REM 2006
Research and Education in Mechatronics
KTH, Stockholm, Sweden
June 15-16, 2006

A research threewheeler vehicle with processor controlled tilting and steering mechanism

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***Abstract* - Subject of the paper is the development of a research vehicle providing processor controlled tilting and single wheel steering. The design of the vehicle chassis and the mechanical tilting and steering mechanism is done in 3D-CAD on the occasion of a diploma thesis at the IKA of the RWTH Aachen. The body of the frame construction could be accomplished exclusively by CNC bent tubes, laser cut sheets and few CNC milled parts as tig welding was used. The 125ccm motor of an Aprillia scooter is integrated in the frame to drive the vehicle.**

At Bochum University of Applied Sciences the actuators and control algorithms for tilting and single wheel steering are designed. A Mercedes servo hydraulic recirculating ball steering driven by a DC servomotor provides controlled tilting while cornering the vehicle. The power-pack designed for the A-class supports the actuator with hydraulic power. Synchronised by the Ackermann condition each front wheel is steered separately by linear piston EC-motor drives.

An 80486 subminiatur controller system with modular periphery called X-MAX-1 made by SORCUS is used to control the vehicle. Six analog and counter input signals as well as four analog output signals are treated within 1 msec sampling time. The programming is done by defining the control structure in the block oriented simulation environment WINFACT followed by automated C++ code generation and compilation for the osx multi tasking operating system.

The tilting threewheeler prototype gives the authors the opportunity to carry out special research work with algorithms which combine tilting methods with steering motion. Keywords: auto code generation, 3D-CAD design, tilting threewheeler, separate front wheel steering.

I. INTRODUCTION

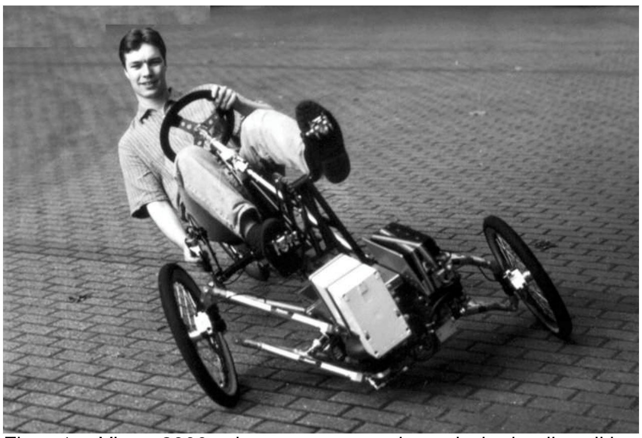


Fig. 1. Virage2000, human powered and hydraulic tilting, UaSB in 1999

At Bochum University of Applied Sciences (UaSB) several research vehicles have been developed in order to give the students of the mechatronic course the opportunity to study modern engineering development and to carry out research work in the automotive field. The basic idea of this project is the development of fast, nimble vehicles on three wheels, increasing the comfort by an active tilting mechanism while cornering and on the other hand the safety at curve excursions as well. The tricycles VIRAGE2000 and VIRAGETTE have been developed in 1999 until 2002 [Poh2002].

Since a couple of years the construction activities of muscle- and motor driven threewheelers have gained importance worldwide due to different undercarriage shaping (see [Casto]). Examples cover this trend in the area of motorized prototypes, e.g. the Mercedes-Benz F300 LifeJet [DC1997, Köh1999] and the Carver from van den Brink [Bri1999] similar to the BMW Clever; in the area of human powered prototypes the German Tripendo [Tripendo].

All concepts are driven by the desire to improve the driving delight and agility, as well as economic transportation.

Fig. 2. Mercedes-Benz F300 Lifejet, BMW Clever, Tripendo

II. CONCEPT OF THE RESEARCH THREEWHEELER OF THE UASB

After the experience with threewheeler design at Thorax Fahrzeugentwicklung GmbH [THO2005] and UaSB the partners considered to build a motorized vehicle with the requirements according to Tab.1.

Threewheeler
2FW (steered), 1BW (driven)
1 driver
Hydraulic tilting actuator
Steer by wire
Tilting angle up to +/- 45°
Left and right frontwheel separately steered

Tab.1 Design requirements of the research threewheeler Moragette

The working title is Moragette. The design of the vehicle chassis and the mechanical tilting and steering mechanism was done in 3D-CAD on the occasion of a diploma thesis [Con2005]. UaSB designed the actuators and control algorithms for tilting, the steering wheel simulator and single wheel steering [Oha2004] in order to realize steer by wire.

a) Packaging of Moragette

The vehicle frame is very compact with 1m wheel base and 2m axle base. The collateral frame is designed to allow up to 45° tilting angle. In the front center the tilting mechanism is placed, on both sides beneath the driver legs are the steering actuators. The 125ccm motor of an Aprillia scooter is integrated in the rear frame to drive the vehicle. 12V batteries in the rear provide the electrical energy for controller, servo units and hydraulic pumps.

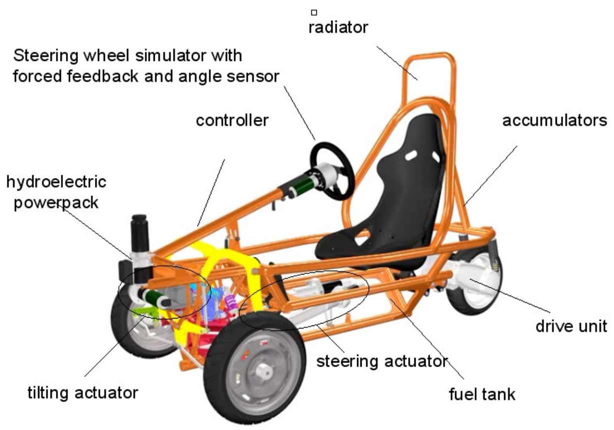


Fig. 3. Packaging of MORAGETTE

b) The tilting mechanism

The necessary energy to hold the vehicle in every tilting position is provided by a hydraulic unit. The designer chose a hydraulic power steering which is very simple to apply. The hydroelectric power pack launched with the Mercedes-Benz A-class provides the hydropower. While usually the power steering is moved by the drivers arms, in this case a DC Maxon servomotor with planetary gear and chain drive rotates the input shaft. By this way a tilt by wire functionality is achieved.

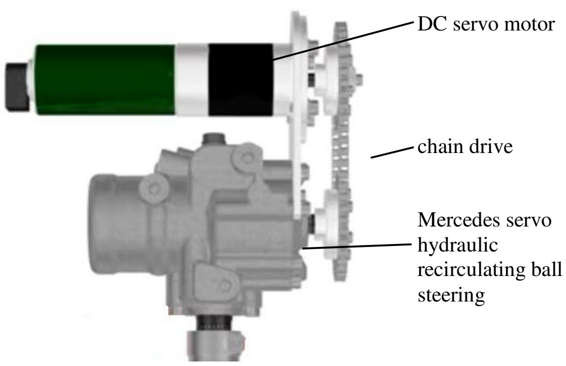


Fig. 4. DC-servomotor with hydraulic power steering combined to the electro hydraulic tilting unit

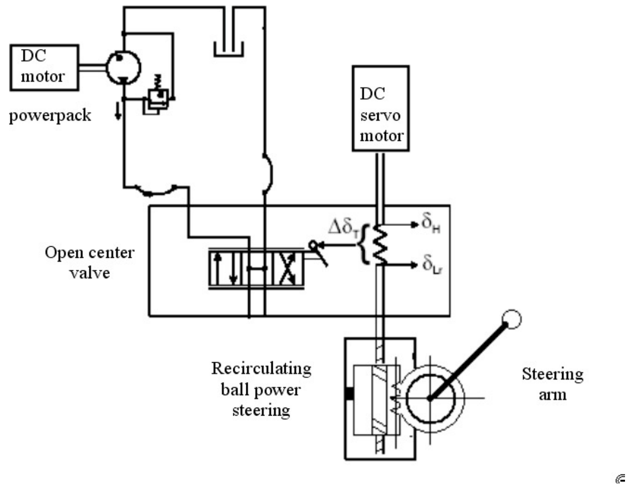


Fig. 5. Hydraulic scheme of tilting mechanism

The scheme Fig. 5 shows the hydraulic supply by the power pack, the open center valve, the DC servomotor driving the input and the rotary gear with the steering arm, which provides the tilting force.

c) The single wheel steering mechanism

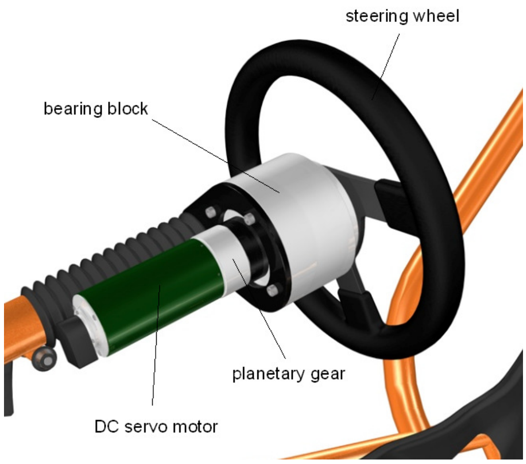


Fig. 6. Steering wheel simulator unit

Another DC Maxon servomotor provides the processor controlled steering forces to give the driver a realistic feeling while moving the steering wheel. The steering wheel itself is mounted in a strong bearing block. The steering demand value is measured by the motor integrated angle sensor. In the first step the forces to turn the wheel back to neutral position are simply proportional to the rotary angle. The steering feeling is quite sufficient with this method. Later it is considered to add the measured set value of the two steering actuators to give real force-feedback.
The measured steering-wheel angle gives the set value for the angle of the two front wheels. The design of the steering actuators is shown in Fig. 7.

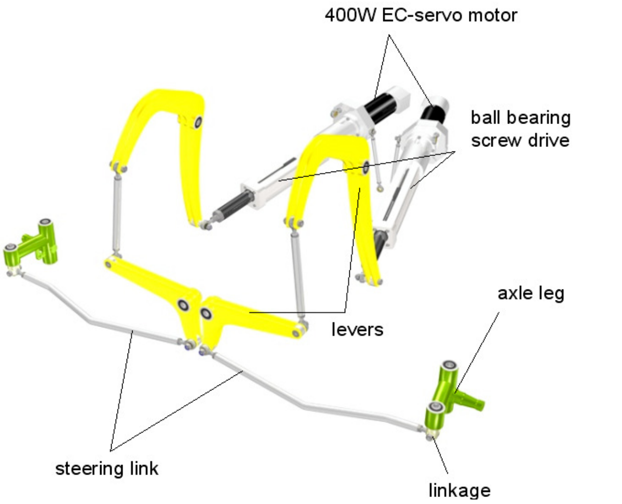
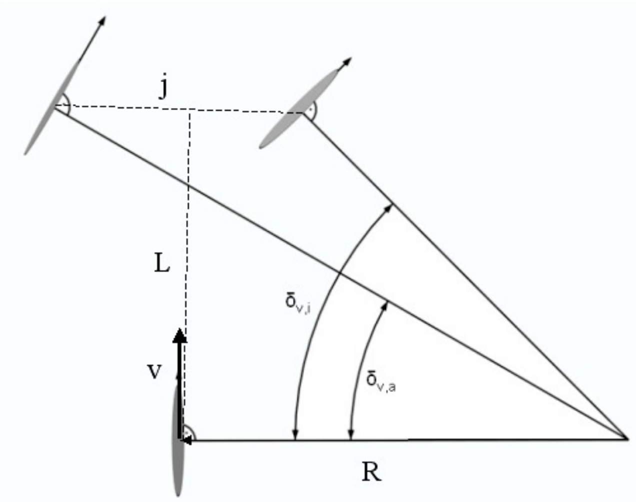


Fig. 7. Wheel steering mechanism with levers and steering links

Each front wheel is driven by a 400W EC Maxon servomotor mounted on a screw drive. The linear movement is transformed by two levers and the steering links down to the axle legs. The steering angle is measured parallel to the levers.

III. STEERING AND TILTING KINEMATICS

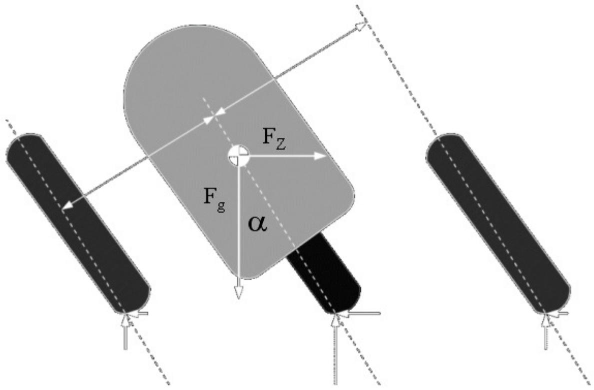
The Ackermann vehicle model reflects the power free case of the curve excursion. The inner steering angle δ_i is calculated from the driver´s demand angle, which is set to the outer wheel angle δ_a (see equation (1) in Fig. 8). Equation (2) was derived to obtain better results in integer arithmetic.



$$\delta_i = \arctan\left(\frac{1}{\frac{1}{\tan\delta_a} - \frac{j}{L}}\right) \ (1) ; \delta_i = \delta_a + 0.01\delta_a^2 \ \ (2)$$

Fig. 8. Ackermann condition for front wheel steering

The tilting algorithm was derived using the following simple model: from the parallelogram of the centrifugal force F_Z and gravity F_g the desired tilting angle α is calculated by the equation 7, which is optimized for 16 bit integer calculation and based on equation 3 to 6.



$$R = \frac{L}{\tan\delta_a} (3) ; F_Z = \frac{mv^2}{R} (4) ; \ F_g = mg \ (5)$$

$$=> \tan\alpha = \frac{v^2}{R * g} \ \ (6) \ \alpha = \frac{\delta_a v^2}{20} \ (7)$$

Fig. 9. Simple vehicle model and calculation formalisms

By the aid of the hydraulic cylinder the vehicle is tilted. An angle sensor gives the control variable to the micro controller system, which calculates the set value for the DC motor mounted to the power steering. The lever driven by the output shaft sinks one front wheel and moves up the other front wheel.

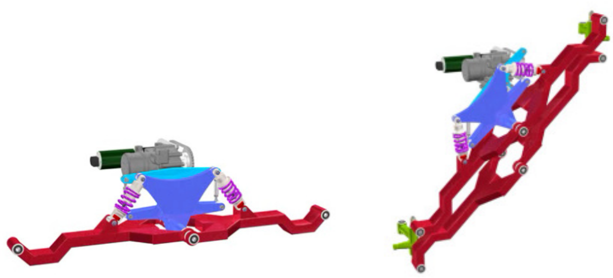


Fig. 10. Tilting unit in the front section

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IV. THE CONTROLLER CONCEPT

Fig. 11. Sorcus DIP5 subminiatur processor system

To calculate four control loops and the steering/tilting angle demand value the SORCUS X-MAX system with a 100Mhz 80486 CPU was chosen. SORCUS provides the osx multitasking operating system. It calculates the main task within 1ms sampling time in integer formalism. Modules for analog signal in-/output 12bit wide and linear encoder interfaces are available, which are necessary for the installed motor encoder measurement systems [Sorcus].

V. AUTOCODE GENERATION

The program code is developed by means of automated ANSI-C-Code generation using the block oriented simulation language WINFACT/BORIS [Kah2004].

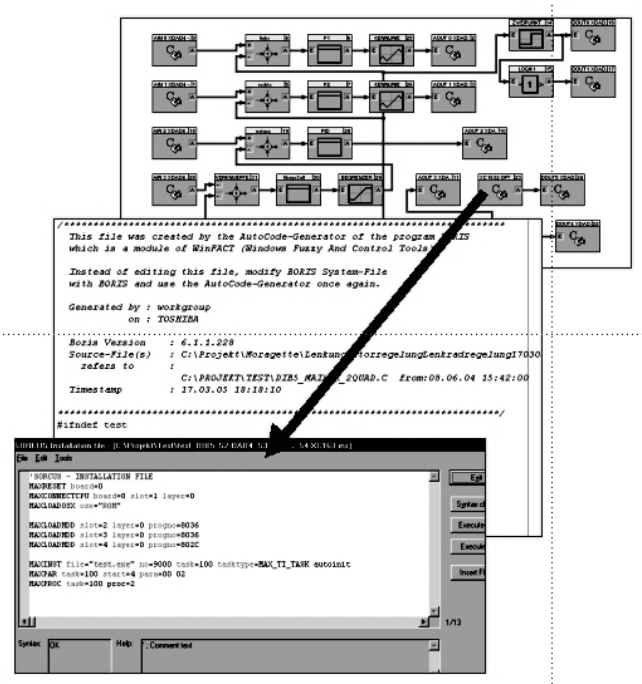

Fig. 12. Top down process of micro controller programming with auto code generation of ANSI C++

First of all the software had to be adjusted to the operating system and the hardware interfaces of the SORCUS X-MAX System.

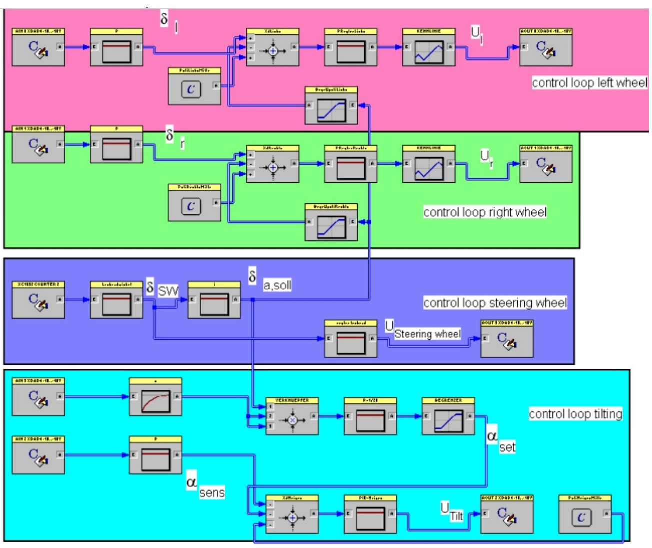

Fig. 13. Structure of control loops in WINFACT6

Subsequently the structures of the four control loops were designed using either normal WINFACT functions and either controller interface functions.

Because of the consequent top down programming method a very quick and easy application development process could be obtained (Fig. 12).
The graphical structure in Fig. 13 shows the two feedback loops for the front wheel steering, the calculation of the demanded steering angle and the force feedback for the steering wheel and the feedback loop for tilting.

VI. FIRST DRIVING EXPERIENCES

The tests with tilting algorithms are at the beginning. At first a direct tilt control method is tested (Fig.14).

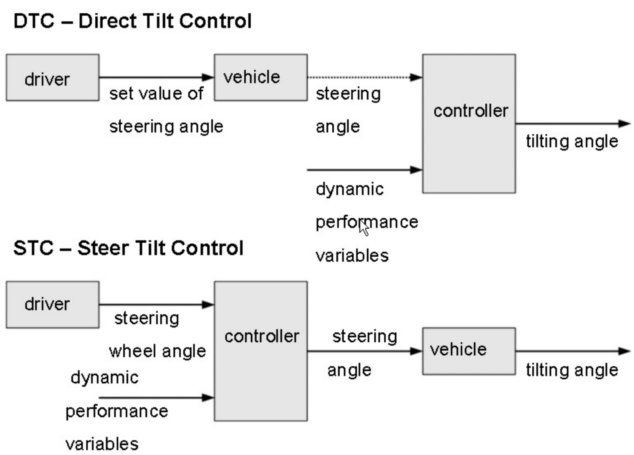

Fig. 14. Tilting strategies

During the first practical tests problems with the vehicle upright position occurred. While driving forward the upright position oscillated without noticeable activities of the tilting actuator. The reason was detected in the interaction between the tilting actuator and the spring strut units, which later were omitted to optimize the tilting stability. It is considered to implement a steer tilt control method by modulating the steering angle while cornering in order to begin the tilting process. [Kar1992].

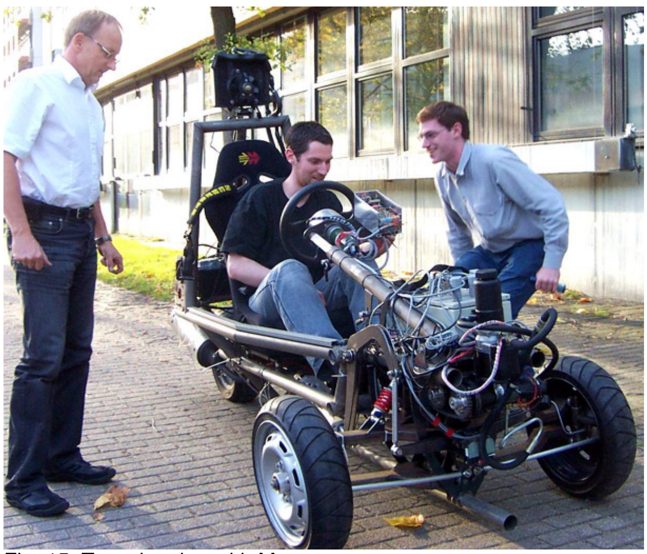

Fig. 15. Test situation with Moragette

Fig. 16. Tilting Moragette

The steer by wire equipment of the Moragette provides all possibilities to implement those new functionality for research (Fig. 15,16).

VII. ACKNOWLEDGMENT

This work was partly supported by the research founding of the Ministry of School, Science and Research of Northrhine-Westfalia and Bochum University of Applied Sciences.

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