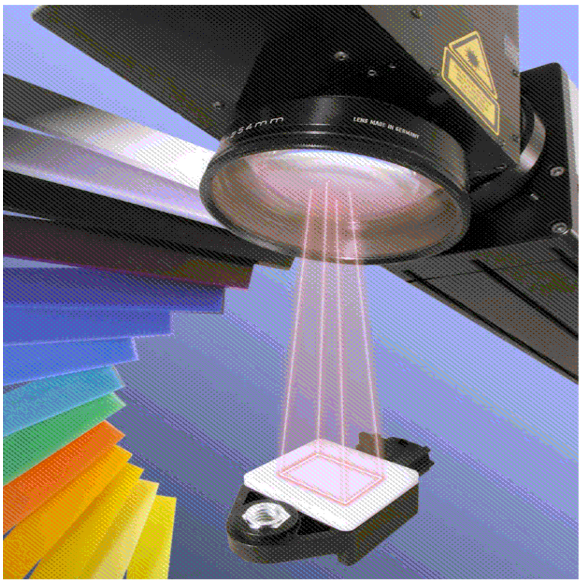
Result-Adaptive PID Control improves Laserscanner Positioning

Authors: M. Lugmair, R. Froriep, F. Kuplent, L.Langhans

Abstract :Laserscanners are used for steering laserbeams, for example in lasermarking machines. The beam steering must be as fast and precise as possible. Time constants are in the order of milliseconds. PID controls, tuned for maximum speed, often do not achieve the required accuracy, while the tradeoff for highest accuracy is lower speed. This conflict can be resolved by making the control parameters suitable functions of the error signal. This method is patented [1] . Its feasibility has been demonstrated experimentally.



Scanning head of a laser marker from Baasel Lasertech

There are many methods to adjust control parameters depending on other variables like e.g. the error signal. These methods are called Gain Scheduling or Gain Switching. Two new methods to adapt control parameters for improving the position control of laser scanners are presented here: an adaptive adjustment of the proportional part and of the integrating part of a PID-control. Since this new concept is suitable for high speed control, we call it RAPID-control (**R**esult-**A**daptive **PID** control).

A laser scanner consists of a rotary magnet with a laser mirror attached to it. By applying a voltage to a coil, the magnet can be rotated and thus a laserbeam, which is reflected by the mirror, can be steered. A capacitive sensor on the axis measures the angle. With two orthogonal scanners, a laser beam can be steered in x and y in a plane (figure 1). Such a system can be used for cutting or marking of workpieces of various materials.

The functionality of the new control concept has been proven by measurements on a real laser scanner. The laser scanner was connected to a “hardware-in-the-loop” simulation system (SIMULINK/The Math Works Inc. and ControlDesk/dSPACE GmbH). This system allows a quick changeover from simulation to the real control process (so called rapid control prototyping).

P-Adaption reduces residual error

It is known, that a fixed P- or PD-control will correct the real output value the faster and with higher precision, the higher the control loop gain is. The maximum value for the gain, however, is limited, because the control can overshoot and start ringing.

For high accuracy and small overshoot, one needs a smaller gain for larger errors and only for small error signals, when the system has nearly settled, the gain can be larger.

To achieve this without switching, this behavior is realized with a continuous adaption function, the value of which is determined by the momentary error value. The value of the adaption function is then multiplied with the P-value of the PD-control and thus increases the P-value after settling. A suitable function is for example (e being the error value):

$f(e)=1+(c_1-1)/\ [(c_2.e)\mathrm{sqr}+1]$ (1)

This function has two parameters, which have to be aligned correctly for optimizing the control. For two different values of the parameters c_1 and c_2, the value of the function of e is shown in figure 2. One can see, that parameter c_1 determines the value of the function at e=0, while c_2 determines the steepness of the function. The functional value for large error values is 1 (that is, the P-value is not increased) and for small values of e, the functional value becomes c_1 (which means, that the P-value is increased by the factor c_1). The flow chart in figure 3 shows, how the adaption function is set into the control function. The block “Adaption“ contains the adaption function. Figure 3 also shows the necessary interface blocks for the rapid control prototyping (red frames).

The effect of the adaption in the control loop can be seen in figures 4 to 6 . Figure 4 shows the temporal behavior of the controlled value x with residual error or offset, which results from an optimally aligned PD-control (the uninterrupted red line is the nominal value w or set-point, the interrupted lines show the allowable tolerance interval). The testsignal is a symmetric stepfunction. If now the P-value is adapted with the described function, the residual error can be reduced significantly (see figure 5). The settling curve is hardly influenced by the adaption. The temporal behavior of the value of the adaption function can be seen in figure 6. Only after about 4 ms the functional value increases from 1 to 3 . The P-value of the PD-control is then 3 times larger in the stationary state than during settling action, which causes the controlled value x to reach the tolerance interval. What happens, if you increase the P-value by a factor of three without the adaptive function, can be clearly seen in figure 7: The stability is reduced and the controlled variable begins to oszillate.

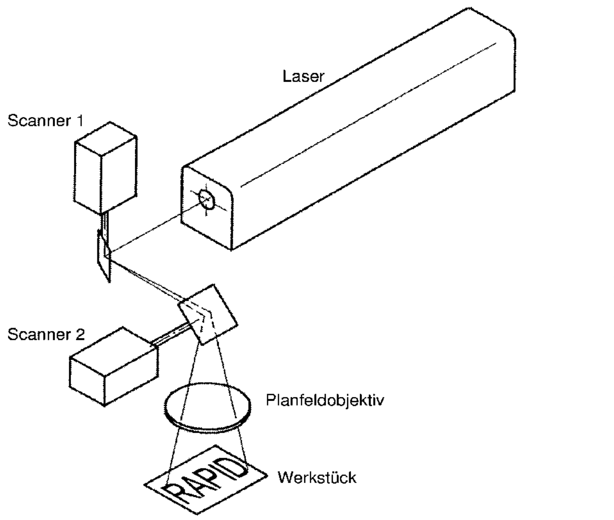


Fig. 1. Schematic drawing of a laser marking system

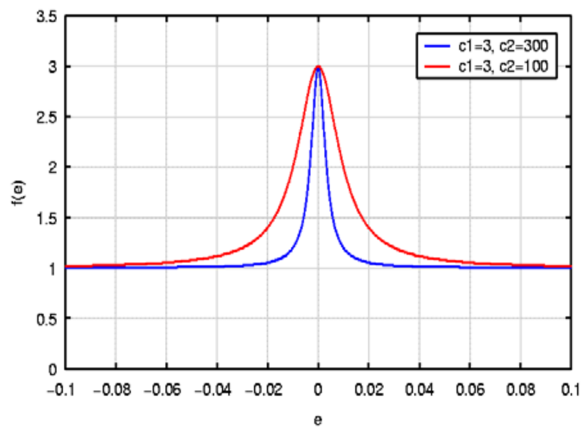


Fig. 2. Adaption function for the P-parameter versus error e

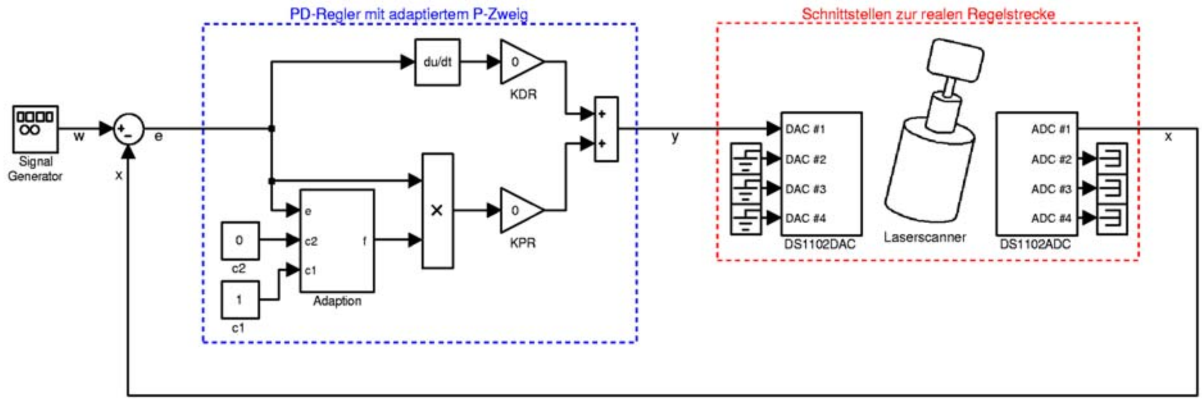


Fig. 3. Graphic program (SIMULINK) of a PD-control with adaptive P-parameter

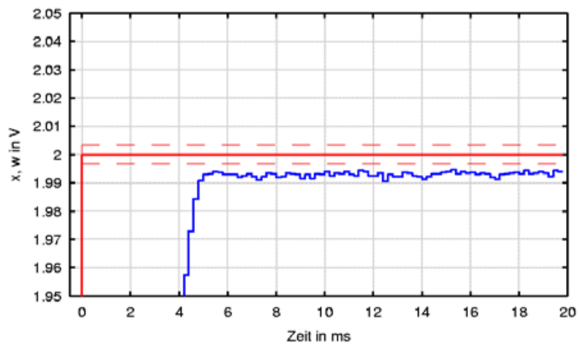


Fig. 4. A non-adaptive PD-control shows a residual error (offset)

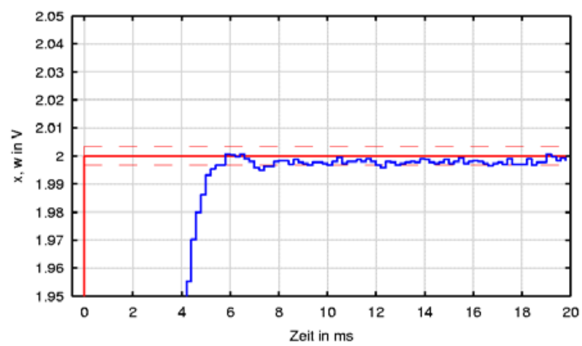


Fig. 5. Adation of the P-parameter reduces the residual error

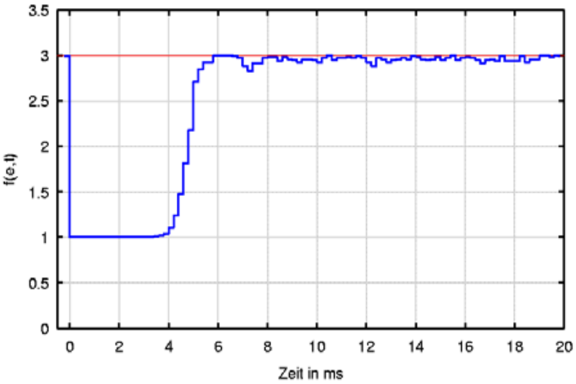


Fig. 6. Temporal behavior of the adaption function for P

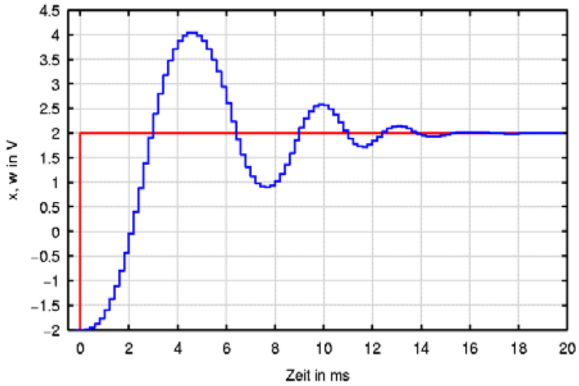


Fig. 7. Increasing the P-parameter without adaption results in a weakly dampened oszillation

Fast settling with I-Adaption

Using integration, the difference between set-point and measurement can be made zero in steady state. If you add integration to a P- or PD-control, however, it will get slower. This can be avoided by tuning up the integral part only for sufficiently small error values.
The function below can accomplish this adaption:

$f(e)=1/[(c_1 xe)sqr+1]$ (2)

Only one parameter has to be set. It determines the steepness of the function. Figure 8 shows the behavior of the function versus the error e for two different values of the parameter c_1. For large values of e the functions value approaches zero and for small errors it approaches the value one. The integral part of the control is multiplied by the functional value of the adaptive function on the left (see figure 9). Therefore the integrator input is clamped to zero during settling (the error value being large), and only after the error value gets small (after settling), the input is opened. Integration of e and reducing the error starts only after the settling phase, so that no overshoot occurs.

In figures 10 to 12 the effect of the adaption of the control can be seen. Figure 10 shows, that a conventional (not adaptive) integrator causes a large overshoot and therefore a longer settling time. As can be seen in figure 11, the residual error can be eliminated without overshoot by adaption. The functional values, which are generated by the adaptive function, are shown in figure 12: During the settling phase, the functional value is zero and then changes to one. Because of this, the input value of the integrator is zero during settling and the integrator is inactive, as can be seen clearly in figure 13. It shows the output values of the complete integrator of the adaptive PID-control. During the first three milliseconds, the values are nearly constant. Only at the end of the settling phase they start rising. Then the error signal is integrated until the error is eliminated.

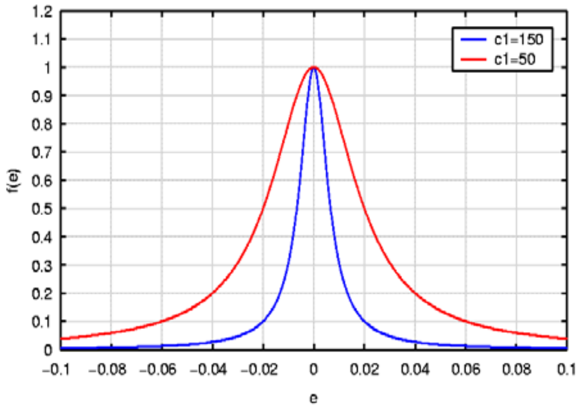


Fig. 8. Adaption function for
the I-parameter versus error e

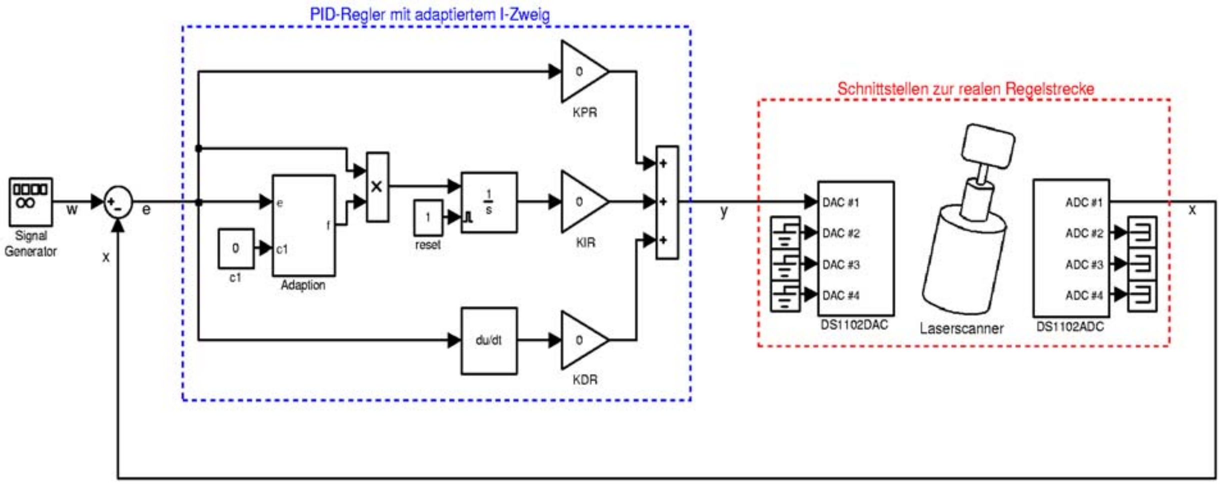


Fig. 9. Graphic program (SIMULINK) of a PID-control with adaptive I-parameter

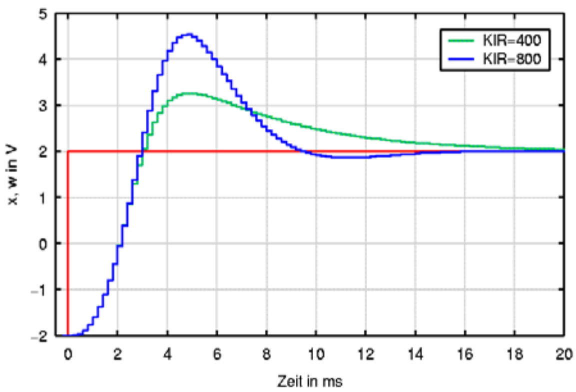


Fig. 10. The Integrator of a conventional PID-control causes large overshoot

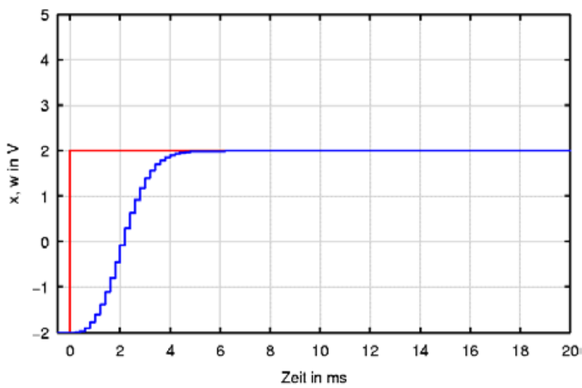


Fig. 11. A PID-control with adaptive I-parameter shows no overshoot

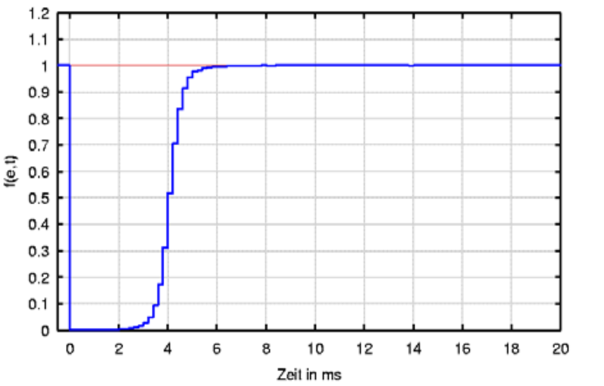


Fig. 12. Temporal behavior of the adaption function for the I-parameter

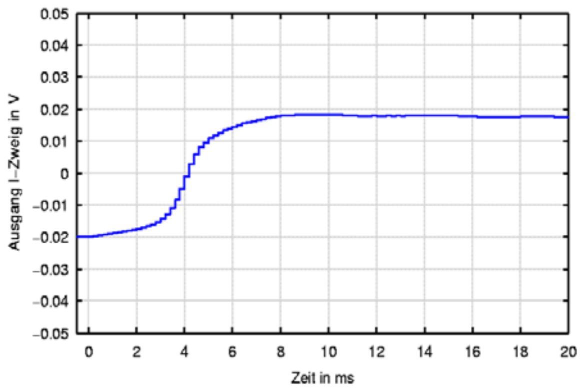


Fig. 13. Temporal behavior of the integrator output

Conclusion

By systematic experiments on a real apparatus, it was established, that the position control of laserscanners in lasermarkers can be improved by suitable adjustments of the gain. That is, the P-parameter of a PD-control or the I-parameter of a PID-control are so modified by the error value, that the accuracy is increased and the settling time becomes very short. In [2], a combination of P- and I-parameter adaption is investigated, as well as an adaption of the D-parameter.

Literature:

1 L.Langhans: >Regeleinrichtung mit adaptiver Parameterkorrektur<; German Patent DE 196 19 271 C2
2 M. Lugmair: >Reglerentwicklung für ein Laserscannergalvanometer<; Diploma thesis, Munich University of Applied Science/Baasel Lasertech, Munich (2002)
3 H. Mann, H. Schiffelgen, R. Froriep:> Einführung in die Regelungstechnik<; 8. edition, Hansen Verlag, Munich, 2000

Authors:

Dipl.-Ing(FH) Martin Lugmair did his Diploma thesis in the faculty of Fine Mechanics and Microtechnology/Physical Technologies at the Munich University of Applied Science
Prof Dr.-Ing. Rainer Froriep teaches control technology at the Munich University of Applied Science
Dipl.-Ing. Franz Kuplent is associative teacher for control technology at the Munich University of Applied Science
Dr. Lutz Langhans is employee of Baasel Lasertech in Starnberg

Contact:

Dr. Lutz Langhans
Baasel Lasertech
Petersbrunnerstr. 1b
82319 Starnberg (Germany)
e-mail: lutz.langhans@baasel.de
fon: +49(0)8151 776 145
fax: +49(0)8151 776 159

Prof. Dr.-Ing. Rainer Froriep
Labor für Steuerungs- und Regelungstechnik
FH München
FB 06, Feinwerk- und Mikrotechnik/Physikalisches Institut
Lothstr. 34
80335 München
e-mail: r.froriep@fhm.edu
fon: +49(0)89 1265 1369