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Steering Method for Automatically Guided Tracked Vehicles

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Introduction

- Usage of automatically guided construction machines enables increased working efficiency
- Application fields: e.g. transportation, roadworks, earthworks,…
- 2 possible chassis designs:

Wheeled Chassis

e.g. Wheeled loader
(Kunze 2011)

Tracked Chassis

e.g. Tracked loader
(Kunze 2011)

Introduction

- **Advantages of tracked vehicles:**
  - advanced traction
  - low soil compaction
  - high manoeuvrability
- **Disadvantages of tracked vehicles:**
  - lower working velocities
  - reduced mobility
- **Propulsion methods for tracked vehicles:**
  - mechanically compounded drives
  - hydrostatic drives
  - electric drives

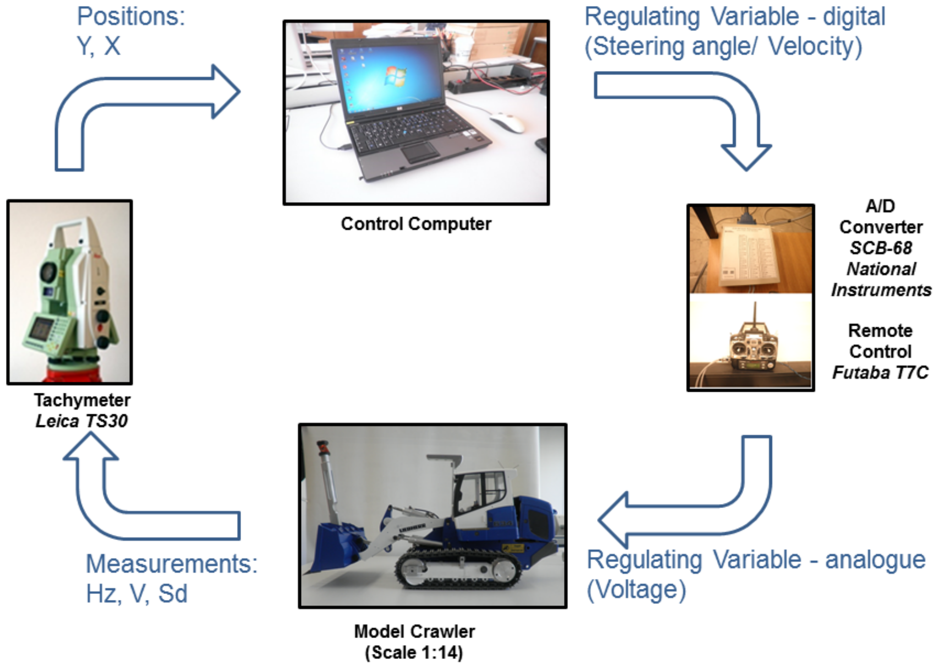
  } step-less drives/ infinitely variable drives

Construction Machine Simulator

- The purpose of the simulator is to test and evaluate different sensors, sensor combinations, as well as filter and control algorithms.
- Model vehicles, at scale 1:14, have the ability to automatically drive along a reference trajectory → realization by lateral control algorithm

Simulator Components

- Crawler model (scale 1:14)
- Control computer
- Tachymeter, as guidance sensor
- A/D converter
- Remote Control



Steering Method

Generally, steering method of a two-track crawler chassis is based on a skid-steer concept (Beetz 2012)**.**

<u>Disadvantage:</u> Overall speed declines, consequently working speed declines

Requirements on the pesented steering method:

- Overall speed must remain constant during curve drive
- Override protection for the drive power unit
- Easy calibration procedure

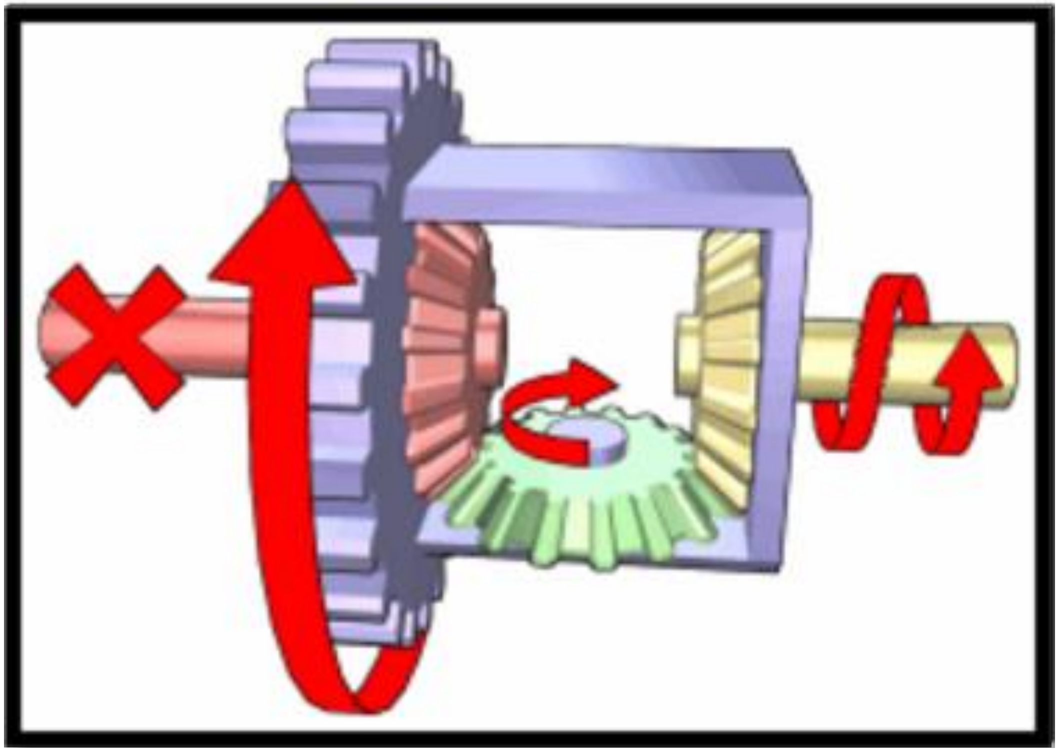
Vehicle Prerequisites:

- two stage, continous, electric drive (one actuator per track)
- step-less drive functionality

The IIGS model crawler at scale 1:14 fully meets the criteria of step-less drive functionality.

Steering Method

Role model: mechanical differential steering block of a motor vehicle, with compensating gear, as key part.



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Goal: Mathematic modelling of the compensating gear functionality

Steering Method

Starting point: Kinematic model for tracked vehicles according to Le (1999)

$\boldsymbol{R} = \frac{\boldsymbol{B}\cdot(\boldsymbol{v_l}+\boldsymbol{v_r})}{\boldsymbol{2}\cdot(\boldsymbol{v_l}+\boldsymbol{v_r})}$, R - curve radius, B - gauge, v_l, v_r - left and right track velocity ***(I)***

Solve ***(I)*** for v_l and v_r: $v_l = v_r \cdot \frac{(2R+B)}{(2R-B)}, v_r = v_l \cdot \frac{(2R-B)}{(2R+B)}$

Definition: $\frac{(2R+B)}{(2R-B)} = n, \rightarrow v_l = v_r \cdot n$ and $v_r = \left(\frac{v_l}{n}\right)$ ***(II)***

<u>straight drive:</u> $n = 1 \rightarrow v_l = v_r = v_{total}$

<u>curve drive:</u> $v_{total} = \frac{1}{2} \cdot (v_l + v_r) = \frac{v_r \cdot n}{2} + \frac{v_l}{2 \cdot n}$ ***(III)***

Solve ***(III)*** for v_l and v_r: $v_l = (v_{total} \cdot 2 \cdot n - v_r \cdot n^2), v_r = \left(\frac{v_{total} \cdot 2}{n} - \frac{v_l}{n^2}\right)$

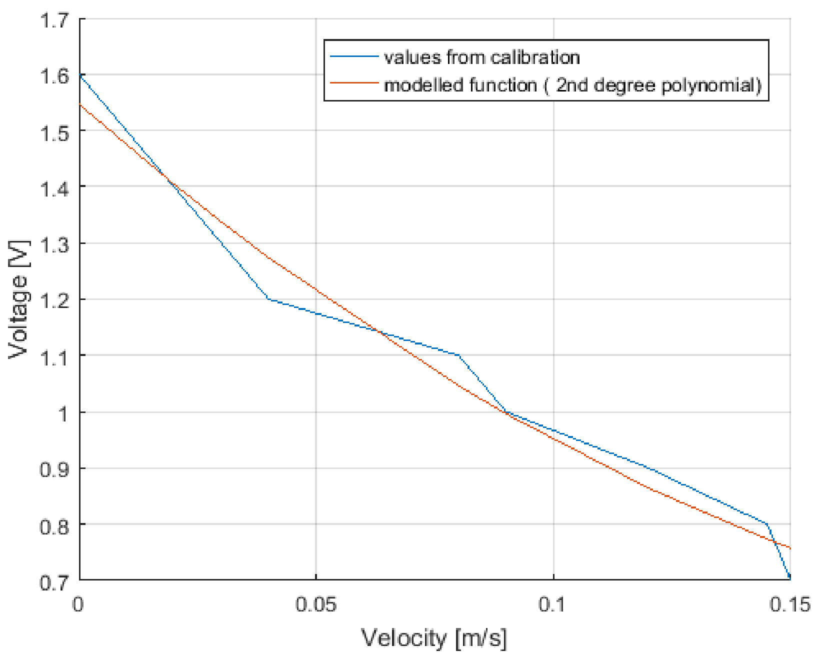
Substitution using ***(II):*** $v_l = v_{total} \cdot \boxed{\frac{2 \cdot n}{1+n}}, v_r = v_{total} \cdot \boxed{\frac{2}{1+n}}$

Steering parameter *n* is element of the scaling term for v_{total} in order to perform curve drives.

Steering Method

- Realisation of the continous electric drive: applying voltages to left and right actuator
- Characteristic: 1.6 V: full stop; 0.7 V: full forward
- Preferable: metric size for velocity, e.g. [m/s], [km/h],..

→ **Calibration**: Transfer function between voltage and velocity

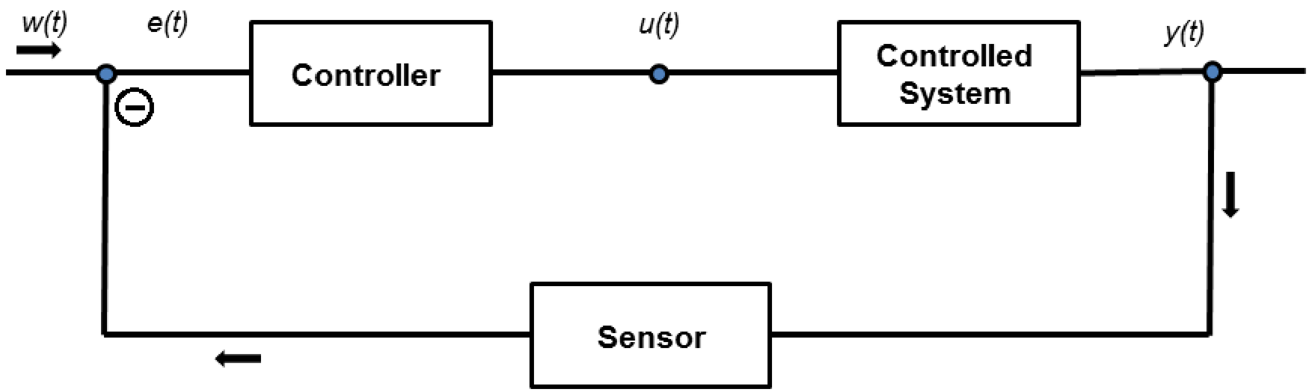


Resulting Transfer Function (forward drive)

$$U = 14.26 \cdot v^2 - 7.40 \cdot v + 1.55$$

U - applied voltages at actuators
v – velocity

Steering Method



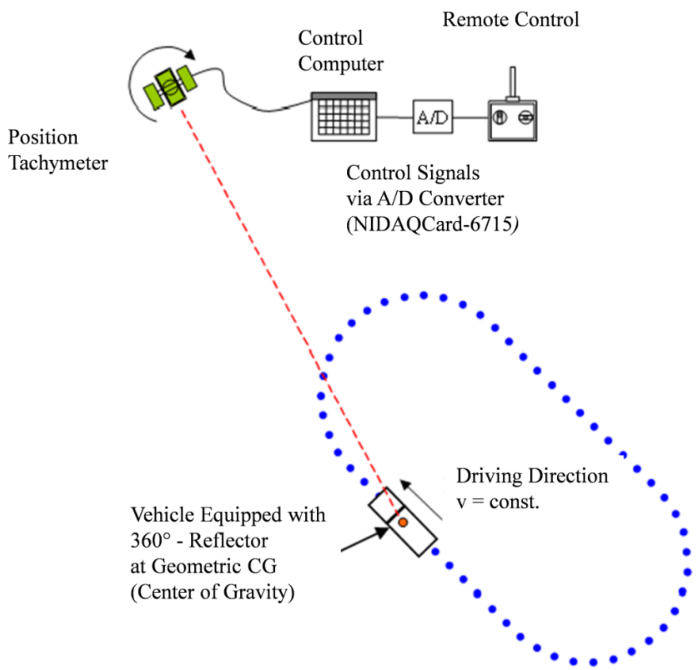
Controller: PID, with empirically determined parameters
Controlled System: Model Crawler (scale 1:14)
Sensor: Robotic Tachymeter Leica TS 30

Variable	Meaning within Closed-Loop	Appropriate Simulator Item
w(t)	reference variable	reference trajectory
e(t)	control deviation	lateral deviation between reference trajectory and actual position
u(t)	regulating variable	steering ratio, defined by steering parameter
y(t)	controlled variable	position

Evaluation Technique and Experimental Setup

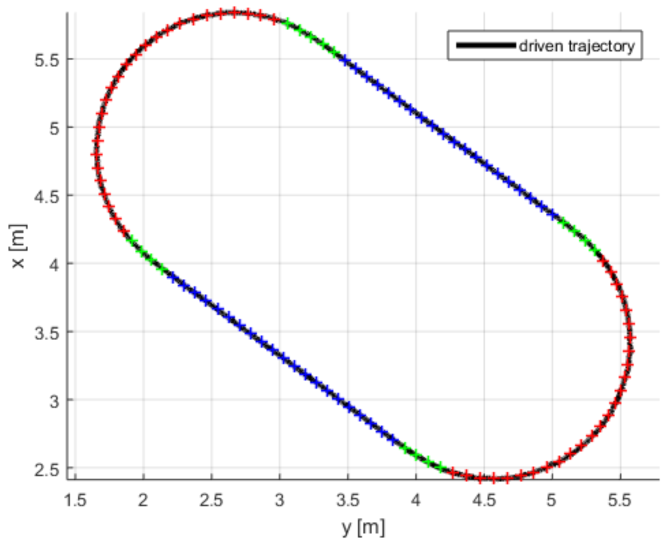
- Comparison between reference trajectory and measured trajectory
- 3 different trajectories: oval, eight and kidney which consisting of route design elements as straight lines, circle arcs and clothoids
- Analysis of the RMS of perpendicular distance/lateral deviation:

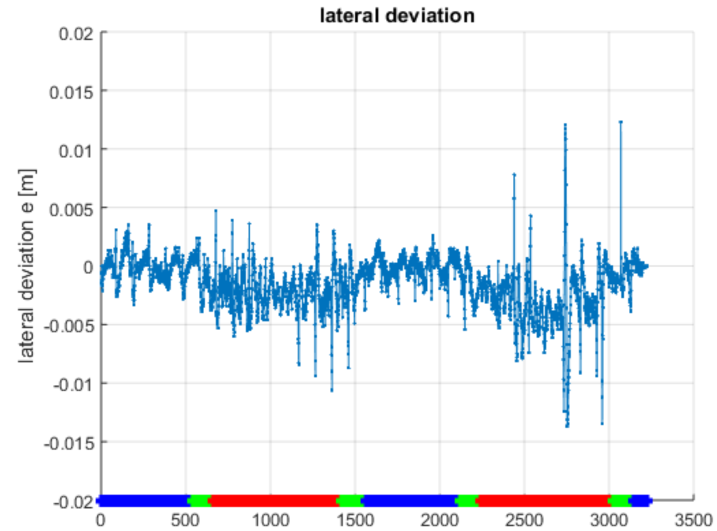
$$RMS = \sqrt{\frac{\sum_{i=1}^{n} {e_i}^2}{n}},\ e_i \text{ - lateral deviation, } n \text{- number of measurements}$$



Principle sketch of the simulator setup, (Beetz 2012).

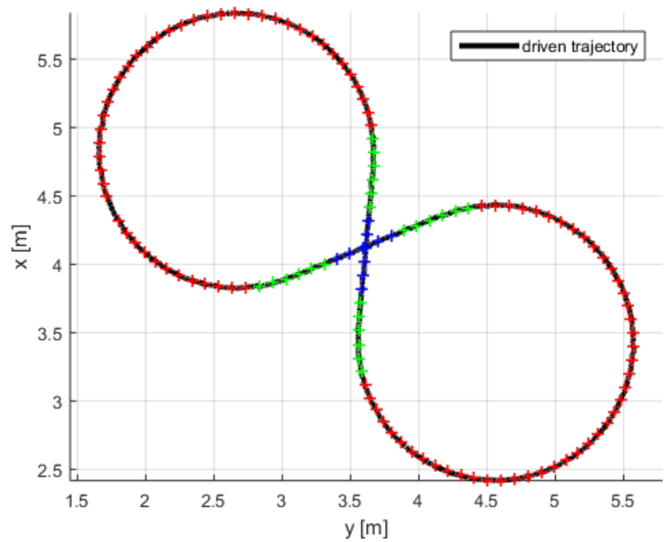
Results

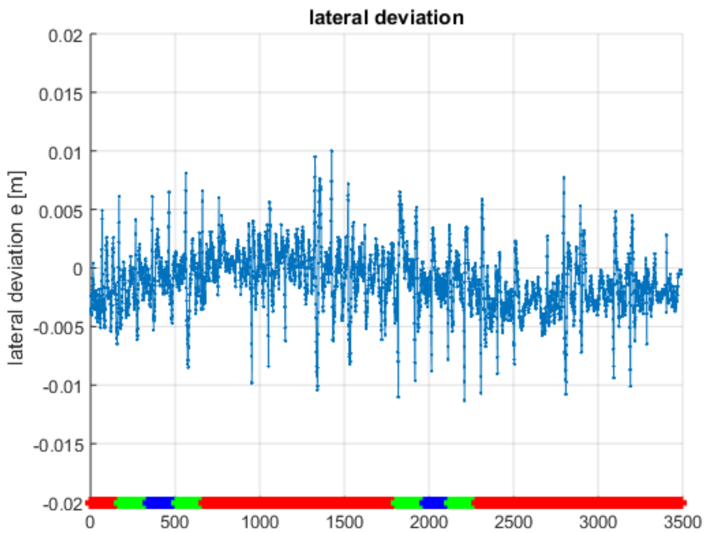




	Number	Individual RMS	Average RMS	Weighted Total RMS
Clothoid	1	0.0022 m	0.0021 m	**0.0027 m**
	2	0.0019 m		
	3	0.0021 m		
	4	0.0022 m		
Straight Line	1	0.0010 m	0.0009 m	
	2	0.0008 m		
Circle Arc	1	0.0040 m	0.0035 m	
	2	0.0029 m		

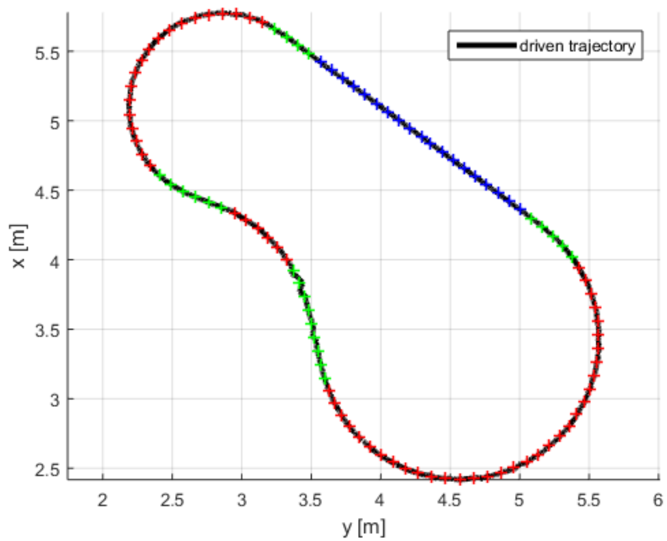
Results

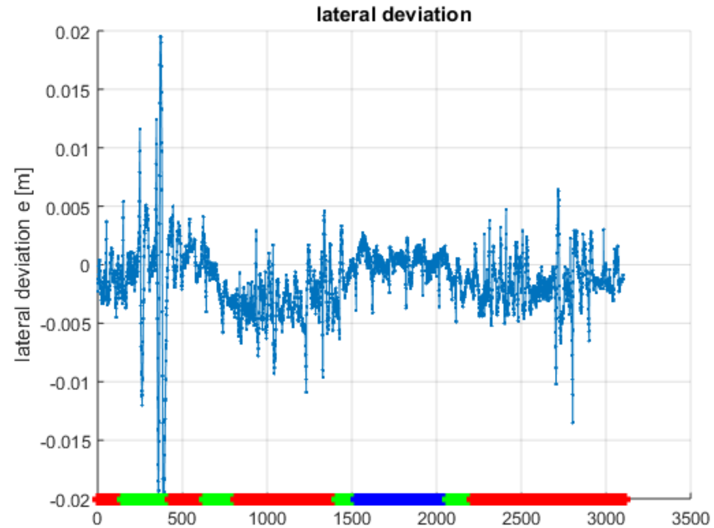




	Number	Individual RMS	Average RMS	Weighted Total RMS
Clothoid	1	0.0030 m	0.0027 m	**0.0027 m**
	2	0.0027 m		
	3	0.0024 m		
	4	0.0027 m		
Straight Line	1	0.0024 m	0.0023 m	
	2	0.0021 m		
Circle Arc	1	0.0032 m	0.0028 m	
	2	0.0024 m		

Results





	Number	Individual RMS	Average RMS	Weighted Total RMS
Clothoid	1	0.0093 m	0.0035 m (0.0023 m)	**0.0033 m (0.002 m)**
	2	0.0039 m		
	3	0.0018 m		
	4	0.0011 m		
	5	0.0029 m		
	6	0.0019 m		
Straight Line	1	0.0011 m	0.0011 m	
Circle Arc	1	0.0023 m	0.0026 m	
	2	0.0017 m		
	3	0.0038 m		

Conclusion and Outlook

- Alternative steering method has been introduced
- Method fully meets the set requirements of constant curve drive, override protection and simple calibration procedure
- RMS for guidance quality of **2.9 mm**, respectively **2.5 mm** by consideration of the outlier, could be achieved by the presented method
- Results can be regarded as satisfactory;
  e.g. position accuracy requirements for tracked pavers and curb and gutter applications according to Stempfhuber & Ingesand (2008): **5 mm**

<u>In the future:</u>

- Extension of mathematical model by slippage
- Investigation on backward movement and spot turns
- Longtidual control/ speed control
- Control of hight and attitude of the tool

Thank you for your Attention!