University of Stuttgart
Germany
Institute of Engineering Geodesy

Automatic Lateral Control of a Model Dozer

Alexander Beetz, <u>Volker Schwieger</u>
Institute of Engineering Geodesy
University of Stuttgart

FIG Regional Conference

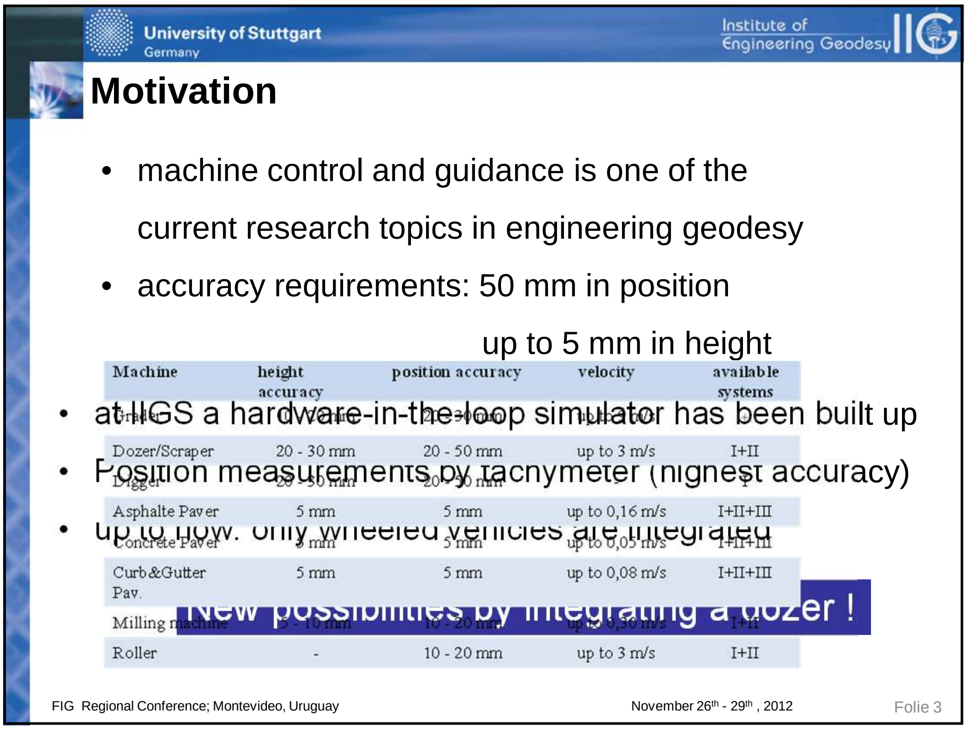
Montevideo, Uruguay, 26 – 29 November, 2012

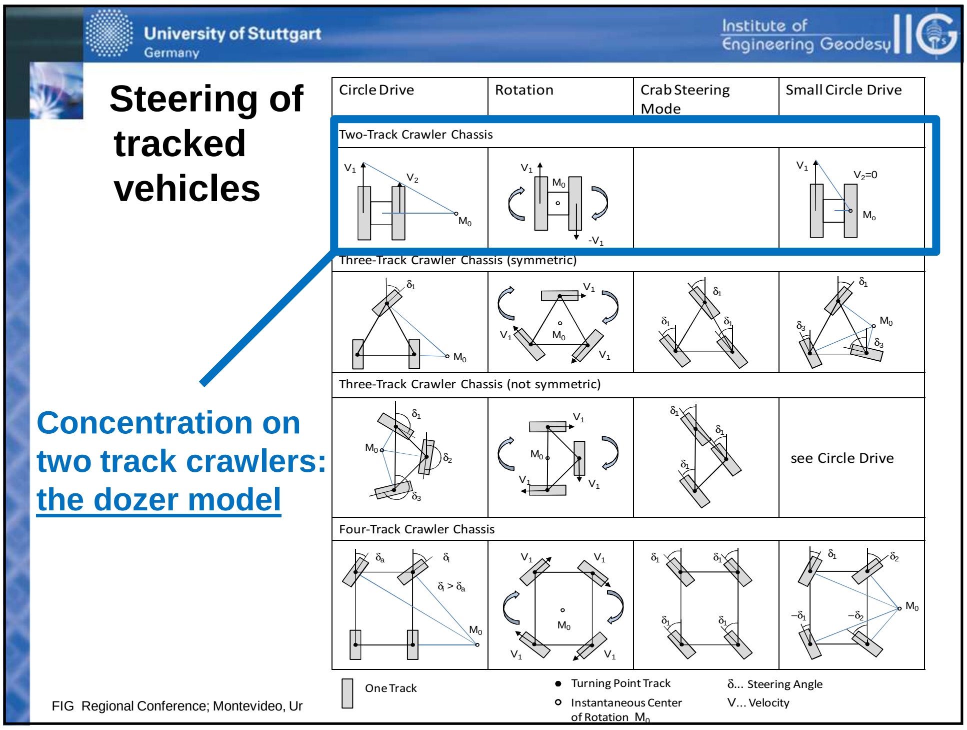
University of Stuttgart
Germany
Institute of Engineering Geodesy

Structure

- Motivation
- The dozer model
- Integration of dozer model into simulator
- Calibration of steering
- Results
- Conclusion

FIG Regional Conference; Montevideo, Uruguay November 26th - 29th, 2012 Folie 2


University of Stuttgart
Germany
Institute of Engineering Geodesy
Motivation
• machine control and guidance is one of the current research topics in engineering geodesy
• accuracy requirements: 50 mm in position
up to 5 mm in height
Machine | height accuracy | position accuracy | velocity | available systems
• at IIGS a hardware-in-the-loop simulator has been built up
Dozer/Scraper | 20 - 30 mm | 20 - 50 mm | up to 3 m/s | I+II
• Position measurements by tachymeter (highest accuracy)
Asphalte Paver | 5 mm | 5 mm | up to 0,16 m/s | I+II+III
Curb&Gutter Pav. | 5 mm | 5 mm | up to 0,08 m/s | I+II+III
New possibilities by integrating a dozer !
Roller | - | 10 - 20 mm | up to 3 m/s | I+II
FIG Regional Conference; Montevideo, Uruguay
November 26th - 29th , 2012
Folie 3


University of Stuttgart
Germany
Institute of Engineering Geodesy
Steering of tracked vehicles
Circle Drive
Rotation
Crab Steering Mode
Small Circle Drive
Two-Track Crawler Chassis
Three-Track Crawler Chassis (symmetric)
Three-Track Crawler Chassis (not symmetric)
see Circle Drive
Four-Track Crawler Chassis
One Track
Turning Point Track
Instantaneous Center of Rotation M_0
δ... Steering Angle
V... Velocity
Concentration on two track crawlers: the dozer model
FIG Regional Conference; Montevideo, Ur

The dozer model

without slippage

track velocities

$v_r = r \cdot \omega_r$ and $v_l = r \cdot \omega_l$

r – roller radius / ω - angular velocity

dozer velocity

$$v = \frac{v_l + v_r}{2}$$

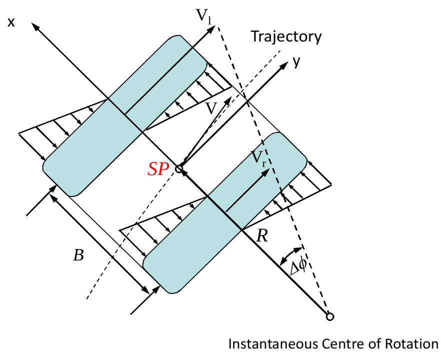
radius

$$R = \frac{B \cdot v}{v_r - v_l} = \frac{B \cdot (v_l + v_r)}{2 \cdot (v_r - v_l)}$$

B – distance between the two tracks

orientation change

$$\Delta\varphi = arctan\left(\frac{(v_l - v_r) \cdot \Delta t}{B}\right)$$



University of Stuttgart
Germany
Institute of Engineering Geodesy

The dozer model

with slippage

slip values

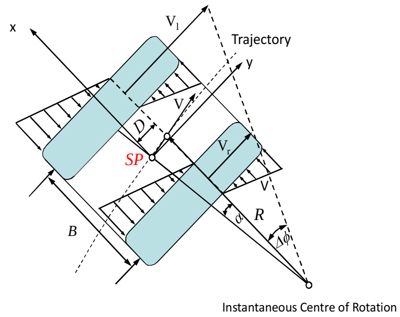
$i_l = \frac{v_l - v_l'}{v_l}$ and $i_r = \frac{v_r - v_r'}{v_r}$

v – actual velocity
v‘ – roller velocity

track velocities

$v_r = r \cdot \omega_r \cdot (1 - i_r)$ and
$v_l = r \cdot \omega_l (1 - i_l)$

Further computations
as in case without slippage.



Not considered for dozer model implementation !

University of Stuttgart
Germany

Institute of Engineering Geodesy

Integration of dozer model into simulator

Tachymeters:
Leica TS30 and **TCRP 1201**,
Trimble SPS930
Reflector: Leica GRZ 101

Computer and remote control

Dozer model 1:14

Trajectory length: 11 m
2 straight lines, 4 clothoids, 2 arc
Point distance: 0.1 m

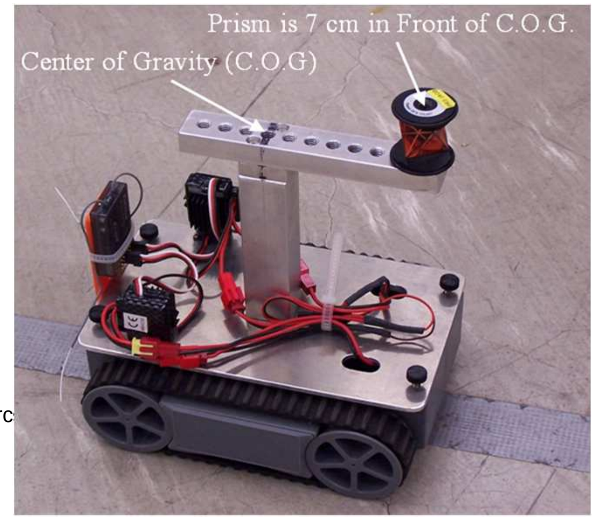
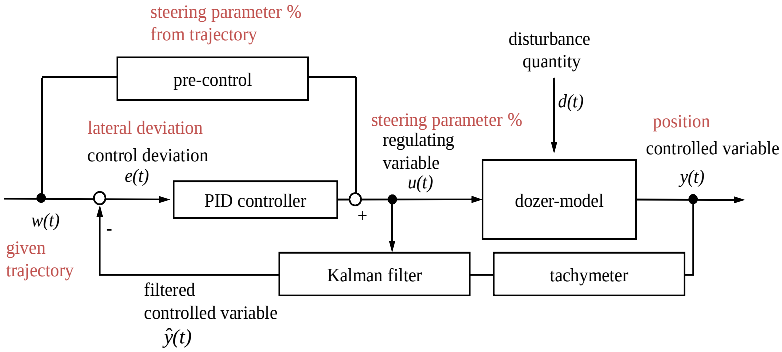


FIG Regional Conference; Montevideo, Uruguay   November 26th - 29th, 2012   Folie 7

University of Stuttgart
Germany

Institute of Engineering Geodesy

Integration of dozer model into simulator: Closed control loop



steering parameter:

$$p = \frac{v_r}{v_l} \cdot 100$$

FIG Regional Conference; Montevideo, Uruguay   November 26th - 29th, 2012   Folie 8

University of Stuttgart
Germany

Institute of Engineering Geodesy

Steering calibration

Velocity in dependence of *p*:

$$v = \frac{v_l + v_r}{2} = \frac{v_l \cdot (1+\frac{p}{100})}{2} \qquad v_l = \frac{2 \cdot v}{1+\frac{p}{100}} \text{ and } v_r = v_l \cdot \frac{p}{100}$$

Radius in dependence of *p*:

$$R = \frac{B \cdot v}{v_r - v_l} = \frac{B \cdot (1 + \frac{p}{100})}{2 \cdot (\frac{p}{100} - 1)}$$

- Calibration is relationship between *p* and curvature *1/R.*
- *p* is a ratio of two velocities.
- Velocities are proportional to voltages for given velocities.
- The velocities driven are 6 cm/s and 10 cm/s.

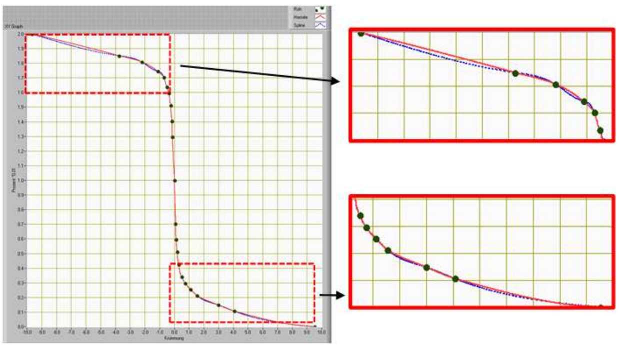
FIG Regional Conference; Montevideo, Uruguay November 26th - 29th , 2012 Folie 9

University of Stuttgart
Germany

Institute of Engineering Geodesy

Steering calibration

Non-linear calibration function



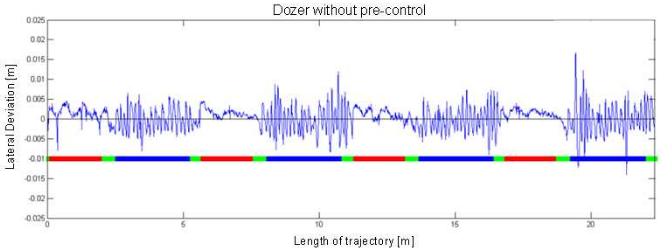
Hermite interpolation (red) and spline interpolation (blue)

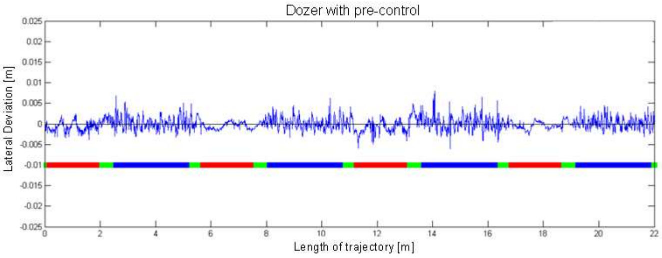
FIG Regional Conference; Montevideo, Uruguay November 26th - 29th , 2012 Folie 10

Results

4 laps, 1st eliminated

Pre-control = anticipated computation point of 7 cm





Results

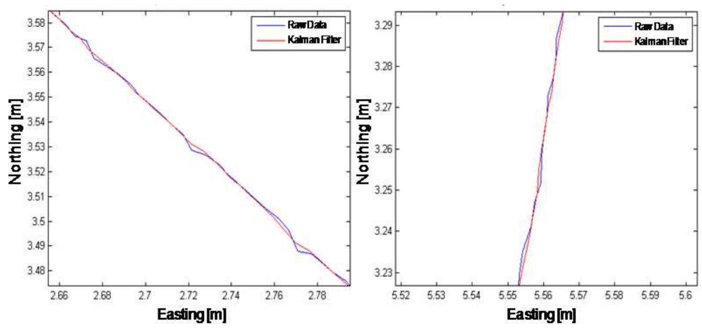
Dozer without pre-control	**[m]**			
	straight	clothoid	circle	total
Lap 2	0.002	0.003	0.003	**0.003**
Lap 3	0.002	0.003	0.004	**0.003**
All Laps	0.002	0.003	0.004	**0.003**

Dozer with pre-control	[m]			
	straight	clothoid	circle	total
Lap 2	0.001	0.001	0.002	**0.002**
Lap 3	0.001	0.003	0.002	**0.002**
Lap 4	0.001	0.002	0.002	**0.002**
All Laps	0.001	0.002	0.002	**0.002**

Pre-control improves solution by 1 mm / 50 % !

University of Stuttgart
Germany
Institute of Engineering Geodesy

Results



Kalman filter doesn‘t improve the RMS, but trajectories are smoother !

FIG Regional Conference; Montevideo, Uruguay November 26th - 29th , 2012 Folie 13

University of Stuttgart
Germany
Institute of Engineering Geodesy

Conclusion

Comparison to wheeled vehicles

	straight	clothoid	circle	total
Front Wheel Steering (Beetz & Schwieger 2010) PID-controller with pre-control	0.001	0.002	0.002	**0.002**
Dozer (Beetz 2012) PID- controller with pre-control	0.001	0.002	0.002	**0.002**
Rear Wheel Steering (Beetz 2012) Multi-value controller with disturbance transfer function	0.002	0.003	0.004	**0.003**

Control RMS comparable to wheeled vehicles !

FIG Regional Conference; Montevideo, Uruguay November 26th - 29th , 2012 Folie 14

University of Stuttgart
Germany

Institute of Engineering Geodesy

Thank you very much for your attention!

CONTACT:

Prof. Dr.-Ing. habil. Volker Schwieger,
Dr.-Ing. Alexander Beetz

Institute of Engineering Geodesy
University of Stuttgart
Geschwister-Scholl-Str. 24 D
70174 Stuttgart
Germany

Phone: ++49-711-685-84040 / -84042
Fax: ++49-711-685-84044
E-mail: volker.schwieger@ingeo.uni-stuttgart.de /
alexander.beetz@ingeo.uni-stuttgart.de

FIG Regional Conference; Montevideo, Uruguay November 26th - 29th, 2012 Folie 15