Haptic Simulation of a Gear Selector Lever
Using Artificial Potential Fields

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Abstract: In this paper, we address the problem of haptic simulation of a gear selector lever using a two degrees–of–freedom mechatronic lever. To reproduce the behavior of a customary gearshift, we propose suitable virtual artificial potential fields that generate the desired force profiles. The artificial potential functions are based on generalized sigmoid functions and contain parameters that have intuitive physical meaning and that can be easily adjusted to change the force sensations fed to the user. To validate our approach experiments have been carried out.

Keywords: haptic device, gearshift lever, artificial potential functions.

1. INTRODUCTION

The automotive industry is experiencing not only a strong enhancement of automation in primary driving tasks, e.g., automated gear shifting, lane–keeping systems, adaptive cruise control, park–assists, automatic hill–hold, brake–by–wire, etc, but also, the introduction of more auxiliaries and interior functions, e.g., USB–connectors, mp3 players, navigation, among others. These trends lower the driver’s workload significantly, and draw the driver’s attention more and more to the interior functions of the car. Adding more functionality to vehicles increases driver satisfaction or pleasure, however, it can also lead to a significant increase of driver distraction. Haptic cues might offer a promising and relatively unexplored alternative to give warnings and other messages to the driver, and also to aid drivers in the execution of their driving tasks.

The term “haptic” comes from the Greek word haptesthai, which refers to the sense of touch. Accordingly, haptic interfaces are devices that provide humans with the means to act on their environment, by generating mechanical signals that stimulate the human touch senses (Hayward et al., 2004).

In the recent years, the automotive industry has been taking a keen interest in haptic (Bigelow, 2004). Car makers such as BMW, Audi, Lexus, Nissan and many more have already installed haptic interfaces in their automobiles. Haptic devices in the car can be classified in two categories (Hjelm, 2008): a) devices that are constantly in contact with the driver, for instance, the haptic steering wheel (van Erp and van Veen, 2001; Enriquez et al., 2001; Ho et al., 2005; Toffin et al., 2003; Mohellebi et al., 2009; Steele and Gillespie, 2001), the Nissan haptic gas pedal, and the haptic car seat. Some of these devices use vibration to give the haptic feedback and they can be used to give warnings to the driver; b) devices that the driver must actively touch. Examples are buttons, knobs, levers and tactile displays, such as the BMW iDrive (Bernstein et al., 2008), the Immersion TouchSense. See also (Bengoechea et al., 2009; Gil et al., 2008; Angerilli et al., 2001; Frisoli et al., 2001) for other applications of haptic in automotive environments.

In this paper we investigate a controlled haptic force feedback shift lever that can accurately reproduce the behavior of a customary gearshift during driving, and that might also be used to control interior and comfort functions in the car (Fig. 1). As stated in (Bengoechea et al., 2009), the primary advantage of haptic levers over customary gear selectors is their ability to reproduce the behavior of manual, automatic or semi–automatic transmissions by simply changing the virtual environment, i.e., the force profiles or haptic patterns.

In this work, we follow the methodology proposed by (Ren et al., 2007) to construct virtual artificial potential functions base on sigmoid functions to generate the desired force profiles. In contrast with discontinuous force models of the gearshift (see for instance(Angerilli et al., 2001; Frisoli et al., 2001)) which might produce undesired oscillations near the location of the discontinuity (Bengoechea et al., 2009; Ren et al., 2007), our resulting
potential function are analytical functions with continuous first derivatives. This feature guarantees smoothness of the force field. Moreover, by adjusting the parameters of the virtual artificial potential functions, the force sensations fed to the user can be easily changed. Experimental results show that the human operator is effectively guided by the force patterns whilst giving the feeling of a real gearshift transmission.

2. ARTIFICIAL POTENTIAL FIELD

The artificial potential field paradigm (Kathib, 1986) has been widely used not only in robotics for obstacle avoidance and mobile robot navigation, but also in haptic rendering applications (Salisbury et al., 1995; Ren et al., 2007). The main idea behind the artificial potential field methodology is to construct a scalar potential function, in which the hills represent obstacles and the valleys represent attractors. The desired attractive or repulsive forces are generated from the gradient of the scalar potential function (Kathib, 1986). In this paper, we follow the methodology proposed in (Ren et al., 2007)—based on generalized sigmoid functions—to generate force profiles that mimic the behavior of a desired gearshift transmission. The two main advantages of this technique are on one hand, the smoothness of the force field, due to continuous first and higher order derivatives, an on the other hand, the easy adjustment of the magnitude and effective range of the potential field.

The artificial potential field based on generalized sigmoid functions can be written as (Ren et al., 2007)

$$ U_d(p) = \sum_{i=1}^{M} \beta_i \prod_{j=1}^{N} f_{\text{sig}}(\phi_j(p)), \quad (1) $$

where $p = [x, y, z]^T$ is the position vector of a point in space, $\phi_j(p)$ is a surface function,

$$ f_{\text{sig}}(\phi_j(p)) = \frac{1}{1 + \exp(-\gamma \phi_j(p))} $$

is the generalized sigmoid function and $\beta_i$ is an adjusting parameter. The value of $\gamma$ depends on the application at hand (Ren et al., 2007). In our case, it is related to the user’s preference for force magnitude. To generate the desired attractive forces, the negative gradient of equation (1) is computed as

$$ f_d(p) = -\frac{\partial U_d}{\partial p} \quad (2) $$

Remark 1. A similar approach using artificial potential fields, combined with discontinuous virtual walls has been applied in (Bengoechea et al., 2009; Gil et al., 2008) for the haptic simulation of several gearshift transmissions.

In the next Subsection we illustrate how equation 1 can be used to construct the desired potential field.

2.1 Potential field of an automatic gearshift transmission

The desired force pattern for the simulation of an automatic gearshift transmission is the sum of two potential functions. The first function defines the limits of the workspace (similar to the behavior of virtual walls), while the second function defines the behavior of the desired resting point of the lever (gear or neutral).

The workspace is a rectangle determined by the lines

$$ \phi_1 = y + 3, \quad \phi_2 = 1 - 4x, $$
$$ \phi_3 = -y + 3, \quad \phi_4 = 1 + 4x. $$

By multiplying together the potential field from each line and then taking the negative of the function, i.e.,

$$ U_{d1} = -f_{\text{sig}}(\phi_1(x, y))f_{\text{sig}}(\phi_2(x, y)) $$
$$ \times f_{\text{sig}}(\phi_3(x, y))f_{\text{sig}}(\phi_4(x, y)), \quad (3) $$

we construct a potential field that has a high value outside the rectangle, and decays rapidly inside the rectangle. The potential field of the gearshift positions is built with the following function

$$ f_{\text{gear\_pos}}(x, y) = -(x - x_0)^2 - (y - y_0)^2, $$

where $(x_0, y_0)$ are the coordinates of the desired resting position for the haptic device. The potential field for a three position gearshift is then obtained as

$$ U_{d\text{gear\_pos}} = -\beta_1 f_{\text{sig}}(\phi_{\text{gear\_pos}_1}) - \beta_2 f_{\text{sig}}(\phi_{\text{gear\_pos}_2}) $$
$$ - \beta_3 f_{\text{sig}}(\phi_{\text{gear\_pos}_3}), \quad (4) $$

Equation (4) has minimum points at $(x_0, y_0)$, and therefore, eq. (4) create a stable force field at the desired resting positions. Finally, the total potential field is given by (see Fig. 2)

$$ U_d = U_{d1} + U_{d\text{gear\_pos}}. $$

Following similar computations, we can also design the artificial potential field that replicate the behavior of a manual transmission (Fig. 3).

3. EXPERIMENTAL RESULTS

The haptic interface (Fig. 4) is a two degrees-of-freedom mechatronic device, whose working principle is based on the self-locking property of a worm pair transmission (Serrasrens, 2005). Without actuation, it is therefore impossible to force the worm to rotate by applying a force to the lever mounted on the worm gear. That is, the operator experiences infinite stiffness of hitting a wall when there is no current fed to the electrical actuator. Vice versa, the actuator is able to move the worm gear and lever around their rotation axis rather easily. The transmission ratio from worm to worm gear can be very large, offering thus a good speed reduction and smaller work load on the actuators. One advantage of this worm pair transmission is
the low power consumption, more feedback force requires less power and there is no consumption at all when the lever is kept at its rest position (van Diepen, 2008).

The link between the hardware and software is provided by the hardware server and controller board that come along with the dSpace® software. The DS1102 controller board provides the inputs and output ports. This controller board is connected via a 62-pin SUB-D connector cable to the hardware server, which is build as a standard PC card. The dSpace® software contains the ControlDesk testing environment, the RTrLib1102 real time interface Simulink® library blockset and the Texas Instrument TMS320C ANSI C compiler.

As depicted in Fig. 5, we have implemented a hierarchical control scheme consisting of two loops: the inner–control loop is a position controller with friction compensation based on inverse dynamics control (Spong and Vidyasagar, 1989). This controller computes the input torques as a function of the joint positions and velocities. The outer control loop is a PID force controller with anti-windup (Astrom and Haaglund, 2005). This force controller compute the necessary set points as a function of the measured human force and the force generated by the haptic pattern in order to provide a haptic feeling to the operator.

Fig. 6 shows the experimental results for the automatic gearshift. The picture has been drawn during 20 trials in which the user changes the gear many times randomly. We notice that the movements are constrained by the force patterns generated by eq. (2), see also Fig. 2.

4. CONCLUSIONS AND FUTURE WORK

We have presented the preliminary results of a haptic interface that can be used to test different automobile gearshifts. Current work is ongoing to implement the force patterns of a manual gearshift as depicted in Figure 3. In the same spirit of (Gil et al., 2008), we plan to develop a graphical user interface, were users can easily determine the behavior of the gearshift, and select the desired force profiles.

REFERENCES

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A pneumatic tactile alerting system for the driving environ-
Fig. 5. Control scheme.


Fig. 6. Experimental results for the haptic simulation of an automatic gearshift transmission.
