High accuracy short range laser meter for system calibration and installation

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Abstract: Modern Satellite Laser Ranging Systems are actually able to deliver data with an inherent accuracy of 1 mm and better. Therefor the position of these systems relative to geodetic markers and the calibration value to the intersection of axis has to be monitored continuously with better than 100 mm accuracy.
The Deggendorf University of Applied Sciences in cooperation with Micro-Optronic Messtechnik GmbH has developed a rugged handheld rangefinder with a calibrated single measurement accuracy of better than 50 mm in high accuracy mode. The system guarantees this accuracy up to 5 m distance to any surface and up to 100 m distance to reflectors.
Due to the new patent pending operating scheme the instrument delivers up to 100 measurements per second with 30 mm single shot stability. With intelligent internal calibration procedures this stability transfers into a extremely high absolute accuracy.
In this paper we will present the principal operational scheme an first ranging results.
The instrument will be available to the public in spring 2003.

1) **Introduction:** During the last decade the internal accuracy of SLR systems did improve continuously. Today most of the systems are able to deliver normal points with a formal statistical error of less than 1 mm /1/. To transfer this excellent formal resolution into absolute ranging accuracy it is necessary to deal with possible offsets in the 100 mm range. These possible offsets are caused by three main error sources:
   - Satellite Effects: Center of Mass correction and Satellite Signature /1,2/ are in strong discussion during the last years and special working groups at the ILRS are dealing with this problem
   - Atmospheric correction: It is well known, that the used models for atmospheric range correction only have an accuracy of a few mm /3,4/, some effects of nonlinear absorption are not well understood /5/ but there is continuous research at different groups to improve the situation by modeling /6/ or multi color ranging /4,7,8,9/
   - Stability of Telescope and Ground Survey: Most SLR systems still underestimate the problem, that due to environmental effects (temperature, wind load, etc.) the center of axis of the telescope may move in the sub-mm range within hours or days causing ranging offsets of the same size. Because of the complexity of ground surveys with geodetic instruments, ground surveys sometimes are done only once per year, showing changes in the cm range /10/

   To ensure, that the telescope position relative to ground markers is stable, the distance from the telescope to this markers has to be checked frequently, if possible together with each calibration measurement.

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Fortunately in industrial automation there are similar problems in quality control and positioning. As instruments for industrial metrology are small, simple and rugged, these type of instruments is a perfect choice for frequent short range measurements at SLR systems.
In this paper we will describe the results of a joint R&D project to build a High Accuracy Laser Meter for Industrial Application with the following principal specifications:

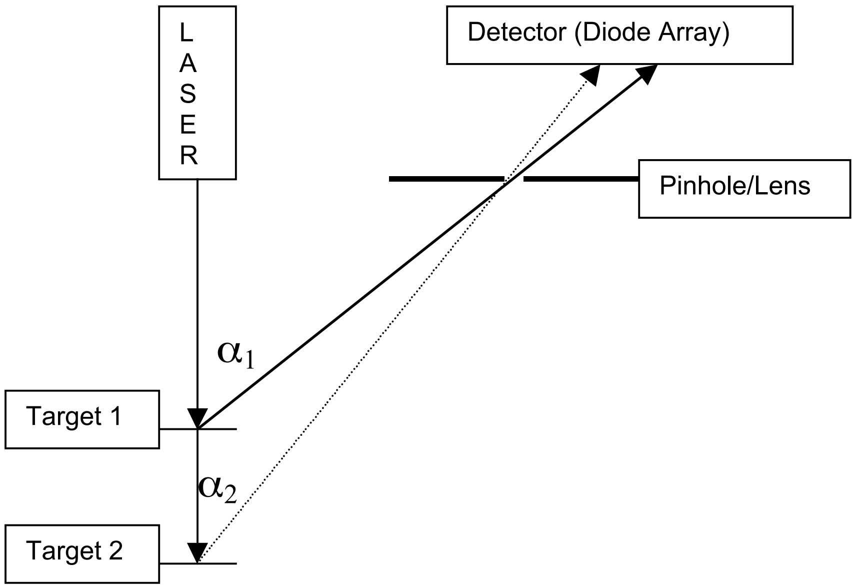
- Short Range: 5 m on non cooperative targets (100 m with reflector) with an eyesafe, visible Diode,
- Accuracy and Reproducibility: 0.1 mm with new operational principle
- High Aquisition Rate: 1 Hz - 1 kHz using a fast simple measurement principle
- Long Term Stability with absolute calibration
- Low Cost

2) **Operational Principle:** The starting specifications of the R&D Project are summarized in the following table:

Name	LDS2700
Ranging Distance	0,1...5 m (no reflector) (2...100 m with reflector)
Resolution	<= 0,1 mm
Reproducibility (90 % target reflectivity)	+/- 0,1 mm
Absolute accuracy (90 % target reflectivity)	+/- 0,5 mm
Data aquisition and output time	<= 1ms (distance < 5 m) > 1ms (distance > 5 m)
Size	Ca. 80 x 80 x 150 mm _
Weight	900…1000g
Operational Temperature	-10°C to 50°C
Output	0...10V RS 232 /RS 485
Price	< 5000 Euro

To meet these Specifications a number of possible operational principles were discussed /11/:

- Triangulation: The angle a between transmitted Laserbeam and detected target point is used to calculate the distance to the target

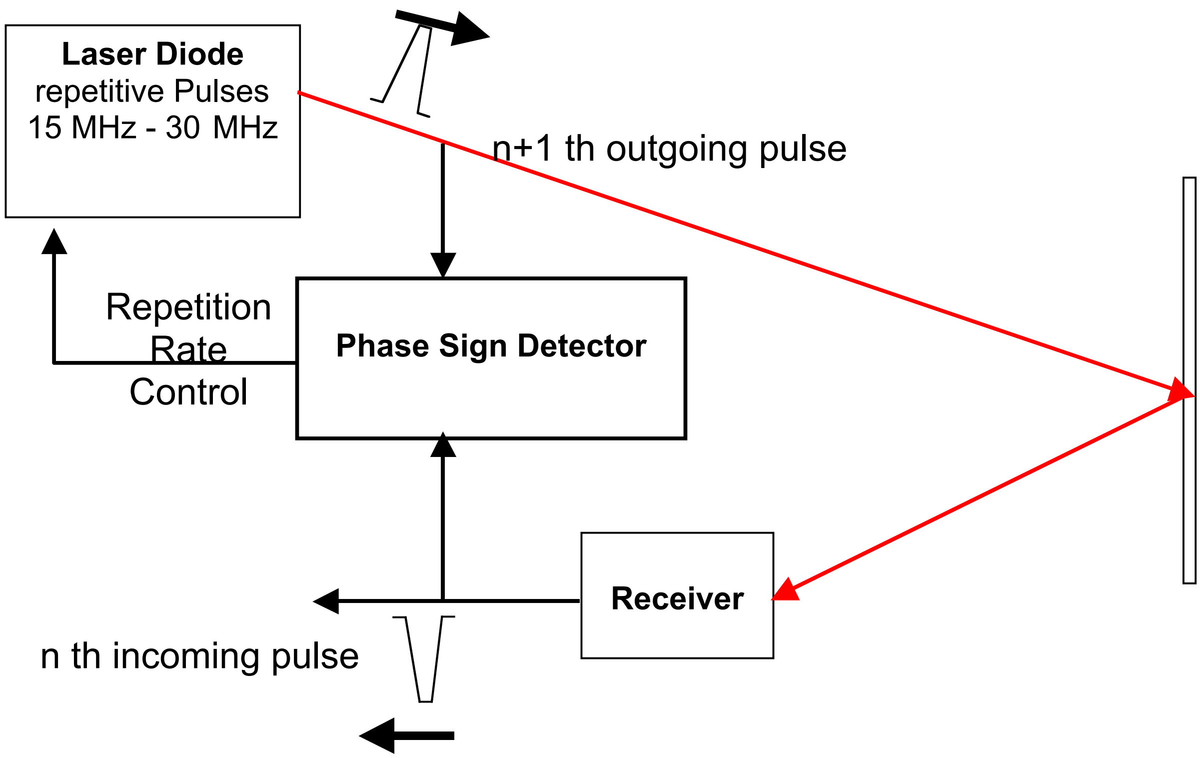


  With this technology mm accuracy is possible in small instruments for short distances (< 50 cm). For long target distance, the separation Laser-Detector has to be too large to get good accuracy.

- Phase Difference: The transmitted Laser Beam is modulated with a fixed frequency and the phase difference between reflected and transmitted beam is measured to calculate the target distance. With this technology a high accuracy only is possible, if the modulation frequency is close to GHz, but with this high frequency, the distance is only known within the interval of one wavelength. To get the absolute distance measurement, a pre-measurement with lower frequency or more sophisticated technologies are necessary (e.g. FMCW /12/). In these cases a data aquisition time of 1 ms is not possible.

- Time of flight: A simple time of flight measurement allows extremely fast single measurements, but the accuracy with inexpensive components will be in the range of a few cm, therefor an averaging over many measurements is necessary to get the 0.1 mm specification. Again this is not possible within 1 ms.

To achieve the specifications we did develop a new, patent pending operational principle, combining the advantages of phase difference measurement and time of flight measurement



The repetition rate of the pulsed laser diode (ns pulse duration) is controlled in a way, that the detected pulse overlaps with the next transmitted pulse. Due to the fast pulse rise time, the coincidence of the two pulses can be measured with even better accuracy than the phase difference if high frequency modulated beams. The time of flight of one pulse allows the absolute determination of the distance with one pulse, the usage of the repetition frequency for the distance calculation inherently averages over more than 10000 measurements within one ms and therefor gives sub mm ranging accuracy. The complete distance measurement is done by a simple frequency count, the absolute calibration is possible by measurement of an internal fiber with known length.

A simple calculation shows, that with an maximum repetition rate of 30 MHz a range of zero to 5 m can be realized (Fig. 1) with standard voltage controlled oscillator with a tuning range of 2, for long distances the repetition rate has to be decreased to appr. 1 MHz resulting in longer data aquisition times of > 10 ms.

To get the specified accuracy of 0.1 mm, the necessary resolution of the frequency is around 100 Hz (Fig 2.). Therefor the frequency measurement is simply done by digital cycle count

Fig. 1: Laser Diode Repetition Rate versus Target Distance

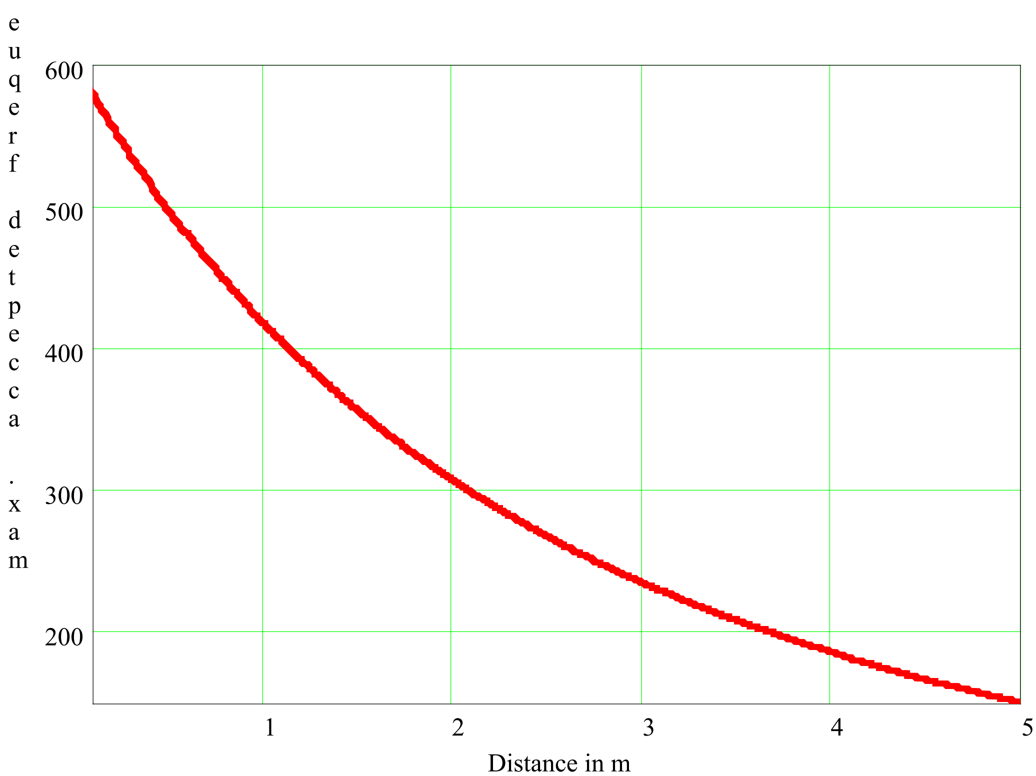


Fig. 2: Max. acceptable frequency error for 0.1 mm ranging accuracy versus Distance to Target

3) **Results:** After finishing the technology demonstrator for the instrument in Spring 2002 we did make a number of measurements to test, whether we are able to meet the accuracy specifications with the system.
The results for ranging to a white target in appr. 1.8 m distance and for the calibration with the fiber are shown in Fig. 3 and Fig 4.
As the single measurement R.M.S. is much better than 0.1 mm, the absolute ranging accuracy of the instrument therefor is limited by the mechanical positioning error of the calibration fiber relative to the detector.

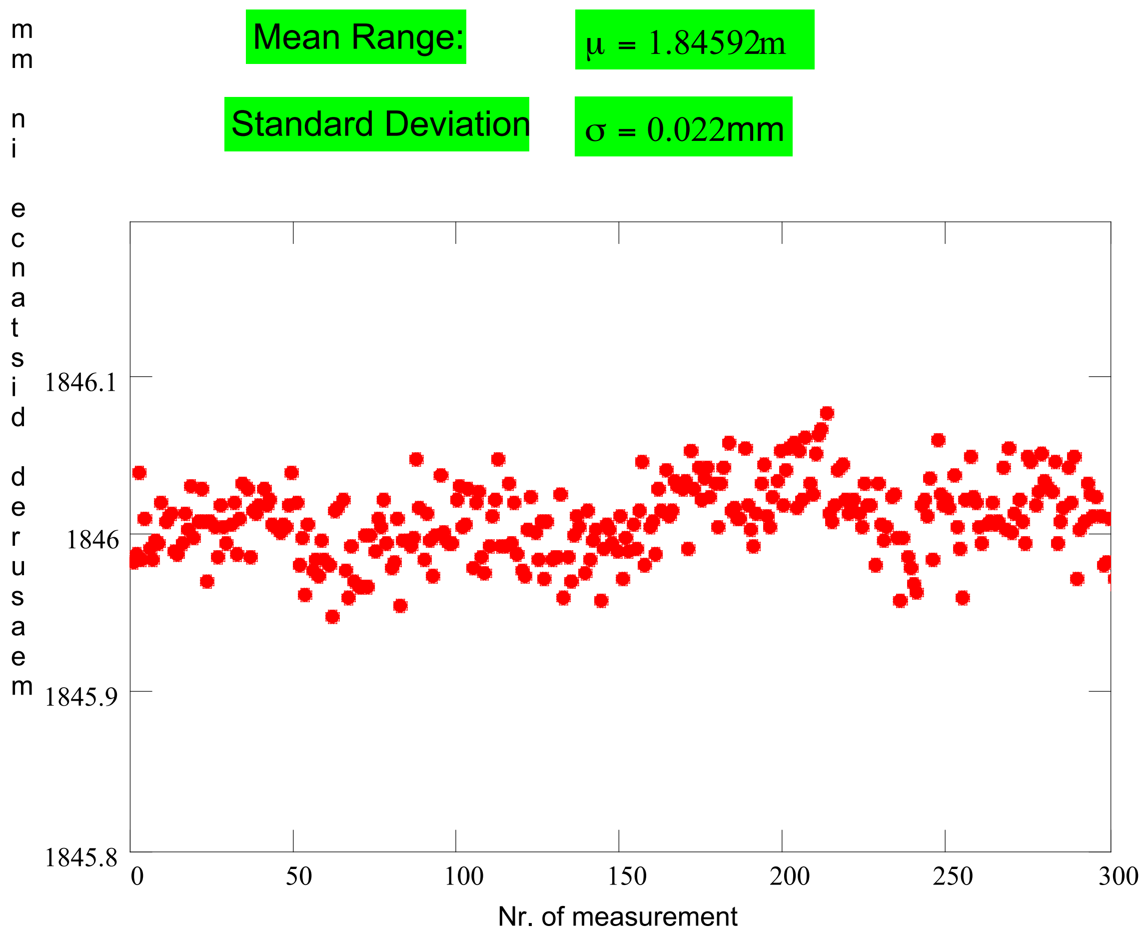


Fig. 3: Ranging Results(temperature drift compensated)
10 ms aquisition time

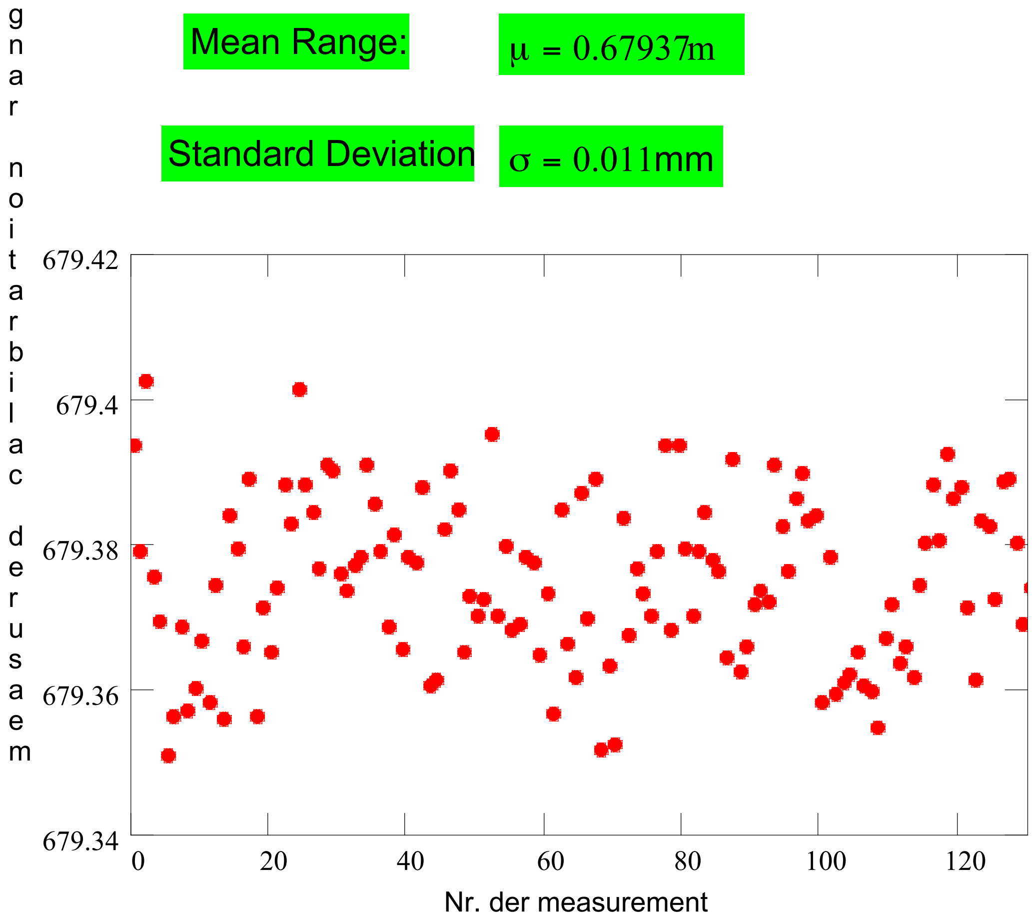


Fig. 4: Calibration Results (temperature drift compensated)
10 ms aquisition time

4) **Status of Project:** The test measurements with the technology demonstrator were finished in summer 2002 and we are now working to build and test the interface boards, the controller board and software and to integrate everything into one box to get a prototype instrument until end of 2002. The start of the serial production is expected in spring 2003 with first delivery in summer.

5) **Application in SLR/Summary:** Due to the small size and the low weight of the rangefinder, it can be mounted on every SLR telescope. Because of its simple, remote controlled operation and the high ranging accuracy to check on a routine basis (e.g. together with each calibration)

the distance of the telescope to some selected markers around the station with sub mm absolute accuracy. With this measurements, the station can ensure, that the local stability of the system is good enough to get full advantage of the high formal SLR accuracy. A correlation of the marker measurements with apparent range biases may help to localize the source of the bias.

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