Abstract: - The paper deals with the progress of our laboratories in development of objective methodology of assessment of possibly dangerous drivers, who suffer from Parkinson disease in different state and/or different phase of medication. In the beginning there are main theoretical principles and models of driver-car control described. Further, in following chapters two experiments performed on Parkinson disease suffering drivers (and control group of healthy drivers for comparison) are described. The first type of measurements were done with use of a simple trajectory following simulator composed from a steering wheel and PC set, meanwhile the second type of experiment was performed with use of a light car driving simulator. These two approaches had to lead both to an objective methodology which should tell us whether the driver is capable of safe and reliable driving.

Keywords: - Parkinson disease, impaired drivers, driving simulation, driver’s abilities objective assessment

1 Introduction
Most of the developed countries are facing the ageing of the population. Due to low nativity level, better living conditions and better medical care we reach higher age. The car has become the crucial part of our life and it means there are more elderly drives on the roads nowadays. These drivers suffer from many illnesses that has not appeared in past as the people didn’t get old enough. Partial disability after brain strokes, developing Alzheimer disease or Parkinson disease are examples of these. These are mostly illnesses affecting the muscular system, the patients have mostly problems walking and possible ban on driving significantly changes their quality of living.

The main aim of the project “Automated Monitoring of Hazardous and Dangerous Driver's Behaviour”, being now solved as a national grant in Czech Republic, is to discover patterns of driver’s behavior on the road, which testifies for dangerous or unsafe behavior. Natural driver’s impairment, weathers it caused by age, fatigue or disease, must be deeply studied in the laboratory so that such drivers can by reliably detected by automatic devices.

There are no objective measurements that can serve the surgeon as a key to the decision of whether to cancel the driving license or not. There are no known relations between the clinical signs of the disease and abilities (or quality) of the driver. It needs to be critically admitted there are no objective measures for the evaluation of the driving ability for healthy drivers either. The need for the measurements presses on the activities to find such objective measures. The aim is to find any physically measurable values that, aggregated in some reasonable way, offer a metrical value to assess the driver’s ability. This work shall serve to evaluate the abilities of Parkinson disease drivers, but possibly the results can be applicable on the drivers with Alzheimer disease on low level of development as well.

2 Activities of drivers
Based on the traditional piece of work [1], the driver’s activity can be divided into three levels. The first level consists of the typical vehicle positioning on the road, speed and direction control with a feedback. The second level of control is so called ruled control – the driver interacts with other participants, road signs etc. The activity of the driver is necessarily controlled by the traffic rules. All these rules can be transformed into the logical implications of: If <condition> than <action>. Driver behavior can then be described as if the driver has created a linguistic (fuzzy) controller with a knowledge base of these traffic rules. This controller calculates the values for regulators of location and speed on lower level. The top level consists of the so called knowledge control, where
the driver decides on the trajectory of the move, he navigates and optimizes the driving which is based on the knowledge of geography, the traffic level, knowledge of the exceptional situation etc.

The task to solve is the measures for the lowest level, the control of the location, speed and direction with a feedback. The interest is focused on the capability of the driver to keep the car on the road and in the desired driving lane. His activity can then be described using the elementary physical variables (location, speed, acceleration, direction etc.). The cognitive capabilities can be measured only using the psychological tests and pseudo-quantification.

3 Transversal control

The control of the location and direction of the car can be described by so called two-pointed visual control model [1,2,3,4]. The driver controls the position of the front wheel by the steering wheel according to the formula:

\[ \delta = K_f \dot{e}_f + K_n \dot{e}_n + K_i e_n \]  

(1)

\[ y \] - the distance of the car centre from the right edge of the driving lane

\[ \psi \] - car course (immediate driving direction)

\[ e_f \] - angle between the horizontal axis of the car and the tangent to the inner curve in the point of sight

\[ e_n \] - angle between the horizontal axis of the car and the direction towards the lane centre in the close distance

\[ \delta \] - steering angle of the front wheel

**Fig.1:** Variables describing the transversal control of the car

If we assume the driver is tested at the driving simulator, based on these facts we could create the block chart for transversal control.

**Fig.2:** Block chart of the regulatory circuit for transversal control

In this regulatory circuit, the driver acts as a regulator, in this case his behavior is approximated as a linear continuous PI regulator. This is how his behavior appears if we rely on his outer appearance. In reality we have no information on how the optical analyzer of the driver analyzes the scene and extracts the necessary values, we have no information on the decision making process of the regulatory interference. We know only little on the “action members” the spinal motoric neurons that innervate the respective muscle fibers of the hands and lead to the hand movement performing the regulatory action. The analysis of the situation, decision making process and the action itself needs some time that is reflected in the dynamics of the human operator. This dynamics is the most affected by the possible faulty or insufficient activity of the neural structures and therefore the limitation of the patient’s capability to drive. The human operator dynamics is traditionally described via the dynamic system of second or third grade with transportation delay [5,6].

Regarding the diagnostic point of view, the most interesting fact is the human operator dynamics change during the progression of the illness and the moment in which the values reach the level in which the regulatory action is dramatically worsened up to the state in which the instability is probable. We try to find such warning signs that show us it was the time do recommend the patient to stop the driving activity on his own before such critical situation comes.

Therefore we need first evaluate the quality of the eye – hand mechanism. We don’t need any complicated driving simulator experiments to do so, it is enough to measure the dynamic properties of the patient driver himself. We do not need any car dynamics to be taken into account and the car dynamics and scene projection can be neglected. Most of the information about patient driving ability
can be obtained from the observation of the moving point on the screen using the steering wheel.

4 Transitional characteristics of the eye-hand system

A very simple experiment to record the transitional characteristics is organized in the following way. The point is deviated in the impulsive way with random amplitude and time sequence. The operator has to move the cursor through the steering wheel trying to follow the point. One measurement consists of 42 steps. The feedback differ even at healthy driver, therefore all the feedbacks are normalized through a one-unit amplitude and average of these 42 steps. The final response is the average transitional characteristics of the respective operator. The typical scheme of the transitional characteristics can be seen on the picture 3. For further assumption the average transitional characteristics is taken into account, resulting from the average of all 42 responses.

Fig.3: A typical set of transitional characteristics

For surgeons, the terms impulsive and transitional characteristics are not very illustrative. Even the technician cannot guess at the first sight, what is the effect of the transitional characteristics on patient’s performance. That’s why the illustrative interpretation was selected to compare the properties of healthy drivers and patient drivers when avoiding an obstacle that suddenly appears in front of the driver (e. g. There is a car getting out of the side road, unexpected).

For this reason we choose the model situation that is easy to cope for healthy drivers. Supposing the car is going at the constant speed of 80 km/h, i.e. 22, 22 meters per second.

Suppose furthermore that in the time of t=0 the driver has noticed the obstacle he is trying to avoid by sudden movement of the steering wheel. The sampling period is than 0,025 s. (the obstacle is 2 meters wide – a small van, driving off the side road suddenly). We suppose the driver can see the obstacle at the distance of about 20 meters in front of him. The driver performs the sudden movement of the steering wheel to avoid the obstacle and we assume furthermore the amplitude of the action on the wheel is 5° turn. (The angle cannot be bigger due to the road condition, water, icing etc.).

The increments of wheel turn in the individual sampling periods copy the development of the transitional characteristics, i.e. the individual angle increments \( \varepsilon(k) \) are obtained by the multiplication of the transitional characteristics and the overall turn angle (5°).

At each sampling step, the wheels are turn by the \( \varepsilon_i(k) \) angle. The tangents angle to the trajectory (the hypotenuse of the elementary triangle (see the picture Fig.4) is in the \( i^{th} \) steps closing the angle with the x axis according this formula:

\[
\alpha_i = \sum_{k=1}^{i} \varepsilon_i(k)
\]

(2)

\[
\Delta x = \Delta s \sin \alpha_i
\]

(3)

\[
\Delta y = \Delta s \cos \alpha_i
\]

(4)

Where the \( \Delta s \) is the path increment during one sampling period, at the assumed constant speed a constant as well: \( \Delta s = v \Delta t = 22,22 \times 0,025 = 0,55556 \) m.

If we add the individual elemental angle increments, we get the \( \alpha i \) and by multiplication its sinuses and cosines by 0,555556 we obtain the \( \Delta x \)
and $\Delta y$. By their addition we get the overall trajectory.

From the control set of drivers the oldest drivers were selected (all over 50), there the assumption exists their reaction time is longer. The results are seen in the following picture.

**Fig.5:** Avoiding the obstacle – drivers over 50 years

It is very apparent from the picture that all drivers including the oldest one (84) managed to avoid the collision in time. Further we can see there are small differences in the transport delay (Donders reaction time), but significant differences can be found in the course of the transitional action. The results of younger drivers vary around the quickest response (HR40).

We cannot clearly separate a wide range of less seriously attacked Parkinson patients. With some Parkinson patients, the response is much worse as can be seen on the following picture.

**Fig.6:** Avoiding the obstacle – Parkinson patients with seriously affected driving capabilities

It must be noted that it is not very wise to take the average transitional characteristics as the base for all the patients. It is necessary to perform the visual check of the measured characteristics in order to eliminate the rough errors. With many patients, the integrative part would not apply and their transitional characteristics show permanent regulatory deviation. These must be eliminated from the measurement. Some patients show permanent rough errors during all the measurement (the response is long, reaction polarity is adverse etc. The automated analysis of these errors is reaching outside the scope of this short article.

It is apparent that these drivers cannot avoid the collision. The SR26 would avoid it just by few centimetres. These drivers would be recommended not to drive on their own anymore.

5. The use of the simulator

Surprisingly, many patients who cannot successfully follow the point on the screen are quite capable to keep the car on the road, as was proved on the simulator. Probably the predictive feedback is one of the elements, which is not applied when following the point on the screen. The vehicle dynamics in the horizontal control is defined by the astatism of the second grade. The transition of the vehicle is polarized in the second grade in zero, which means on respect to the wheel it behaves as double integrator (the steering angle of the wheels is bound to the transitional acceleration). An example of the simplified transversal transition is the formula:

$$F_y(p) = \frac{Y(p)}{\Delta(p)} = \frac{7.7 (0.036 p + 1)}{p^2 (0.26 p + 1)}$$

The driver shows the delay of the second or third grade in his transition and above all, he suffers from the transport delay. Thanks to this quite complicated dynamics the vehicle trajectory is affected by the oscillation with the frequency lower than 1Hz. Each driver is moving zigzag on the road. With experienced and fresh driver the amplitude of the oscillation is about 0.5 m, due to the fatigue and worse conditions (worse visibility) the amplitude can rise and end up in driving off the road (lane).

On the following two pictures, the simulator drive trajectories of two Parkinson patients are shown. On the horizontal axis, there is the distance in km/s, vertical axis shows the distance from the right edge of the lane. The black line shows the left edge of the vehicle, the red one is the right edge. The first driver is difficult to distinguish from a healthy driver. He keeps driving in his lane and during the whole drive (10 km/s) he never passed the centre line into the opposite direction, once only he crossed the right line (15 cm/s).
The other driver has many times gone into the opposite direction (in one case 2.5 m deep) and once he passed the right line by more than 1 meter. On the real road this could mean an accident. The driver HZ74 can only hardly keep the car in his driving lane and it is recommended to stop him from further driving on his own.

Fig. 7: Trajectory of the test drive on the simulator for Parkinson patient driver, difficult to distinguish from healthy driver (L.S. Left side of the vehicle, R.S. Right side of the vehicle)

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Fig. 8: The trajectory of seriously ill patient who is not capable to keep the car in his driving lane (L.S. Left side of the vehicle, R.S. Right side of the vehicle)

Unfortunately, not in all cases the situation is this clear, if the driving off the lane is the criteria. Whole range of the healthy drivers keep at the division line and cross it very often, while the amplitude of driving zigzag is low. In this case it is more significant to assume the difference of the amplitudes of the individual extremities. The critical value is the difference of the amplitude extremities is more than 2 meters. In such a case the driver driving zigzag cannot keep in his driving lane and the driving off the lane or in the opposite direction is possible. Some of such findings are comparable to those in [7] and/or can be also found in our previous publications (for example [8]).

6 Conclusion
From the performed experiments and their analyses can be deduced, that it is possible to discriminate between the groups of the drivers who are capable of relatively safe driving and those who are not. It is easy to assume that drivers with developed disease had serious problems at the car simulator and with the simple simulator setup as well. On the other hand, some drivers performed much better behind a steering wheel than in common everyday tasks. Also some members of control group (mainly some elderly drivers) demonstrated as bad performance as the drivers suffering from Parkinson disease.

Generally it is possible to say that obtained results present a step forward to objective evaluation of Parkinson disease suffering drivers, which can be used by medical doctors, but can also be utilized in automatic systems detecting hazardous and/or dangerous drivers on roads.

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