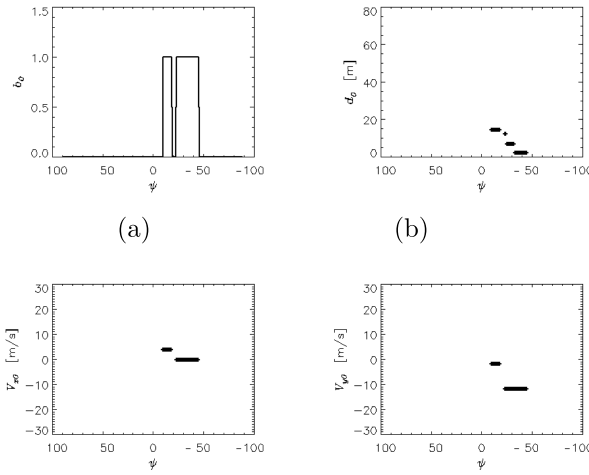


Figure 2: Observer-centered coordinate system for behavior planning. (x, y) determines the lateral and longitudinal position in Cartesian coordinates, d_{obj} and Ψ represent radial coordinates. Δv_{obj} is the relative velocity of the object.

ing to the scene shown in fig. 1 is presented in fig. 3. The view observed by the visual sensor is occupied ($b_o = 1$) by objects in a range from $\Psi \simeq -9°$ to $\Psi \simeq -45°$ (fig. 3(a)). There are four objects in different distances (fig. 3(b)), of which three parking object have the same velocity (negative velocity of the observer) differing from the velocity of the leading object.

Based on the determined data and evaluating the lane-information given by the simulation the stimuli for the neural fields are generated based on the



(a) (b) (c) (d)

Figure 3: Information determined from simulation results (fig. 1). All values are determined according to angle-coordinates Ψ of the actual view. Only objects which can be observed by the sensor are included. (a) occupancy b_o of the view concerning objects (b) distance d_o to detected objects (c),(d) relative velocity of the objects in x- and y-direction

task of cruise control. The generation of the stimuli and the applied field dynamics are described in the next section.

5 Field dynamics

The active control of the behavior of a vehicle is limited to the control of steering angle and velocity. In order to determine the desired controlled variables in dependency on sensor information, knowledge, trajectory requirements and behavioral demands, two one-dimensional neural fields as presented in section 3 are designed. The field positions z have been set to Ψ and Δv respectively to be able to directly apply the solutions generated by the field evaluation. The excitations $u_\Psi(\Psi)$ and $u_v(\Delta v)$ of the fields are interpreted as a continuous preference functions of which the position of the maximum is the most preferred controlled variable. For the stimulation of the fields the information needed for the control has to be formulated in those field-variables.

The field controlling the steering angle is influenced by the position and velocity informations of other road users (especially the guiding vehicle), by information describing the free driving space and by lane information. According to this information the stimulus is determined according to three stimulus-functions. The functions describe

- the danger estimate $\mathcal{O}(\Psi, t)$ for each detected object taking into account the relative speed and the distance to the object. The influence on the field must be inhibitory as the collision with objects has to be avoided.
- the street-course-factor $\mathcal{L}(\Psi, t)$, which is determined for one reference distance to ensure a smooth trajectory within the actual lane. The stimulus is designed excitatory with the center of the lane showing the greatest attraction to the vehicle.
- the direction towards $\Psi\mathcal{D}(\Psi, t)$ of the leader. The vehicle is supposed to follow the leader, so the direction towards the leader has to be an excitatory stimulus in the field.

The stimuli-functions are distributed over a certain range of angles by a convolution with a Mexican Hat function. The convolution is performed to regard the variances and the distribution of information over neighbored angle values. For each stimulus the convolution

$$S_i(\Psi, t) = \int_{-\gamma}^{\gamma} f_{MH,i}(\Psi - \Psi') \cdot i(\Psi', t) d\Psi' + \eta_i$$

is performed, where i can be replaced by $\mathcal{O}$, $\mathcal{L}$ or $\Psi\mathcal{D}$ for the different stimuli-functions. The convolution is performed over the whole range of $\psi' \epsilon [-\gamma, \gamma]$. The function $f_{MH,i}$ is parameterized with different values for the three functions $f_{MH,i}(\Psi - \Psi')$. The threshold

$$\eta_{0,i} = \begin{cases} \eta_{\mathcal{O}} & , \quad i = \mathcal{O} \\ 0 & , \quad i = \mathcal{L}, \Psi\mathcal{D} \end{cases}$$

is introduced, as a high inhibition value has to be put on the field if a dangerous situation concerning other objects occurs, which is supposed to out-range the lane- and the leader-stimulus very fast. The magnitudes of the different stimuli-functions must be adapted to the desired effect on the neural field. In case of cruise control a smooth trajectory following the leader is demanded until the influence of other objects requires different actions (collision avoidance). The stimulus of the field for the steering angle at time t is then determined by

$$S_\Psi(\Psi, t) = -S_{\mathcal{O}}(\Psi, t) + S_{\mathcal{L}}(\Psi, t) + S_{\psi\mathcal{D}}(\Psi, t) \quad . \quad (3)$$

The field controlling the velocity is influenced by the actual velocity, the velocity to be reached according to actual traffic rules and the relative velocity of the leader. There a two stimuli-functions which are imposed on the neural field:

- the stimulus $S_{\mathcal{R}}(\Delta v)$ based on speed limits or favored speeds is realized as a Mexican Hat function centered at the difference between the magnitude of the actual and of the intended velocity. The magnitude of the stimulus is chosen such that it is dominant if the distance to the leader is greater than security distance, otherwise the leader's velocity should dominate the change in velocity.
- the stimulus $S_{v\mathcal{D}}(\Delta v)$ invoked by the leader is a Mexican Hat function centered at the magnitude of the relative velocity of the leader. The magnitude of the stimulus is proportional to the distance and time derivative to the leader (e.g. if the leader has a lower velocity than the ruled velocity, the leader will approach the observing vehicle, so the observer-velocity has to be reduced proportional to the change of distance to avoid a collision).

Both stimuli are supposed to have excitatory influence on the field excitation because each velocity is supposed to attract the field. The change in velocity, Δv, is determined as a result of the field dynamics, where the position of the maximum represents the advised change in velocity. The stimulus of the velocity field is build additively

$$S_v(\Delta v, t) = S_{\mathcal{R}}(\Delta v, t) + S_{v\mathcal{D}}(\Delta v, t) \quad . \quad (4)$$

The field equation for both neural fields are given by the formulation of the Amari-equation (eq. 1)

$$\begin{aligned} \tau_\Psi \dot{u}_\Psi(\Psi, t) &= -u_\Psi(\Psi, t) + h_\Psi + S_\Psi(\Psi, t) \\ &+ \int_{\Gamma_\Psi} w_\Psi(\Psi, \Psi') \varphi_\Psi(u(\Psi', t)) d\Psi' \end{aligned}$$

and

$$\begin{aligned} \tau_v \dot{u}_v(\Delta v, t) &= -u_v(\Delta v, t) + h_v + S_v(\Delta v, t) \\ &+ \int_{\Gamma_v} w_v(\Delta v, \Delta v') \varphi_v(u(\Delta v', t)) d\Delta v'. \end{aligned}$$

The time constants τ_Ψ and τ_v are chosen according to the time scale on which the field is supposed to react on the stimulus. The preactivations h_Ψ and h_v were set to the value of -1 for both fields. The stimuli are determined according to eqs. 3 and 4. Both interaction kernels $w_\Psi(\Psi, \Psi')$ and $w_v(\Delta v, \Delta v')$ are realized as Mexican Hat functions parameterized according to eq. 2. As nonlinearities $\varphi_\Psi(\Psi, t)$ and $\varphi_v(v, t)$ tanh-functions shifted to the range $[0, 1]$ are used. The convolution is performed over the set Γ_Ψ and Γ_v of the field-sites respectively.

The evaluation of the field-excitation is performed by the determining the position of the maximum

$$\mathcal{N}_\Psi(t) = \arg\max_\Psi u_\Psi(\Psi, t)$$

for the change in steering angle and by

$$\mathcal{N}_v(t) = \arg\max_v u_v(\Delta v, t)$$

for the change in velocity. For security considerations thresholds $\mathcal{N}_{\Psi,max}$ and $\mathcal{N}_{v,max}$ for Ψ and Δv are applied regarding the maximal allowed range of change. The applied change in steering angle is determined by the minimum operation

$$\Psi_{control} = sign(\mathcal{N}_\ominus) \cdot \alpha_{\mathcal{N}_\Psi} \min\left(|\mathcal{N}_\Psi|, \mathcal{N}_{\Psi,max}\right)$$

and the change in velocity by

$$\Psi_{control} = sign(\mathcal{N}_v) \cdot \alpha_{\mathcal{N}_v} \min\left(|\mathcal{N}_v|, \mathcal{N}_{v,max}\right) \quad .$$

The variables $\alpha_{\mathcal{N}_\Psi}$ and $\alpha_{\mathcal{N}_v}$ are velocity dependent factors to take into account the dynamics of the vehicle.

To examine the behavior of the designed cruise control different traffic scenes were generated by the simulation program. The parameters of the field-equations and the stimuli are determined by evaluating the reaction of the system for a variety of scenes. The results for one simulated scene are presented in the next section to give an illustration of the field dynamics.

6 Experimental Results

A result for the field excitations at time t_0 is shown in figs. 4 and 5. The sensor data were generated from the scene described in fig. 1. According to those data the stimuli of both fields were determined and are shown as dashed lines in figs. 4 and 5 (for presentation purposes the stimuli where shifted upwards from the zero-line). For the presented situation the field excitations have a single maximum at $\Psi \simeq 1°$ and at $\Delta v \simeq -9m/s$. The presence of single peak solutions proofs the reliability of the controlled variable for Ψ and Δv. The change of the steering angle and the velocity according to field excitations at time t_0 is given in figs. 6 and 7. The steering angle of the vehicle changes smoothly over time (fig. 6(d)). The vehicle drives through the right curve while keeping the lane and following the leader. The change in the steering angle (fig. 6(c)) can be found within a small range, so a comfortable trajectory was sustained. The stimulus (fig. 6(a)) as well as the field-excitation (fig. 6(b)) show negative values at the positions of objects to be avoided (e.g. parking vehicles in view) and positive values at angle positions to be favored (e.g. leading object and lane). The maximum of the field-excitation is shifted to the left as long as the parking vehicles can be detected, so the vehicle does not drive in the center of the lane but a little bit shifted to the left, to keep a security distance towards the parking vehicles.

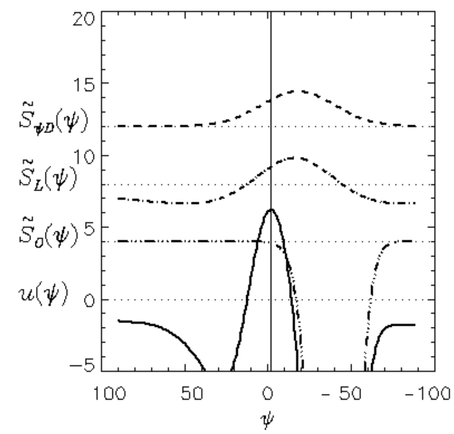


Figure 4: Excitation of a neural field. Additionally the stimulus according to objects, lane and leader are presented (shifted to a virtual zero). The data material is determined according to the scene presented in fig. 1

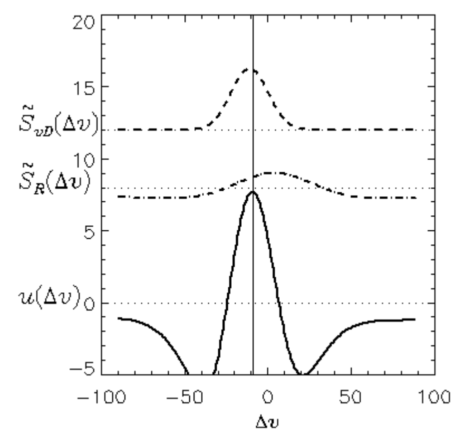


Figure 5: Excitation of a neural field for the change in velocity. Additionally the stimulus according to the intended and the leader velocity are presented (shifted to a virtual zero). The data material is determined according to the scene presented in fig. 1

The velocity (fig. 7(d)) is a smooth function of time. The vehicle is not decelerated or accelerated abruptly because no dangerous situation occured. While the leader gets closer, the velocity of the obsserving vehicle is reduced such that the leader is within security distance finally. The change in velocity (fig. 7(c)) is reduced smoothly until the observing vehicle reaches the speed of the leading vehicle. The field-excitation (fig. 7(b)) amplifies the decision imposed by the stimulus (fig. 7(a)).

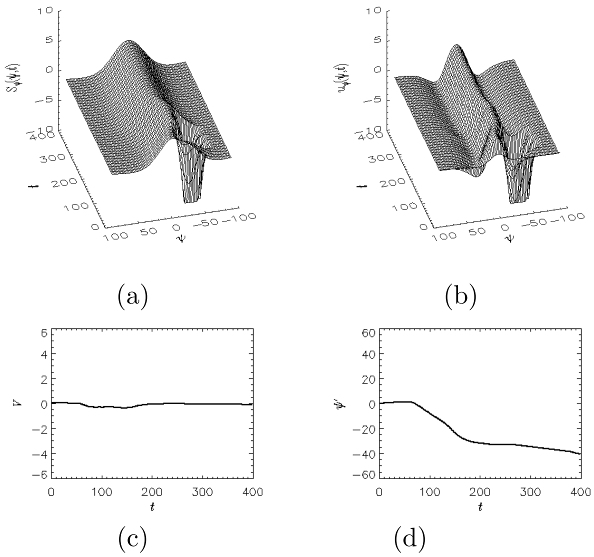


Figure 6: Presentation of time dependent curves in dependence of time [in s] and change in steering angle Ψ [in $^\circ$] for (a) the stimulus $S_\Psi(\Psi, t)$ (b) the neural field $u_\Psi(\Psi, t)$ (c) the determined change in steering angle (d) the angle position of the vehicle relative to a stationary observer

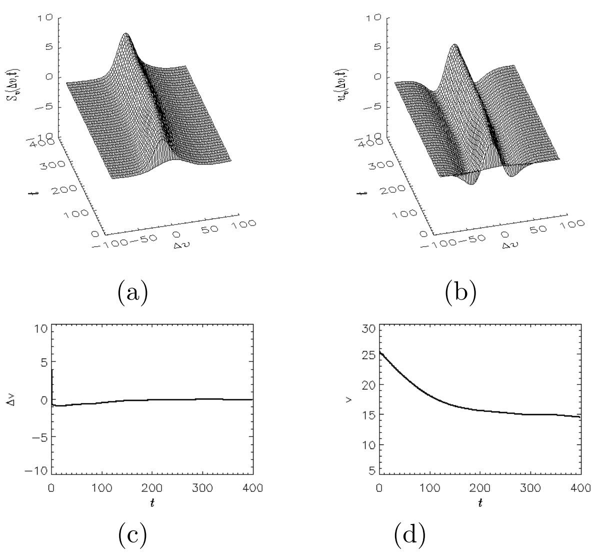


Figure 7: Presentation of time dependent curves in dependence of time [in s] and change in velocity Δv [in m/s] for (a) the stimulus $S_v(\Delta v, t)$ (b) the neural field $u_v(\Delta v, t)$ (c) the determined change in velocity (d) the angle position of the vehicle relative to a stationary observer

7 Conclusions

This paper shows the applicability of neural fields to the problem of behavior planning in driver assistance systems. The special behavior of cruise control was selected and the stimuli of two one-dimensional neural fields controlling steering angle and velocity were designed to fulfill this task. Ideal data produced by a simulation program were applied to test the performance of the designed fields. The goal of producing single peak solutions of the field-activation was reached for the presented scene. The obtained values for the change in steering angle and in velocity resulted in a comfortable trajectory and driving speed. In the oncoming work the dynamics of the fields have to be tested on a variety of scenes with more complex object constellations (oncoming traffic, moving obstacles, objects endangering the vehicle). Further work is going to be invested in determination of stimuli from additional information (pre-knowledge, GPS-information) which can be superimposed additively to the existing stimuli. The examination concerning noise in the input data has to be performed as well to be able to work on real world data.

References

[1] S.-I. Amari. Field Theory of Self-Organizing Neural Nets. *IEEE Transactions on Systems, Man, and Cybernetics*, 13, 1983.

[2] S.I. Amari. Dynamics of pattern formation in lateral inhibition type neural fields. In *Biological Cybernetics*, volume 27, pages 77–87. Springer Verlag, 1977.

[3] T. Bergener, C. Bruckhoff, P. Dahm, H. Janßen, F. Joublin, R. Menzner, A. Steinhage, and W. von Seelen. Complex Behavior by means of Dynamical Systems for an Anthropomorphic Robot. *special issue of Neural Networks*, 1999.

[4] S. Goerzig and U. Franke. Ants - intelligent vision in urban traffic. volume 1, pages 545–549, 1998.

[5] U. Handmann, T. Kalinke, C. Tzomakas, M. Werner, and W. von Seelen. An Image Processing System for Driver Assistance. In *IV'98, IEEE International Conference on Intelligent Vehicles 1998*, pages 481 – 486, Stuttgart, Germany, 1998. IEEE.

[6] U. Handmann, I. Leefken, C. Tzomakas, and W. von Seelen. A Flexible Architecture for Driver Assistance. In *Proceedings of SPIE Vol. 3838*, pages 2 – 11, Boston, 1999. SPIE.

[7] U. Handmann, G. Lorenz, T. Schnitger, and W. von Seelen. Fusion of Different Sensors and Algorithms for Segmentation. In *IV'98, IEEE International Conference on Intelligent Vehicles 1998*, pages 499 – 504, Stuttgart, Germany, 1998. IEEE.

[8] R. Sukthankar. *Situation Awareness for Tactical Driving.* Phd thesis, Carnegie Mellon University, Pittsburgh, PA, United States of America, 1997.

[9] Qiang Zhuang, Jens Gayko, and Martin Kreutz. Optimization of a Fuzzy Controller for a Driver Assistant System. In *Proceedings of the Fuzzy-Neuro Systems 98*, pages 376 – 382, München, Germany, 1998.