Robot Environment for Combat Vehicle Driving Simulation

Roman KAMNIK, Miha AMBROŽ, Peter ČEPON, Jernej KUŽELIČKI, Ivan PREBIL, Marko MUNIH

Abstract: This paper presents a driving simulator of a combat vehicle aimed for driver-vehicle interaction study and design of full scale driving simulator. The simulator consists of a real-time combat vehicle dynamics simulation module, a graphical presentation module, a robotic seat motion system, and a force feedback steering system. The simulation module simulates dynamic motion and interaction with environment of a combat vehicle in real-time. The graphical presentation module generates driving scenes that are displayed on a screen by a back projection. The robotic system generates seat motion cues by the help of a three degree-of-freedom hydraulically driven mechanism. The force feedback steering system is an interface between the driver and the simulator. In the paper the configuration of the driving simulator and the results of experimental evaluation are presented.

Keywords: Driving simulator, combat vehicle dynamics, robotic seat, force-feedback,

1 Introduction

Driving simulators are being used effectively for vehicle system development and human factor study by reproducing actual driving conditions in a safe and controlled environment. The driving simulator is a tool that gives a driver impression of maneuvering an actual vehicle by predicting vehicle motion caused by his input and feeding back corresponding visual, motion, audio and proprioceptive cues. Driving simulators originate from the aircraft industry, however, automotive industry currently deeply relies on their exploitation. Most sophisticated are the driving simulators from Daimler, Ford, Honda, Renault and Toyota automotive companies. Simulators are being used for training in normal and critical driving conditions, analysis of the driver responses, and evaluation of user performances in different conditions [1]. Important role have the driving simulators in military applications since they create a virtual proving ground for engineering evaluation of combat vehicles and driver performances.

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This paper presents a prototype driving simulator for six-wheel combat vehicle. The driving simulator was developed in the framework of feasibility study that investigated the possibilities of subsystems integration. In the first part of the paper the configuration of the developed simulator is described, while in the second part, the results of experimental evaluation are presented.

2 Configuration of driving simulation environment

The configuration of robot environment for combat vehicle driving simulation is presented in *Figure 1*. The simulation environment incorporates four main modules. In simulated driving, the driver maneuvers the vehicle in computer model via active steering wheel. Vehicle motion dynamics and interaction with environment is calculated on-line in real-time. Based on calculated values the computer graphics presents the vehicle in 3D environment what provides visual feedback, while the two robot systems provide sensational (haptic) feedback to the driver. The haptic feedback to the driver is presented by the hydraulic robotic seat that provides vertical driver seat motion and the steering wheel system that generates the wheel aligning torque on the steering wheel. Each

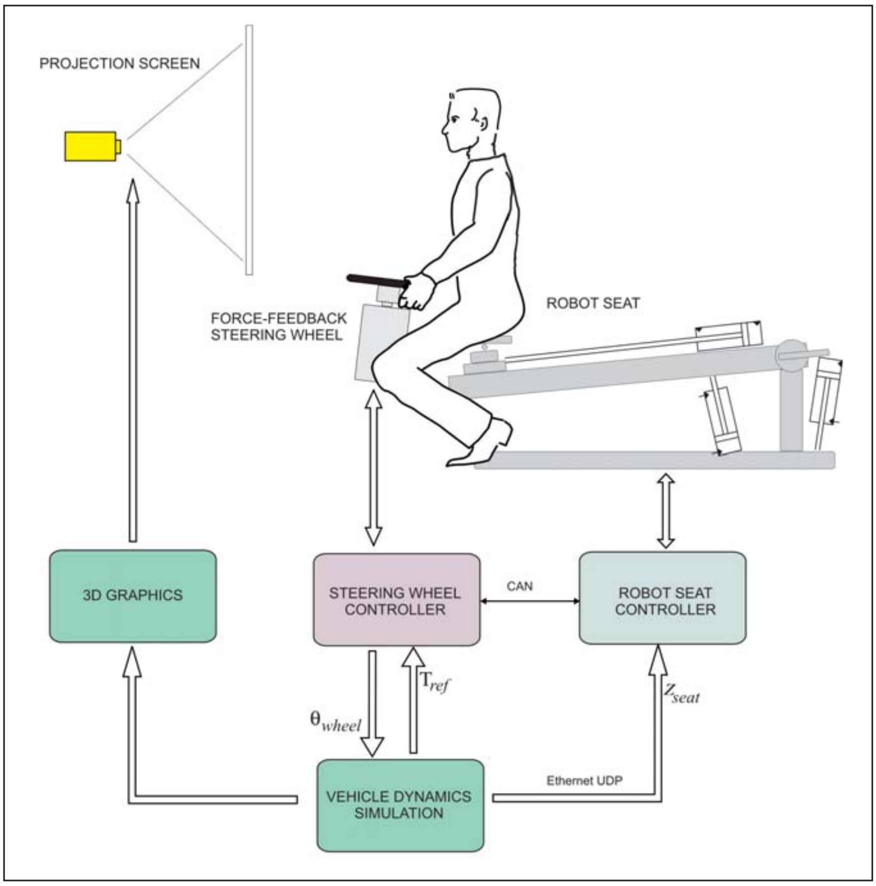

Figure 1. *Configuration concept of robot environment for driving simulation*

particular simulation environment module is described in details in the following chapters.

2.1 Simulation model of combat vehicle

The simulation model of combat vehicle incorporates the model of vehicle dynamics, the model of vehicle powertrain and propulsion system, the model of braking system, the model of steering mechanism and the model of vehicle - terrain interaction.

The model of vehicle dynamics is multibody-based and modelled using the Open Dynamics Engine. The vehicle is represented as a multibody system consisting of bodywork and four to eight wheels. The setup of a six-wheel vehicle is shown in *Figure 2*. The wheels, together with suspension elements, are connected to the bodywork with double-hinge joints. The unsprung mass consists of wheel mass and suspension elements mass [2, 4]. Spring and damping characteristics of each wheel suspension are modelled by assigning the joint characteristics. Since the wheels are modelled as rigid bodies, the tyre spring and damping characteristics are computed separately and mechanically combined with suspension characteristics.

The powertrain is modelled as the system of a generic wheeled vehicle that in general consists of the engine, clutch, main gearbox, reduction gearbox, differential gear(s), and hub gears. Each power transmission element transfers torque and shaft angular velocity according to its transfer function.

The braking system of the vehicle is modelled as a source of tangential force on the braked wheels, the amplitude of which depends on the position of the brake pedal as user input. Braking force can be individually applied to each of the wheels. The simulator provides a basic model of braking force reduction on the rear axle depending on the normal force on the rear axle. A simple model of slip-detection based anti-lock brake system is also implemented.

The steering system of the vehicle is modelled as a transfer function that transfers the steering wheel rotation angle as user input to rotation angle of the individual steered wheel. The model provides means of modelling of kinematic steering mechanism and its steering angle difference to fulfil the Ackerman condition. All the steering mechanism geometrical characteristics found on real vehicles (camber angle, castor angle, toe-in angles etc. are also modelled [2, 4, 3]). Transfer functions for steering can be assigned for each axle of the vehicle separately. In this way, it is possible to model vehicles with unconventional steering systems (e.g. rear wheel steered fork lifts or vehicles with four wheel steering as shown in *Figure 4*).

Terrain is modelled as a triangle mesh and used in collision algorithm to

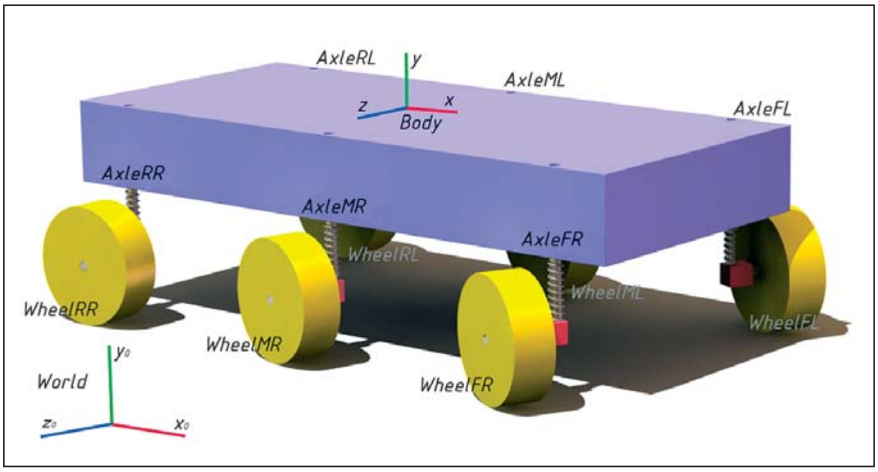

Figure 2. *Vehicle multibody model*

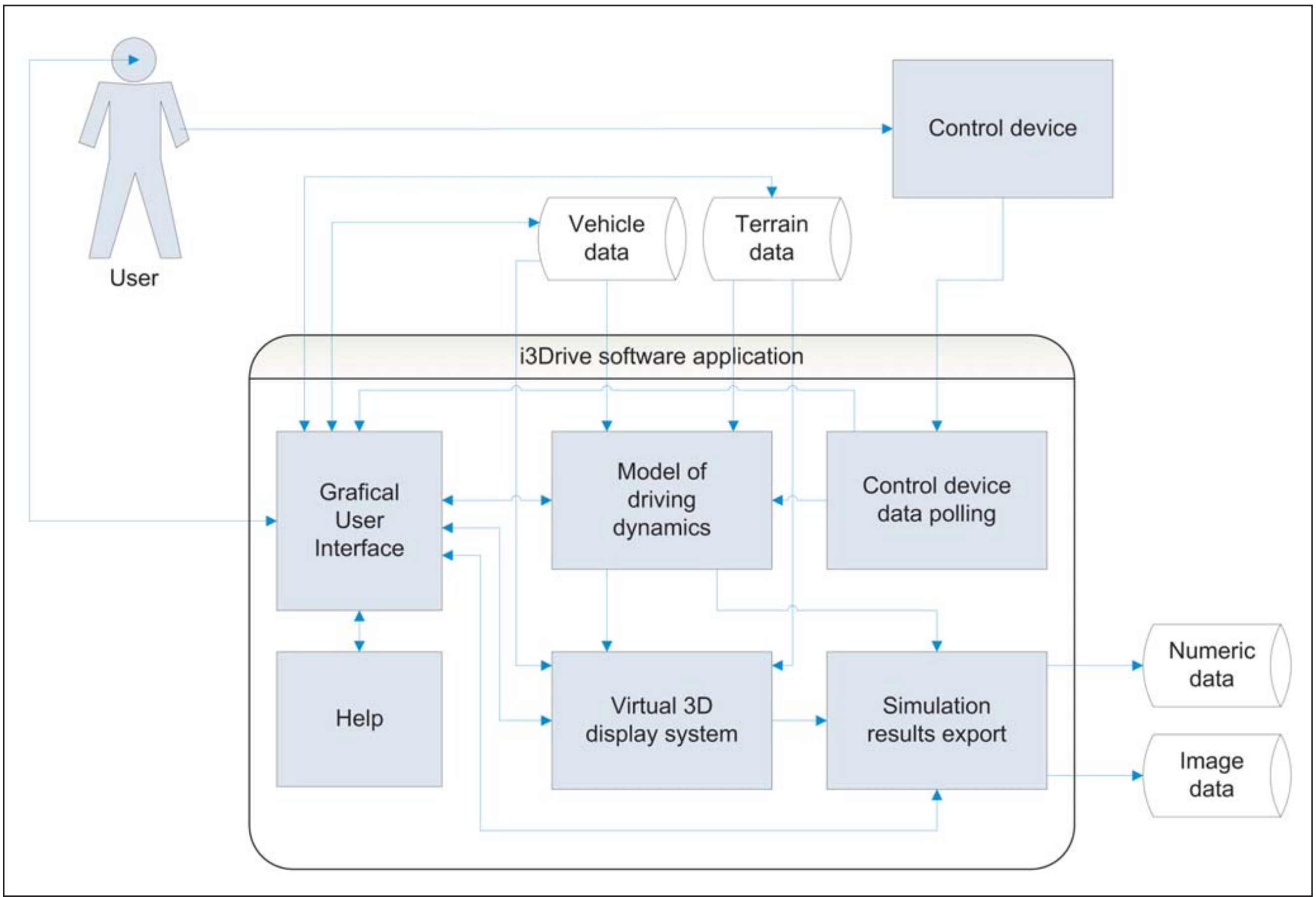

Figure 3. *i3Drive application scheme*

excitate the vehicle dynamics model. The ODE collision detection system is used to determine the contacts between vehicle parts and the terrain geometry. The shape of the terrain triangle mesh is arbitrary and without restrictions for triangle dimensions. This way, the memory required for storing triangle data and the number of vertices used in collision detection can be effectively reduced in the "flatter" areas of the terrain, whilst the more agitated areas can be represented by a larger number of triangles providing more accurate simulation. The point data to generate the terrain mesh can be obtained from various sources. These include field measurements and GIS data for existing real terrains, or different 3D modelling techniques for artificial terrains. The forces that occur on the tyre-driving surface contact depend on many factors, of which the most significant are the longitudinal wheel slip and lateral wheel slip angle. These two quantities are computed for each wheel in every simulation step. The forces are modelled separately for the longitudinal and the lateral direction of the wheel [6]. The model also includes calculation of the aligning torque on the steered wheels that

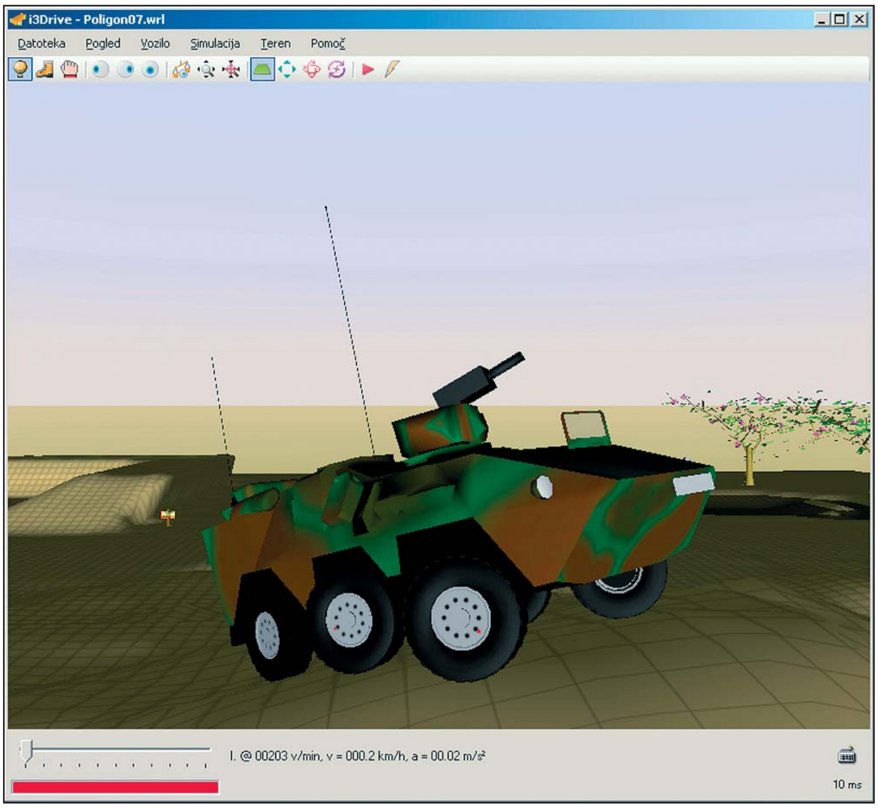

Figure 4. *i3Drive main window*

is included into the simulation as steering wheel centering, i.e. steering torque feedback.

2.2 Software application for interactive vehicle simulation

The simulation models are incorporated into a software application named i3Drive that includes components for display in virtual 3D environment, modules for polling control devices, a graphical user interface to control the application behaviour and components for simulation results export. The advantage of the configuration is that the user has access to all the relevant simulation parameters regarding the vehicle, the terrain and the simulation intrinsics, which makes it possible to realistically simulate real vehicles on real terrains. Together with the possibility of real-time interactive driver input processing this makes the application useful for vehicle operator training. The structure of the application is schematically shown in *Figure 3*.

The largest part of the application main window (presented in Fig. 4) is occupied by the display area where the vizualisation in virtual 3D environment takes place. The user can control the simulation and display parameters with menu commands and toolbars and monitor the simulation status in the status area. Special care has been taken to provide easy access to common tasks such as switching viewpoints and changing navigation and simulation parameters.

Simulated vehicle dynamics is presented in interactive virtual 3D environment. The user is represented by the virtual person, or avatar, that can be controlled independently of the simulated vehicle. This enables the user to observe the virtual 3D environment, and thus the driving simulation, from different perspectives and different points of view. The avatar can be attached to the simulated vehicle to provide the "driver's view" or custom views of parts on the vehicle. To achieve a better view of the simulated vehicle when driving on larger driving surfaces, any fixed or moving viewpoint

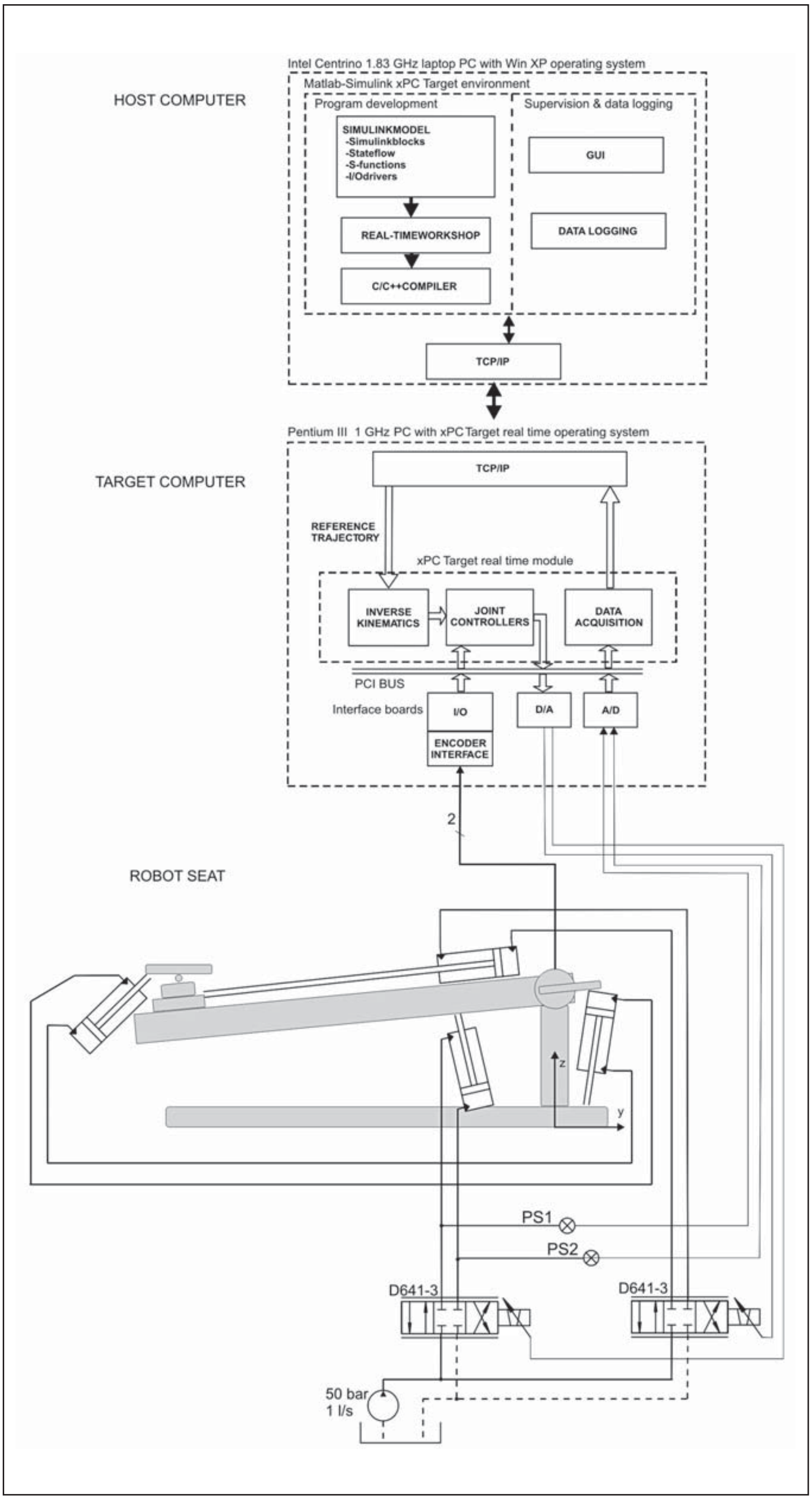

Figure 5. *Control scheme for robotic seat*

can be set to automatically follow the simulated vehicle by rotating the virtual camera.

From programming point of view the display system is independent from the simulation engine and the mathematical model. This is achieved by running the simulation engine and the virtual 3D environment display in separate operating system threads assuring only synchronization between the two timers. This way it is possible to achieve shorter simulation intervals to improve simulation accuracy and stability while keeping the display update interval long enough to ensure display in real time. On a 2600 MHz Pentium 4 computer with ATI Radeon 9600 graphics card at 1024×768 screen resolution the current version of i3Drive can achieve the shortest simulation interval of 9 ms at a display frame rate of 25 frames per second when simulating a four-wheel vehicle on a driving surface consisting of 9800 triangles.

The inputs to the vehicle model (steering wheel angle, gas pedal position, brake pedal position, selected gear ratio, clutch state etc.) are delivered by a control device. The hardware control devices can range from standard commercial game controllers (joysticks and steering wheel/pedal combinations) to custom made controllers and detailed vehicle cockpit mock-ups. The software for driving external actuators are built into the control device and the simulation data are used to provide motion and force feedback to the user.

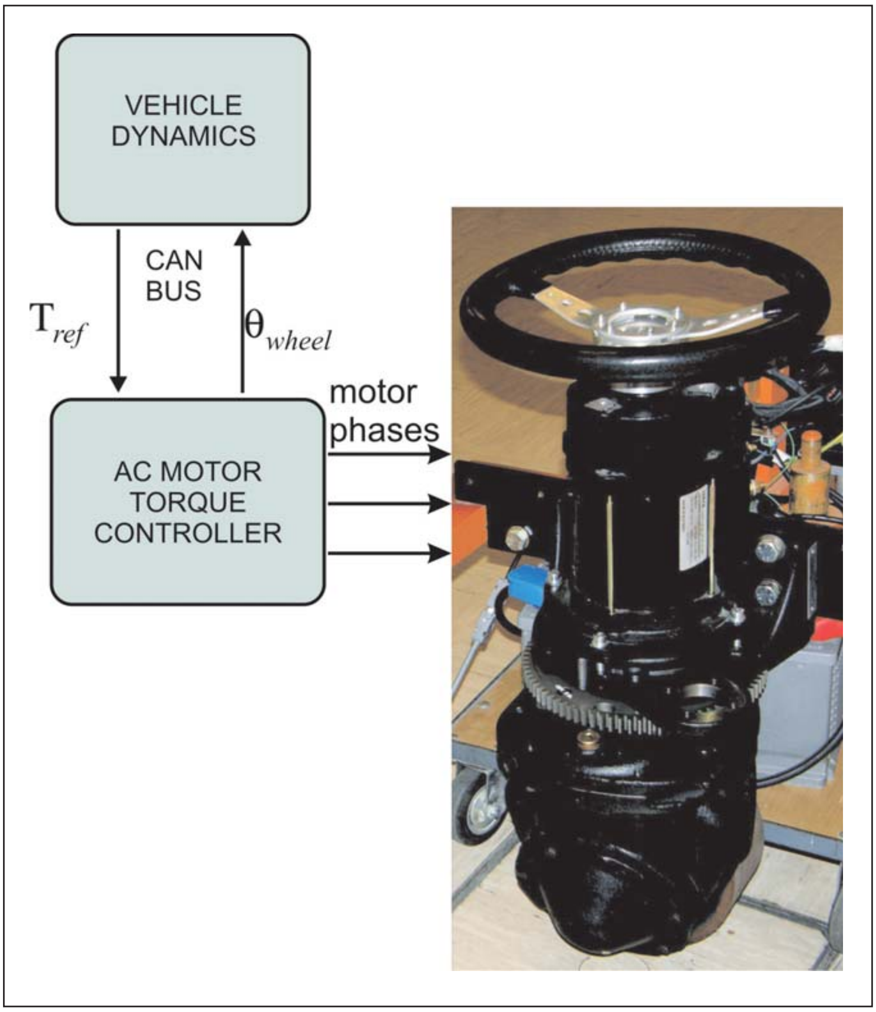

Figure 6. *Force feedback steering*

2.3 Robot system for seat motion simulation

Active driver seat is in the simulation environment realized by the use of a robot device developed for training of standing-up [5]. The standing-up robot device is a hydraulically driven 3 DOF mechanism, which in a way of supporting the subject resembles half of a seesaw. The driver is supposed to seat on a standard bike seat mounted at the robot end-effector. The robot configuration enables an arbitrary seat motion restricted to a subject's sagittal plane. Positioning of the end-effector is accomplished by movement of the two robot segments. The first segment is rotating around its axis in a robot base, while the second translational segment is moving longitudinally along the first one. Both segments are driven by linear hydraulic actuators. At the robot end-effector the orientational mechanism is mounted assuring horizontal seat orientation in any robot position. Constant seat orientation is maintained by a passive hydraulic bilateral mechanism.

The standing-up robot mechanism is driven by an electrohydraulic servosystem presented in *Figure 5*. The system is powered by a hydraulic pump providing the pressure of 50 bars and the hydraulic current of 1 *l/s*. The pump performances allow the maximal speed of the robot end-effector up to 2 *m/s*. Two Moog D641-3 servovalves with incorporated electronics are used to control the pressure difference applied to the linear hydraulic cylinders driving both links. The robot device operates in the position control mode of operation. In this mode, the control objective is to guide the robot end-effector along the desired path specified via TCP/IP connection in terms of velocity and/or acceleration at each point.

Control system of the robotic device is implemented in two levels (see upper part of Fig. 5). At the lower level, the hydraulic servosystem is controlled by a target computer built upon a 1 GHz PC Pentium III platform. On the platform, the xPC Target real time operating system is running at a constant sampling rate of 1 KHz. Two PCI interface boards are used in this controller to interface the external hardware. The PCI-DDA08 board (Measurement Computing, Inc., Middleboro, USA) acquires the analog force and pressure signals, and reads the joint positions via digital inputs. The joint positions are assessed by the help of rotational incremental encoders interfaced via HCTL 2016 integrated circuits (Motorola, Inc., Anaheim, USA). Another Measuring Computing board type D/A PCI-DAS1002 is employed to drive the hydraulic servovalves applying the output voltage in a range of ±10 *V*. At the higher level, an additional computer is used as a host platform for robot system programming, supervision, data logging and control. The environment is based on Mathwork-

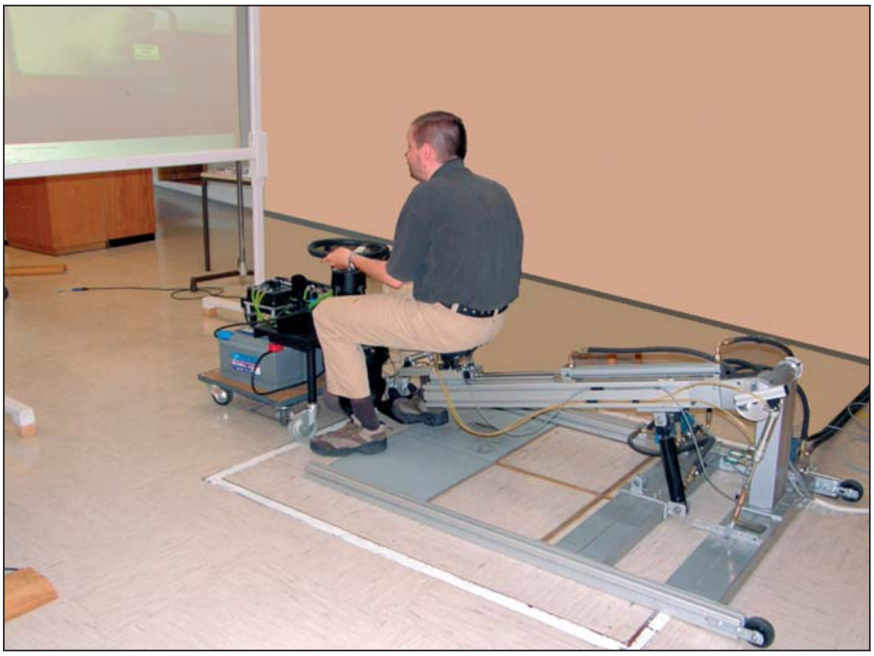

Figure 7. *Experimental evaluation of robot environment for combat vehicle driving simulation*

sMatlab software with Simulink, Stateflow and xPC Target toolboxes. The configuration allows the development of control algorithms in graphical mode by building and connecting functional blocks what provides user friendly graphical software development environment, optimal tuning of parameters, and easy acquisition and logging of signals.

2.4 Force Feedback Steering

For the implementation of force feedback steering an Iskra AML 7103 induction motor is directly coupled to the steering wheel (see *Figure 6*). This direct drive configuration can produce up to 38 *Nm* of zero backlash torque. Consequently, high resolution torque generation enables a realistic driving sensation. The AC motor has an incremental sensor bearing incorporated with resolution of 192 pulses per revolution. The sensor is used for acquisition of steering wheel angle. The AC motor is controlled by Iskra AES1134 controller that is rated at 24 *V* and has a maximal output current capability of 400 *A*. In the controller, a DSP processor performs indirect field oriented torque control at 10 *KHz*.

Fast CAN interface is implemented for communication between motor controller and superior xPC Target controller. The application uses master-slave principle of communication where the target computer behaves as a master device and the AC motor behaves as a slave device on the bus. CAN messages, that can be up to 8 bytes of data long, are transferred with maximum speed of 1 *Mbit/s* allowing that the xPC Target operating system to be running at a sampling rate of 1 *KHz*. Via the CAN bus the reference torque value is transferred to the AC motor controller, while the value of steering wheel angle is transferred in opposite direction.

3 Experimental evaluation

In the experimental evaluation of the robot environment for combat vehicle driving simulation the experimental setup presented in *Figure 7* was tested. The driving scenario incorporated the maneuvering of combat vehicle over an off-road terrain. The driver maneuvered the vehicle by the steering wheel system, while the vehicle motion dynamics and its interaction with the environment were calculated on-line by the i3Drive software. Haptic information about the vehicle vertical motion and wheels aligning torque were delivered to the driver by the help of robot seat and force feedback steering system. A back projection screen was used for providing visual feedback about the vehicle environment in 3D space.

In *Figure 8* a vertical position of the vehicle chassis is presented as an input to the driver seat subsystem. From the input, the vertical seat

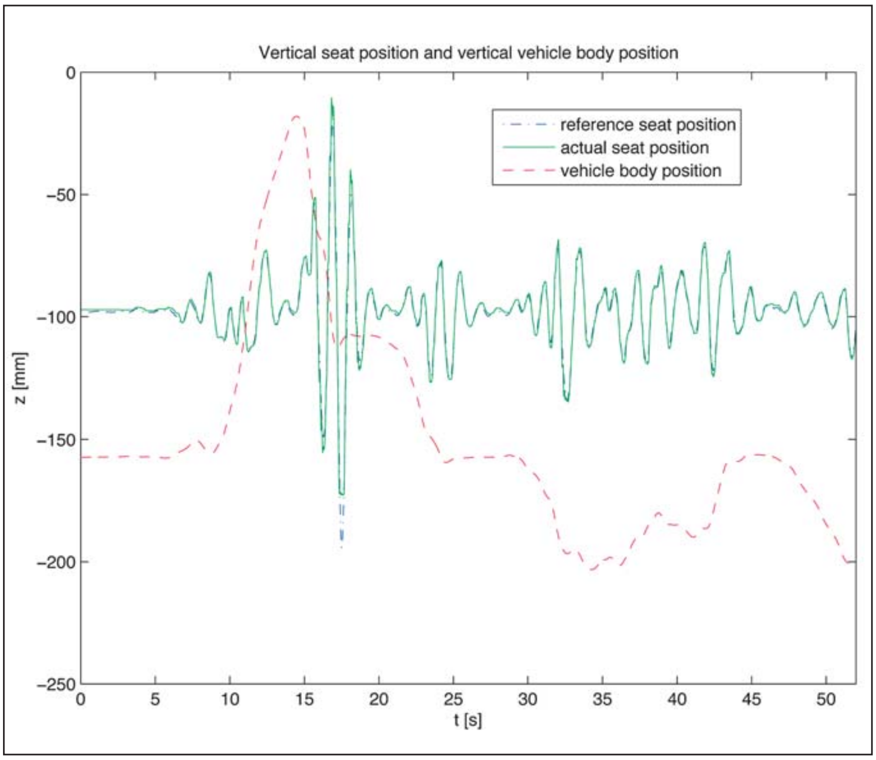

Figure 8. *Driver seat vertical motion*

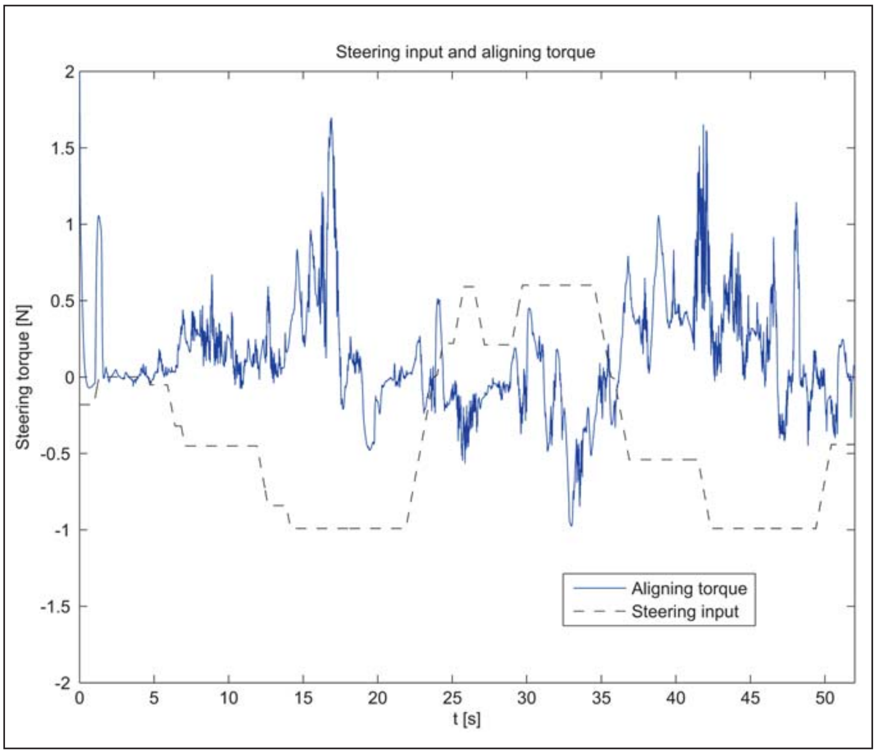

Figure 9. *Force feedback steering*

position was calculated (see dash-dotted line) and delivered to the robot controller. As shown by the graph, the robot controller provided accurate tracking of the reference signal.

Figure 9 presents the steering input to the vehicle model that was acquired by the steering wheel angle sensor during simulated driving. The wheel interaction with the terrain during cornering was calculated as a wheel aligning torque. The aligning torque (presented in graph by a solid line) was delivered to the steering wheel torque controller as the torque reference.

4 Conclusions

This paper describes the design and evaluation of the robot environment intended for driving simulation of combat vehicle. The simulation environment is based on the detailed simulation model of combat vehicle dynamics, the graphics display, the robot seat and the force feedback steering system.

Driving simulation in military applications provides a safe virtual environment in which driving behavior experiments can be conducted that are impossible to undertake in real environments because of potential risks to subjects or vehicles. Driving simulation is also important for virtual prototyping of new vehicle designs that, for example, arises from changes in vehicle configuration and driver training in such situations.

The developed simulator serves as a prototype testbed for the study of simulation capabilities and the possibilities of software and hardware modules integration. Based on the presented results, a high-fidelity combat vehicle simulator is planned to be developed.

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Robotsko okolje za simulacijo vožnje bojnega vozila

Razširjeni povzetek

Simulator vožnje je sistem za simulacijo upravljanja realnega vozila v varnem in kontroliranem okolju. Namen simulatorja je, da vozniku ustvari občutek upravljanja z realnim vozilom v realnih voznih razmerah. To je izvedeno s pomočjo določitve gibanja vozila na osnovi upravljalnih komand ter posredovanjem ustreznih vizualnih, slušnih in taktilnih zaznav vozniku. Simulatorji igrajo pomembno vlogo pri razvoju vozil in študiju akcij voznika. Uporabni so za vadbo vožnje v normalnih in kritičnih razmerah, analizo odzivov voznika ali evalvacijo uporabniških lastnosti v različnih razmerah. Posebno vlogo imajo simulatorji vožnje bojnih vozil, saj omogočajo preverjanje vozila in voznika na navideznem preizkusnem bojnem poligonu.

V prispevku je predstavljen prototipni simulator vožnje šestkolesnega bojnega vozila, ki je bil razvit v okviru izvedljivostne študije, katere namen je bil preveriti možnosti integracije posameznih podsklopov simulatorja. Razviti simulator vožnje bojnega vozila je sestavljen iz simulacijskega modula z dinamičnim modelom vozila, grafičnega modula, robotskega sedeža in haptičnega volana. Konfiguracija simulatorja vožnje bojnega vozila je predstavljena na *sliki 1*. Na simulacijskem modulu v realnem času poteka izračun gibanja bojnega vozila na osnovi podrobnega dinamičnega modela vozila in njegove interakcije z okoljem. Model vozila je načrtan kot togo telo karoserije, na katerega je preko vzmetenja vpetih šest koles (*slika 2*). V modelu vozila so implementirani pogonski in zavorni momenti, preverjanje zdrsa in preprečevanje blokade koles. Interakcija vozila s terenom je določena s pomočjo modela terena, ki ga sestavlja mreža trikotnikov, ter modela in detekcije kolizije med kolesi in terenom. Simulacijski modul je zasnovan v obliki programske aplikacije i3Drive. Na *sliki 3* je prikazana konfiguracija programske aplikacije, na *sliki 4* pa grafični prikaz vozila in okolja v trirazsežnem prostoru, ki je uporabljen za prikaz na projekcijsko platno. Robotski hidravlični mehanizem s tremi prostostnimi stopnjami gibanja, predstavljen na *sliki 5,* zagotavlja gibanje sedeža, ki je identično gibanju sedeža v vozilu med vožnjo. S slike je razvidno, da vse robotske segmente poganjajo hidravlični valji, vodeni preko elektrohidravličnih servoventilov. Regulacija aktivnih sklepov je izvedena z robotskim krmilnikom, ki je zgrajen na osnovi operacijskega sistema, namenjenega delovanju v realnem času xPC Target. Volan, ki predstavlja vmesnik za upravljanje z modelom vozila, je voden glede na izravnalni moment upravljalnih koles. Na ta način je vozniku posredovana haptična informacija o momentih na volanu, ki delujejo pri upravljanju realnega vozila. Volan je direktno gnan s pomočjo indukcijskega motorja, vodenega z direktno regulacijo momenta preko vektorske regulacije magnetnega polja. Konfiguracija sistema haptičnega volana je predstavljena na *sliki 6*. Simulator vozila, robotski krmilnik in krmilnik motorja medsebojno komunicirajo preko povezave Ethernet z izmenjavo paketov UDP.

Simulator vožnje bojnega vozila je bil preizkušen v laboratorijskem okolju pri vožnji po brezpotju. Testni voznik je upravljal s simulatorjem preko volana, pri čemer mu je bila vizualna informacija posredovana na projekcijskem platnu, taktilna pa preko haptičnega volana in robotskega sedeža (*slika 7*). *Slika 8* predstavlja gibanje karoserije in rezultirajoče gibanje sedeža pri eksperimentu. *Slika 9* predstavlja kot vrtenja volana in rezultirajoči izravnalni moment.

Predstavljeni simulator vožnje bojnega vozila je zasnovan kot prototipni sistem za preverjanje karakteristik simulacijskega modela in možnosti integracije posameznih modulov strojne in programske opreme za delovanje v realnem času. Na osnovi predstavljenih rezultatov in opažanj testnega voznika pri eksperimentu je možno zaključiti, da je razvita programska oprema ustrezna in da je realizacija simulatorja bojnega vozila s kompleksnejšo strojno opremo izvedljiva.

Ključne besede: simulator vožnje, dinamika bojnega vozila, robotski sedež, haptična informacija,

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