Steer by wire implementation using Kinect

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***Abstract*—Steer by wire is one of the most advanced technology in the automobile industry. This paper describes implementation of Kinect based Steer-by-wire system. It elaborates a novel concept of vehicle steering by using gestures. The key idea is to replace the steering wheel and angle sensor by Kinect and use its gesture capability for performing steering actions. This paper focuses on advanced control design method to carry out steering functions using gesture recognition.**

I. Introduction

Steering control is core part in any vehicle's design as it controls actual movement of vehicle. Recent advancements in automotive industry make use of electronics and computers for safety and comfort of drivers. The use of electronic components (sensors or encoders) in place of mechanical and hydraulic controls to control a wide range of operations such as acceleration, braking, steering ,etc is known as 'by-wire' technology [11]. The implementation of electronics elevates the performance, provides safety and reliability with reduced manufacturing and operating costs [7]. Conventional steering system comes with steering wheel, steering shaft, power assist unit and gear assembly. When the driver steers, input through steering wheel is transmitted by steering shaft through gear reduction mechanism, enabling steering motion of front wheels [15]. *Steer by wire* system substitutes electronic components in place steering shaft and introduces feedback motor attached to steering wheel.

By implementing algorithms and accomplishing tasks as mentioned, interaction between driver and steering control can be made more efficient and convenient. What we propose is use of Kinect as a motion sensing device which is capable of gesture and speech recognition [12]. Here we have replaced steering wheel, angle sensor and feedback actuator of vehicle by Kinect. The purpose of this paper is to introduce a modified steer-by-wire system which would be capable of sensing angle from driver's hand gestures and convert it into vehicle movement accordingly without actual need of steering wheel.

The use of Kinect in steer-by-wire system provides many benefits. The main benefit of such system is for physically disabled and elderly people. As the person driving the vehicle just needs to specify the gesture or command instead of actually rotating the steering wheel, these people can drive vehicles without much effort. Also as the Kinect is a programmable and reconfigurable device, it can be used in various vehicles with slight modifications in the code. It can also be configured as per driver's convenience to signal gestures. Thus as a whole, the use of Kinect in steer-by-wire system simplifies driving experience.

II. Related Work

Need of simplified interior design and better space utilization leads to the rise of *steer-by-wire* technology. Many physical modifications are required to change characteristics of handling in conventional steering systems. But, vehicles equipped with steer-by-wire can accomplish same characteristics through active steering interventions In conventional steer-by-wire system,mechanical linkage between the steering wheel and the front wheel is removed to provide vehicle stability and to assist driver for autonomous steering control. Fu Xiuwei, Fu Li and Kong Feng [13] proposed a steer-by-wire system using MATLAB environment, active steering control and the controlling scenario of integral separation PID. Their research showed that steer-by-wire controller based on Integral Partition PID Control [13] gives better dynamic characteristics than conventional controller. Also it overcomes some of the defects that conventional system can't.

Handling and stability of steer-by-wire system is very important at high speed and affects the difficulty level of driving. Duan Jianmin, Wang Ran and Yu Yongchuan [3] researched two control strategies viz. the immobile steering sensibility type control strategy and the yaw rate and sideslip angle control strategy [3] and increased handling and stability of steer-by-wire at high speed.

Paul Yih and J. Christian Gerdes [14] proposed a method for altering vehicle handling characteristics by augmenting driver's steering command with vehicle state feedback. The vehicle's response can be reduced or enhanced based on driver's preference and road condition. A vehicle state was accurately estimated using global positioning system and inertial navigation system sensor measurement [14]. They experimented that such a system can achieve modified handling behaviour that is exactly equivalent to physically changing the cornering stiffness of the front tires.

Compared to other steering systems, *steer-by-wire* system provides variable steering ratio, easy assembling and enhancement of active safety. With steer-by-wire implementation, mechanical linkages are replaced by electric links, which assures actual road feel to driver. To improve return ability of steer-by-wire system and reproduce realistic driving feeling, Ba-Hai Nguyen and Jee-Hwan Ryu [6] proposed a method by measuring road wheel motor's current directly. The steering torque on the rack is measured by current sensor. The current sensors are available at low costs and thus offers a simple and cost-effective solution to reproduce a real driving feel. They developed the force feedback control algorithm which not only gave a realistic driving feel, but also improved the return ability.

On-board controller translates higher-level vehicle commands into vehicle motion or activation of the vehicle's equipment. Prototype of Distributed Control System (DCS) developed by RedZone Robotics [1] consists of a network of small, intelligent nodes mounted throughout the vehicle.The nodes communicate via a controller area network bus, with a master unit to oversee the network operation. DCS provides cost-effective, flexible control and monitoring of a variety of robotic vehicle functions [1].

The introduction of Kinect by Microsoft led to a new enhancement in natural user interface at a considerably lower cost compared to that of sensors and cameras. Initially it was just used with the XBOX gaming applications, but after the release of OpenKinect [8] and Microsoft Kinect SDKs [5], it became a platform to develop more useful applications or integrate it with a huge domain of applications other than gaming. The release of above SDKs made it easier for the academic researchers and enthusiasts to create rich experiences by using Kinect. The main intention was to explore the development of natural user interfaces.

Kinect Identity technique [4] made use of multiple technologies and careful user interaction to achieve the goal of recognizing and tracking player identity. It tracks the identity in two ways viz. *biometric sign-in* and *session sign-in*. In former, the system learns about a player's appearance over time and when the already known person comes in it's view, he/she signs in. In the later method, the system remembers a person for a particular session only and doesn't track her after the session expires. The identity system consists of 3 techniques namely face recognition, clothing color tracking and height estimation [4].

Jun-Da Huang [2] used gesture tracking capability of Kinect in physical rehabilitation system viz. Kinerehab [2]. In this system, gestures are used to find out whether the rehabilitation has reached a particular standard and whether the movements of students are correct or not. An interactive interface using Kinect also enhances student's motivation, interest and perseverance with rehabilitation.

Hand gesture detection is an important aspect of HCI. The authors of [9] used Kinect for hand detection and gesture recognition. But typical resolution of 640∗480 for Kinect sensor provides problem in recognition of hand. It was eliminated using a novel shape distance metric called Finger-Earth Mover's Distance to measure the dissimilarities between different hand shapes [10] .

III. Proposed Method

The system consists of two main parts, the steering section and the wheel section. Steering section is actually a modification of usual steer-by-wire system. The steering wheel, angle sensor and feedback motor are replaced by Kinect. Kinect acts as a device which performs function of both the steering wheel and the angle sensor.

Micro-controller(μC) is a core part of system design and it works as an intermediate between steering section and wheel section. It contains algorithms to convert output of Kinect into the desired input for the actuator which is usually represented as voltage levels.

The other part of system viz. *wheel section* consists of actuator, pinion angle sensor and gear assembly. Kinect provides the steering actuator with input angle. The actuator with steering gear (rack and pinion arrangement) is responsible for corresponding turn of the tyres. The dashed rectangular portion in the system architecture (Figure 1) depicts implementation of Kinect in steer-by-wire system.

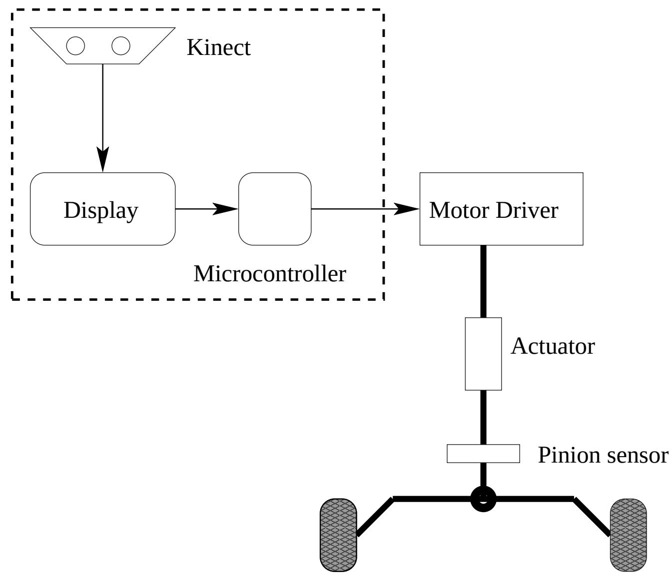

Fig. 1. System Architecture

A. Components

- *Kinect:* Kinect is a device which is capable of gesture and speech recognition. It is a highly advanced and low cost device for effective natural user interface [5]. With Kinect, hand gestures of the driver are tracked. As the driver's hands move in a 3-Dimensional plane, the corresponding co-ordinates are tracked and are converted into a angle which is given to μC. Corresponding hand gestures should be within the range of Kinect, so that positions of hand with respect to Kinect can be shown on the screen of a computer. A graphical display is used as an interface to user for displaying the steering actions through an image of a steering wheel and corresponding hand movements. A specific set of voice commands such as I AM READY to start the steering, STOP to stop steering etc. are also used so as to make the system flexible.
- *Micro-controller:* Most of the control mechanism of a steer-by-wire system depends on the micro-controller(μC). It takes the angle from Kinect and con-

verts it into the pulse(voltage level) with which the actuator should rotate. μC consists of the algorithms so as to convert the data from Kinect and give it to the motor driver. The output of the μC doesn't provide enough power(0-5 V) to rotate the actuator. Here the motor driver comes into picture.

- *Motor controller:* Motor controller is used to supply the motor with necessary input. It helps in obtaining required torque with which actuator should rotate. Motor controller works as a DC to DC step up power converter. It boosts the voltage level as per the requirements.
- *Steering Actuator:* DC servomotor is used to provide steering actuation. It is attached to the remainder of the connecting shaft via flexible coupling. DC servomotor is used because it reduces noise and maximizes the motor life. Servomotor consists of motor, gear head and feedback circuit. If the torque applied by the motor is sufficient to overcome the friction and road forces, wheels begin to move.

B. Gesture and Speech Recognition

A predefined set of gestures is implemented in system. Particular actions occur according to the gesture of user. The main gesture implemented would be virtual steering action by hands. This gesture would specify whether to turn in left or right direction. Also, it would determine by what angle wheels should turn. The gestures are triggered by audio commands from the user. They are used to indicate whether user is ready or not. If user is ready, gesture recognition begins (steering actions).

C. Determination of turning angle of wheels

From a gesture, we determine the angle by which wheels are to be turned based on a steering ratio and lock to lock turns. The steering ratio determines the angle by which wheel should be turned based on rotation of steering wheel. The steering ratio 12:1 means turn the wheel by 1 degree when steering wheel is rotated by 12 degrees. The steering ratio may range between 12:1 to 20:1 depending on the design of the steering system in a particular vehicle. The lock to lock turns specifies the number of rotations of steering wheel when it is rotated from a lock on one side to the lock on the other. Thus knowing the steering ratio and lock to lock turns, we determine the angle by which wheels to be turned based on the angle specified by gesture.

$$\delta = \frac{\theta \times \frac{\frac{LTL}{2} \times 360}{90}}{\mu} \tag{1}$$

where,
θ - Gesture angle
δ - Angle by which wheels to be turned
μ - Steering ratio
LTL - lock to lock turns

Algorithm 1 Measuring Gesture angle

Require: HANDS SHOULD HAVE SAME DISTANCE FROM KINECT
Ensure: DRIVER IS TRACKED
1: Start the system
2: Start gesture tracking by a audio command *I AM READY*.
3: GOTO 5
4: Continue recognising commands until *RESUME* or *HALT* is recognised
5: **while** (command $\neq$ *STOP* **and** command $\neq$ *HALT* **and** *distance between hands* ¡ *threshold*) **do**
6:     **if** (righthand.Z ¡ lefthand.Z) **then**
7:         $Z \leftarrow lefthand.Z - righthand.Z$
8:         $X \leftarrow lefthand.X - righthand.X$
9:         $\tan\theta \leftarrow Z/X$
10:     **else if** (righthand.Z ¿ lefthand.Z) **then**
11:         $Z \leftarrow righthand.Z - lefthand.Z$
12:         $X \leftarrow righthand.X - lefthand.X$
13:         $\tan\theta \leftarrow Z/X$
14:     **end if**
15:     Pass angle θ to μC
16: **end while**
17: **if** ($command \leftarrow$ *HALT*) **then**
18:     GOTO 22
19: **else**
20:     GOTO 4
21: **end if**
22: STOP

D. Workflow

The driver should be given some instructions regarding use of gestures and audio commands. Kinect waits for triggering of audio command to start the gesture recognition (*I AM READY*). Next, it waits until both hands of the driver are recognized. If both hands are recognized and distance between the two hands is greater than some threshold value, whole steering is controlled by hands. Gestures are detected as hands move making virtual action of steering. The gesture system is explained in *algorithm 1*. In *algorithm 1*, lines 6-14 comes into picture only when command isn't *stop* or *halt*. As the driver moves his hands for performing virtual steering action, Z and X coordinates of his hands are tracked and angle between them is measured (Figure 2). This angle is used to determine the angle by which wheel needs to be turned. When the command recognised is *stop*, the gesture system temporarily stops measuring the angle made by the hands. When the command recognised is *halt*, the gesture system stops tracking(steering operation stops). The tracking of user hands along with the illusion of hand wheel is shown on the display screen, so that the driver can actually see by what angle the wheel is turned.

The corresponding angle is passed to μC. It then converts the angle into a pulse (0-5 V) and sends it to motor

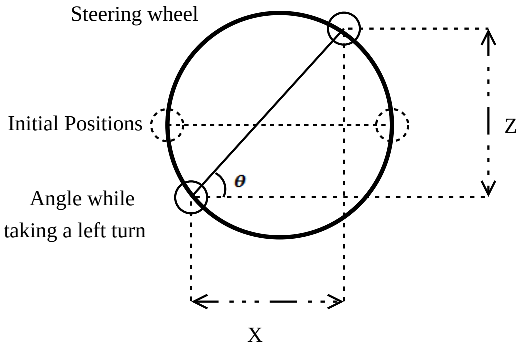

Fig. 2. Gesture angle determination

driver(motor controller). Motor driver supplies appropriate current/voltage to actuator, as voltage output from μC is very low for rotation of actuator. As actuator rotates uniformly, pinion rotates correspondingly making rack to move horizontally. Thus the tierods move and the wheels turns by an angle.

Feedback system is used to provide feedback of actual rotation of wheels to driver. Actual position of wheels is measured by pinion angle sensor. Pinion angle sensor gives feedback to μC. Thus the micro controller gives its output to computer application which runs Kinect and shows the effect of rotation of steering on display screen(a illusion of steering wheel on display is created which rotates). Thus even though driver applies much gesture on rough road, the wheels rotate by less degree and corresponding steering rotation is shown on screen.

E. Fault Tolerance

The steering control system(μC) can diagnose faults by detecting input and output signals and driving current of motor. If this system fails, there must be some alternative to control the steering. The control unit(μC) then stops responding by activating the fail safe relay mode. This is indicated on display screen, activating the manual steering (conventional mechanical steering). The mechanical system of steering control which is used can be folded inside the dashboard by using telescopic cylinder. On activating fail safe mode, the telescopic cylinder can be opened to have the mechanical steering popped up. The vehicle will now be driven by conventional steering system.

IV. Conclusions

The proposed gesture controlled steer by wire system provides flexibility to driver and efficiently controls vehicle movement. Important aspect of this research is how to interact between user gestures and mechanical components of steer-by-wire system. Introduction of angle tracking system based on driver's gesture provides a new way to replace steering angle sensors and other mechanical components. Feedback system is used for steering angle correction due to obstacles and unexpected disturbances while driving. In the simplest form, the proposed system provides a new steering system which works and feels like conventional steer-by-wire system without actual steering wheel. By introducing Kinect based steer-by-wire system, our research shows a new way for driver assistance, flexibility and added new features like voice recognition to initiate steering procedure. While dealing with steer by wire, Kinect accuracy should be dealt properly, as it is very sensitive to human actions.

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