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A dynamic binaural synthesis system for investigation into situational awareness for truck drivers

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Abstract

Yearly, a number of accidents happen, where cyclists are injured by right turning trucks. In Denmark, the proposed solution has been to provide a higher number of mirrors to the truck driver in order to cover visual blind spots. However, this doesn't seem to eliminate the problem. Investigations into the reason for this point to cognitive phenomena such as change blindness, where more visual information won't help. For other professional vehicle operators such as pilots, auditory solutions adding to a higher situational awareness has proven valuable. This paper describes the development of a dynamic binaural synthesis system for investigation into situational awareness for truck drivers. The system is built around several software components enabling the 3D positioning of an auditory representation of a bicycle. The sound is played back over headphones to the truck driver whose head movements are monitored and taken into account in the binaural sound synthesis. To enable experiments in real traffic, the system facilitates an operator interface where the investigator can position the auditory objects according to real bicycles appearing in the traffic. The software is organized in a number of modules communicating over a network protocol (UDP) enabling distribution on several hardware devices. The modules are: Graphical user interface, head tracking server, truck tracking, and binaural synthesis module. The function of the individual modules as well as overall topology of the system will be presented, and initial practical experience with the system used in real driving situations will be discussed.

Keywords: Auditory display, binaural synthesis, tracking, situational awareness.

A dynamic binaural synthesis system for investigation into situational awareness for truck drivers

1 Introduction

Yearly, a number of accidents happen, where cyclists are injured or killed by right turning trucks. In Denmark, the proposed solution has been to provide – by law – a higher number of mirrors to the truck driver in order to cover visual blind spots. Figure 1 shows a case situation with a truck and two bicycles (high-lighted colours). Four mirror positions are seen: 1) The side mirrors on the left and right frontal corners. These positions both contain 2 mirrors, a normal and wide angle mirror. 2) A blind-spot front mirror mounted at the top of the wind shield covering the invisible area in front of the truck. 3) A blind-spot side mirror mounted at the top of the right side window, covering the blind spot below the passenger side door.

To indicate the cognitive load on the driver when bicycles are present, Figure 1 shows a driving situation with two bicycles out of visual line of sight of the driver. When the driver looks in the right hand side mirrors, a reflection of the real cyclist is seen. The cyclist (red) that is positioned along the front part of the trailer will be seen in the direction of the mirrors and in different sizes depending on curvature of the mirror. The same is indicated for the yellow cyclist at the front corner of the driver's cabin. This cyclist will be observed as reflections in the blind-spot mirrors.

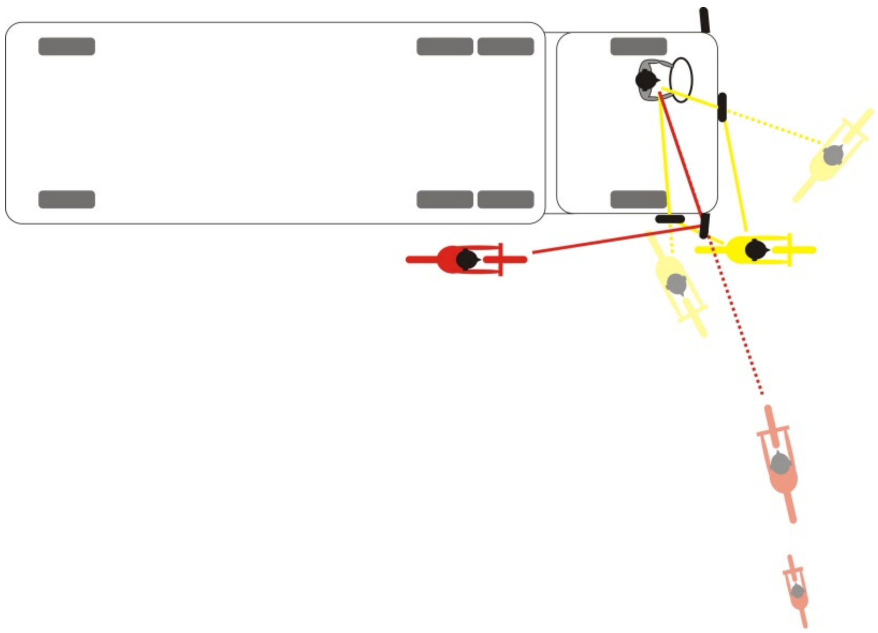

Figure 1: Top view of an eight wheel truck in a driving situation with two bicycles. The driver is positioned in the left side of the cabin. The four black lines around the cabin are mirror positions. High-lighted red and yellow are real bicycles whereas faint colours represent visual images in the mirrors. Full lines (red and yellow) are physical line of sight through the mirrors. Dotted lines indicate the direction of the mirrored images of the cyclists.

One of the cognitive tasks of the truck driver is to map the percept of reflections in the mirrors to real positions on the road around the truck. This is further complicated, since the cyclists will appear and disappear in the mirrors as they change positions relative to the truck, and as the angle of the mirrors change relative to the bicycles, when the truck is doing a right hand turn.

The higher number of mirrors doesn't seem to eliminate the accidents [1]. Investigations into the reason for this point to cognitive phenomena such as change blindness, that more visual information won't eliminate [2].

For other professional vehicle operators such as pilots, auditory display solutions adding to a higher situational awareness have been applied and proven valuable [3], [4], [5].

The aim of this paper is to describe the development of a binaural synthesis system to facilitate investigations into situational awareness of truck drivers in real life driving situations, and along with this, also the driver's acceptance of auditory representations of nearby cyclists.

In order to make a full automatic implementation of such a system, sensors should scan the surroundings of the vehicle for bicyclists, pedestrians, etc. This is not the focus of this investigation, and a concern is whether such a system would provide too many false positives i.e. indications of bicycles when the real object is different as e.g. lamppost, which might lead to the driver ignoring the system. Instead, the sensor network is – at this stage – substituted by a graphical user interface (GUI) that allows an experimenter sitting in the passenger seat to position sound events by hand based on visual inspection of the surroundings. The significance of this is discussed in an accompanying paper [7].

2 Synthesis system

The aim of the system is to facilitate investigations into situational awareness of truck drivers, especially related to the right turn situation, but also in general when approaching bicycles, or when the bicycles are approaching the truck. The system allows for different sounds to represent the bicycle.

The system will be deployed in different trucks for testing real-life driving situations, so it should be easily installed before the driving takes place. This calls for as little equipment as possible to be mounted in the truck. One solution – and probably what would be desirable for fixed installations – would be presentation of sounds over a loudspeaker system, and as such not physically invasive to the driver. This, however, is not feasible in the present setup, so headphone presentation of binaural 3D sound was chosen.

The system comprises a pair of headphones for the truck driver. The sounds presented over the headphones are generated by a 3D binaural sound engine (software) that is processing anechoic recordings of sounds to represent the bicycles. An orientation tracker is mounted on the headphones to monitor the driver's head movements. Furthermore the orientation of the driver cabin is tracked. These orientations are fed to the sound engine enabling a stable positioning of sounds relative to the truck, and allowing the driver to rotate the head.

2.1 System overview

The software is organized in a number of modules communicating over a network protocol even when running on the same computer. This enables distribution on several hardware devices. The modules are: Experimenter interface (Graphical user interface), head tracking server, truck tracking, and binaural synthesis module (3D sound engine).

A sketch of the system is shown in Figure 2, where heavy box edges symbolize hardware, and light edges are software modules.

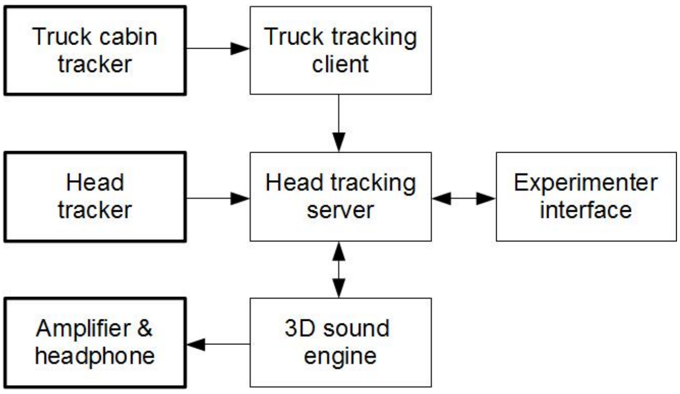

Figure 2: System module overview. Heavy boxes is hardware. Light boxes are software modules running on one or more computers.

All communications between the software modules are handled via UDP network connections with a simple protocol on top. Communication of content between modules is via a number of floating point numbers. The first number is an identifier of the transmitting sub-program. It is followed by a number of parameters dependent on which module is sending data.

The connection between the Truck cabin tracker and the software is a serial connection via USB. The head tracker is transferring data to the software via Bluetooth.

The system relies heavily on software libraries supplied by the manufacturers of the different building blocks (trackers and sound engines) as well as operating system calls (Microsoft Windows sound playback and UDP). The distribution of tasks between sub programs via (internal) network connections also handles eventual blocking system calls which then become non-blocking to tasks handled in other modules.

2.2 Tracking

The tracking is done in two software modules. The central module is the head tracking server. This module also acts as UDP server for the rest of the modules that are UDP clients. These modules are transmitting an ID number, and eventual data to the server, and waiting for the server to transmit an eventual response depending on the client calling. One of the other modules is handling the second part of the tracking: the truck cabin tracking.

The central head tracking server is handling data from the head tracker, (Invensense motion fit 5.1 SDK with MPU-9250 CA-SDK Reference board). This data is received over a serial Bluetooth connection. The head tracker is basing its orientation calculation on fusion of 3 different sensors: Geo-magnetic, gyroscope and 3-axis accelerometer. The sensor data is fused in the sensor board before transmitted to the PC. The factory pre-loaded sensor fusion was used.

The trucks orientation was tracked with a Honeywell HMC5883L digital compass chip mounted on a breakout board and connected through an Arduino Duemilanove to the PC via a serial connection over USB. The compass chips' X and Y headings were read and converted to a compass heading transmitted to the PC at an approximate rate of 5 Hz, which was considered sufficient for a slow driving and turning truck. There was no significant drift on the tracking (< 1° in an hour, and not consistently in one direction). The data was observed to contain noise <±2°.

At the system initiation, the truck driver is asked to put on the headphones and look straight ahead. When the system has initialized the truck's orientation as well as the drivers head orientation is used as offset value i.e. a zero reference for the driver looking straight ahead in the truck. In case of an eventual drift of the trackers or misalignment of the headphones, a reset can be manually done later. Since the magnetic heading might be skewed in the truck cabin, this also allows for alignment of the two geomagnetic trackers in case of different biases of the geomagnetic heading at different positions in and orientations of the truck cabin.

All communication between modules that is passing through the server is time stamped and saved to log-files allowing for post analysis. This covers drivers' head orientation, truck orientation, position of bicycle, choice of sound, and resetting of orientation.

2.3 3D sound engine

The 3D sound engine is based on the diesel power binaural 3D sound engine by AM3D.

The engine allows for 3D binaural rendering of a number of sound sources around a (potential) turning listener as well as addition of sound effects like e.g. reverberation and mixing features like volume control.

The engine API calls were compiled with a container program implementing block-based sound playback (block size was 1024 samples, 44.1 kHz sample frequency) on a Windows computer as well as the necessary UDP communication to ask for orientation (truck and drivers' head) and position (bicycle) from the server program.

A small amount of reverberation was added to aid the distance perception, since perception of distance is hard under anechoic conditions [6].

To enable immediate switching between different sounds representing a bicycle, all sounds were loaded into memory at the program initialization. All 3 sounds were processed to originate from the same position, and the switching between sounds was implemented as level changes (faded in or out). The sound recordings were looped, so switching off sound is also made in the internal sound mixer by attenuation.

2.4 Experimenter interface

The experimenter controls the system through a graphical user interface (GUI) on a tablet computer, see Figure 3. There is a choice of 3 different sounds. The choice is made by the touch of one of 3 buttons. A fourth choice of no sound is also present. Looped playback of the sound is initiated by placing a finger on the screen around a top view sketch of a truck. The finger position indicates the position of the approaching bicycle, which is transmitted to the 3D sound engine. When the experimenter removes the finger from the screen the sound is muted. The touch field is marked by a grid representing 1 by 1 meter squares to aid the correct positioning. Since the system would be used in different sized trucks, a selection of trailer sizes is indicated.

To allow error checking with regard to the head-tracking, a sketch of the drivers head is positioned above the driver's seat on the GUI, and the head is turning according to the head-tracking information in the system. In case of eventual drift or misalignment of the tracking systems a direction reset button was included. This would allow the experimenter to correct any misalignments by resetting to a forward looking direction when the truck is driving straight ahead, and the driver is looking straight forward.

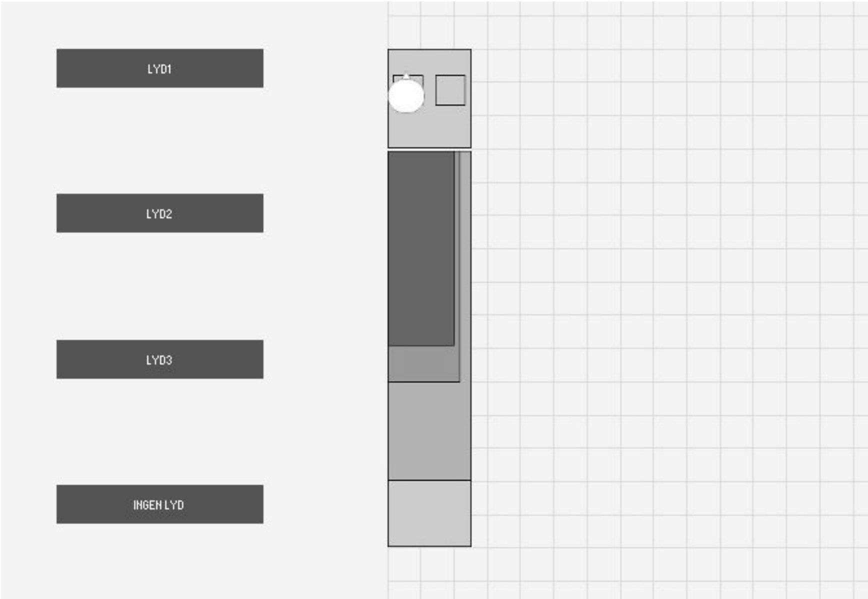

Figure 3: Part of the experimenter interface (text in Danish). The experimenter chooses a sound (Lyd1, Lyd2, Lyd3) or no sound (Ingen lyd). The position of a bicycle is indicated by touching the m^2 marked area around the truck.

The GUI module transmits ID, position (X,Y in meters) relative to the drivers position, sound to play (type1,2,3 or off) and reset of driver and truck orientation. It receives driver head orientation to display.

2.5 Other hardware and tools

A circum-aural headphone (Sennheiser PC 363D) was used. Although it is circum-aural, it has an acoustically very open design that allows the user to attain close to normal listening of the sounds of the surrounding environment, which is strictly necessary to allow the driver to have close to normal driving conditions.

The implementation of the 3D sound engine and the head tracking server was made in C/C++ (Microsoft Visual Studio) whereas the experimenter interface and truck tracking client was programmed in Processing.

3 Pilot study

The system has been put into use in a pilot field study [7].

3.1 Objectives

The aim of this study was to test whether the system would be able to enhance the drivers' situational awareness regarding surrounding bicycles in right turn situations, and test the acceptance towards the system i.e. would the drivers accept to listen to the sounds as auditory representations of the bicycles.

3.2 Methods

Based on a laboratory feasibility study of different sounds to represent the bicycles in the driving situation [8] three different bicycle bell sounds were chosen. The bells were recorded in an anechoic room sounding at slightly different short intervals (between one and two sounds per second) for approximately 20 seconds (looped in the playback)

The system was running on a laptop computer and a Windows tablet connected via a direct Ethernet connection. The tablet was running the experimenter interface. The rest of the system was running on – or connected to – the laptop.

The system was tested with four drivers on six goods delivery routes (two of the drivers having two trials). The drivers had between 9 and 30 years of experience. The trucks were approximately 12 meters long and 2.55 meters wide and equipped with mirrors according to legislation – as described in section 1. The experimenter was positioned at the passenger seat and initiating bicycle awareness signals based on visual inspection through the windows and mirrors. The sound level was adjusted according to expressed wishes from the drivers.

3.3 Results

Results were collected as observations and interviews.

On the 6 routes between 3 and 42 bicycles was encountered. The routes lasted between 4 and 6 hours and most of the routes were in the city centre or periphery of Aalborg, Denmark. One of the routes included roads outside the town (6 hours, 3 bicycles).

The drivers were instructed to act as close to normal as possible, and several drivers therefore opened the door when driving backwards. In these cases, they took off the headphone, because of the wires. In neither of these situations were there bicycles relevant for rendering audible.

In general the truck drivers were happy with the system, and accepted the presence of the bell sounds, when bicycles were in the range of the system. In some cases the drivers saw the bicycles at the same time as the experimenter, but when the experimenter via the system was indicating the presence of a bicycle that the drivers had not yet seen, they acted appropriately by looking towards the relevant mirror seeking visual confirmation.

4 Conclusions

A dynamic binaural synthesis system was constructed to enable investigations into situational awareness for truck drivers. Especially regarding right hand turns involving bicycles. Via the binaural synthesis an experimenter seated in the passenger's seat can place bicycle bell sounds according to real bicycles in the vicinity of the truck. The presentation is made over orientation-tracked headphones.

The system can run on a single computer or distributed over more devices connected via Ethernet.

A pilot experiment [7] showed that truck drivers were able to utilize the system in their navigation, when driving on delivery routes in real traffic. The drivers appeared to accept the system and the bell sounds accompanying occurring bicycles. This stands in contrast to earlier findings in driving simulators, where the drivers where using similar 3D sound systems for only 10 minutes and afterwards expressed concerns regarding whether a system would work in a real-life driving situation [9].

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