Neurointerfaces : Applications

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Abstract

A Neurointerface is a nonlinear filtering system based on Neural Networks that serves as a coupler between a human operator and a nonlinear system or plant that is to be controlled or directed. The purpose of the coupler is to ease the task of the human controller. A Neurointerface and a plant disturbance canceller have been applied to the steering system of a truck and trailer(s). The Neurointerface is used only while the truck is backing. Backing a truck with two or more trailers is essentially impossible for a professional truck driver, but is easily done by an unskilled driver when using the Neurointerface. Neurointerface designs are presented for the truck backer and for human control of construction cranes. The same principles can be applied to ease human control of other complex machines such as aircraft, helicopters, heavy earth moving equipment, robot arms, and so forth.

1 Introduction

Neurointerfaces act as couplers between human operators and complex machinery to be controlled. A Neurointerface is a trainable nonlinear filter based on neural networks that learns to be the inverse of the plant to be controlled, thus making it easy for the human operator to direct the behavior of the plant. Adaptive algorithms for training Neurointerfaces are provided in the paper "Neurointerfaces : Principles", by Widrow and Lamego [1]. Also provided there are designs for plant disturbance cancellers for linear and nonlinear plants, and training algorithms for the disturbance canceller feedback element.

This paper develops the methodology by which a Neurointerface and a plant disturbance canceller can be connected to the steering system of a trailer-truck for use while the truck and trailer(s) are backing. This technology eases the backing task for the driver, and makes it possible for the driver to back up a truck with two or more trailers without first uncoupling the trailers and backing them one at a time. The same principles can be applied to ease human control of other complex machines, such as construction cranes, multi-link robot arms, aircraft, heavy earth moving equipment, and so forth.

2 Experimental Results with the Truck Backer

Application of Neurointerface control has been made to the truck backer-upper. This was done two ways, by computer simulation and with a physical toy truck and trailer, an exact scale model that is approximately 1.5 meters long. Backing the truck and trailers is not a "toy" problem however. The authors have had many discussions with professional truck drivers, and have discovered that no human driver has the skill to back up a tandem, a truck and two trailers. The trailers must be uncoupled before backing one at a time.

The kinematic equations for the motion of the truck and double trailers are easily derived from geometric considerations. Regarding the schematic diagram of the truck and trailers shown in Fig. 1, these equations are

$$\begin{aligned} \frac{\partial \theta_2}{\partial t} &= v\left(\frac{\sin\theta_2}{L2} + \frac{\tan\theta_1}{L1}\right) \\ \frac{\partial \theta_3}{\partial t} &= v\left(-\frac{\sin\theta_2}{L2} + \frac{\cos\theta_2 \sin\theta_3}{L3}\right), \end{aligned} \quad (1)$$

where v is the backing speed of the truck and $L1$, $L2$ and $L3$ are, respectively, the effective lengths of the truck, the first and second trailers.

The results of a typical simulation experiment are shown in Figs. 2 and 3. In Fig. 2, the backing trajectory of the truck and trailers is shown. This trajectory results from application of a sinusoidal command input, plotted in Fig. 3 (a). The command input exercises control over the plant variable θ_3. This is the plant output, and it is also plotted in Fig. 3 (a). The motion of θ_3 versus time should match the response of the reference model if it too were driven by the command input. This response has been computed, and it is also plotted in Fig. 3 (a). These plots are quite

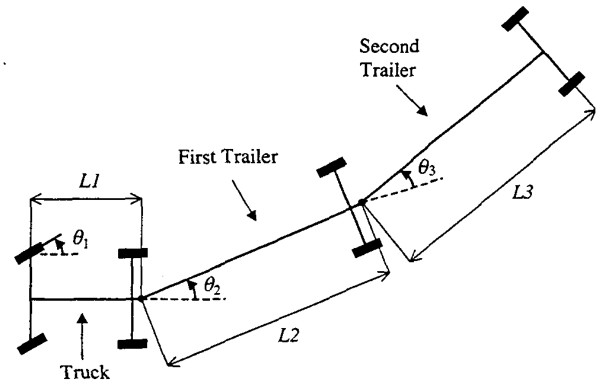

Figure 1: Schematic diagram of a truck and two trailers.

similar. This indicates that the nonlinear Neurointerface, when cascaded with the nonlinear plant model, has a response that fairly closely matches that of the reference model.

The truck steering angle is plotted versus time in Fig. 3 (b). This strange steering function causes the backing trajectory of Fig. 2 and the angle θ_3 response plotted in Fig. 3 (a). It is small wonder that a human driver can not back up a tandem.

In this simulation, the total length of the truck and trailers was 1.5 meters, and the truck was backing at a constant speed of 1 meter per second. The sampling rate for the simulation was 50 samples per second. The off-line computations to obtain the neurointerface and the disturbance canceller used a moving average window in each case of $\mathcal{K} = 10$ samples.

Experiments with the scale-model truck under human steering command have been done. Instead of a computer generated sinusoidal command input, manual steering commands have been inputted to the Neurointerface by means of a small steering wheel connected to a radio transmitter. The received command input was fed to a Neurointerface implemented by an Intel® 486 battery-operated computer. The QNX® real-time operating system was used and all programming was done in the C language. The output of the Neurointerface drove a servo that controlled the steering angle θ_1 of the truck. A photograph of the truck and double trailer is shown in Fig. 4.

Operation of the scale-model truck and trailers worked like the computer simulation. It was easy to steer the truck and two trailers, even while backing at high

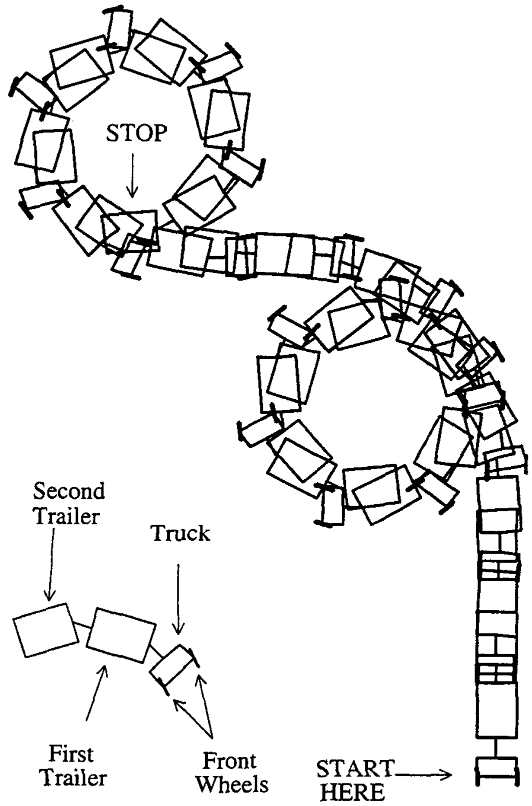

Figure 2: Trajectory of truck and trailers.

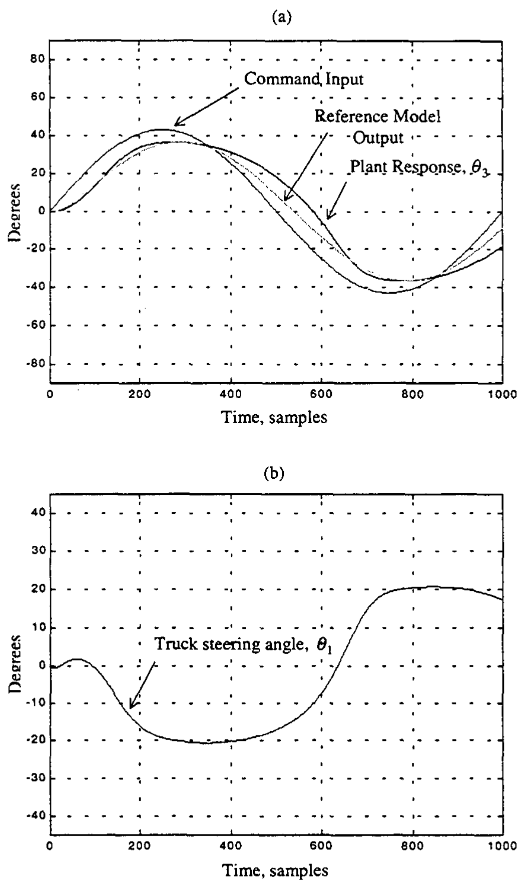

Figure 3: Time plots of truck backer: (a) Command input, reference model output, angle θ_3; (b) Steering angle θ_1.

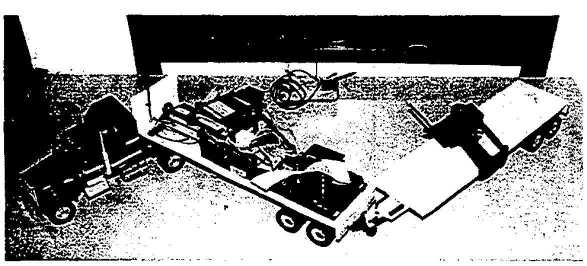

Figure 4: Scale-model truck with double trailer.

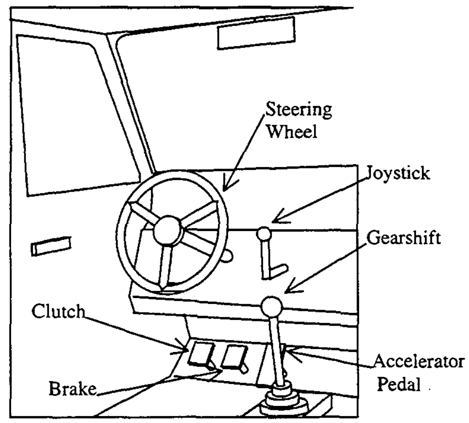

Figure 5: Cab of a large trailer-truck.

speed.

Fig. 5 shows the controls in the cab of a large trailer-truck, with a Neurointerface installed for backing one or more trailers. The steering wheel, the clutch, the brake pedal, the accelerator pedal, and the gearshift are conventional. The operation of the truck going forward is conventional. For backing, steering is done with the Neurointerface controlled by a joystick that may be mounted conveniently on the dashboard or close thereto. While backing, the driver operates the joystick, pushing it left or right, providing the command input. Pushing it left makes the rear of the farthest away trailer curve left, pushing it right makes the rear of the farthest away trailer curve right. The steering wheel and steering column will be turning under the control of the Neurointerface. The driver should keep his hand on the joystick, and keep hands off the steering wheel when backing with the Neurointerface.

3 Control of a Construction Crane

Another application of the Neurointerface is to human control of a large construction crane. A Fixed tower crane is shown in Fig. 6. The tower supports the boom which in turn supports the trolley. A steel cable drops from the trolley to the load. The operator in the cab observes the load and controls its position in three-dimensional space by means of a three-dimensional joystick. The operator can move the joystick handle left or right, and fore or aft, and up or down. The joystick controls the velocity of the load movements. If the operator takes his hand off the joystick, internal springs will return it to its neutral position and the

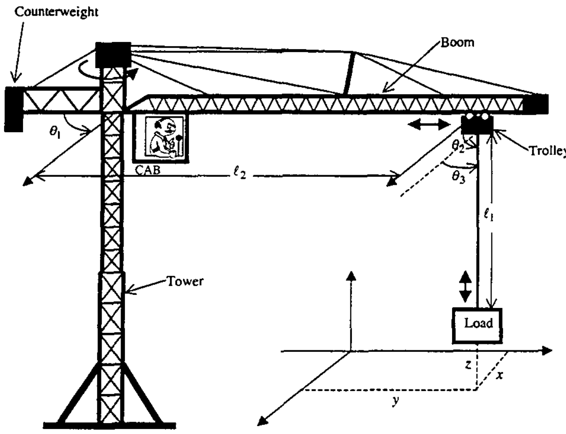

Figure 6: Fixed tower crane.

load will remain in fixed position in three-dimensional space. If the joystick is pushed forward, the load moves forward with a velocity proportional to the joystick displacement. Similar movements of the load take place in response to joystick displacements along its other directions.

The Neurointerface and the plant being controlled are Multi-Input Multi-Output (MIMO) systems in this case. The input command from the joystick that drives the Neurointerface is three-dimensional. The output response of the plant, the time derivative of the position of the load x, y, z (velocity), is also three dimensional.

When controlling the speed of the load, the variables that are controlled are the distance ℓ_2 of the trolley from the tower, the angle θ_1 of the boom, and the length ℓ_1 of the steel cable from the trolley to the load.

Two of the state variables are θ_2 and its time derivative $\frac{d\theta_2}{dt}$, θ_2 being the angle between the steel cable and the boom in the plane of the tower and the boom. Two more state variables are θ_3 and its time derivative $\frac{d\theta_3}{dt}$, θ_3 being the angle between the steel cable and an imaginary horizontal line perpendicular to the boom. Sensors are needed to obtain signals proportional to θ_2 and θ_3. The derivatives may be obtained by electronic differentiation.

If the operator were directly controlling the three variables ℓ_1, ℓ_2, and θ_1, it would be very difficult to change the position of the load without oscillation, without it swinging to and fro at the end of the steel cable. Using the Neurointerface with inputs from the joystick, it is quite easy for the operator to precisely position the load in three-dimensional space and to change its position over time without oscillation.

Disturbance to the load positioning system could come from wind blowing on the load. A disturbance canceller should be included to combat this.

4 Conclusion

Neural networks have been trained to serve as man-machine interfaces for human control of complex machinery. A Neurointerface has been applied to the steering system of a truck and trailer(s) to allow a driver to steer while backing. The steering commands of the human driver are fed to the Neurointerface whose output controls the steering angle of the front wheels of the truck.

Backing a truck and a single trailer requires a good deal of experience and skill on the part of the truck driver. Backing a truck and two trailers in tandem is practically impossible for a human driver. These configurations are unstable and very difficult to control when going straight back or when backing around a curve. With a suitably designed controller that serves as an interface between the driver and the steering gear of the truck, it becomes almost as easy to steer a backing truck with one or more trailers as it is to steer a car going forward.

A Neurointerface can be used for human control of a construction crane. A load supported by a steel cable connected to the crane can be moved precisely from one position to another in 3-dimensional space without oscillation (without swinging to and fro) if a Neurointerface is used to couple operator command signals to the control variables of the crane. The same principles can be used for human control of other complex systems such as aircraft, helicopters, heavy earth moving equipment, and multi-link robot arms.

References

[1] B. Widrow and M. M. Lamego, *Neurointerfaces: Principles*, Proceedings of the IEEE International Symposium 2000 on Adaptive Systems for Signal Processing, Communications and Control (AS-SPCC). Lake Louise, Alberta, Canada. October, 2000.