of the SDH hand using sensor glove and the shadow hand philosophy. The visualisation of the results of the transformation from the sensors readings to the expected gripper's movement helps operator to correctly show his/her intentions and on-line control the 3-finger gripper.

IX. Acknowledgment

Research partially supported by the National Centre for Research and Development under grant No. PBS1/A3/8/2012.

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EVALUATION OF THE OPTONCDT ILR SENSOR

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Abstract—In this paper we evaluate metrological properties of the optoNCDT ILR sensor and compare it with the producer's datasheet. Then we describe its use for the purposes of map creation in mobile robotics. Results are promising so we can use this sensor for cheap map-making mobile robot applications.

Keywords—laser scanner, distance sensor, mapping, mobile robotics

I. INTRODUCTION

In mobile robotics, we often use laser scanner sensors (e.g. Sick [1], [2] or Hokuyo rangers [3],[4]) as a primary source of information for map creation. Unfortunately, although their performance is very good, high price limits their use in laboratory experiments. Many other attempts to obtain reliable map of the environment were described, e.g. [5] or [6]. In this paper we describe our experiences with standard industrial laser distance sensor optoNCDT produced by the Micro-Epsilon company [7].

II. SENSOR DESCRIPTION

Sensor considered for tests is a compact and reliable laser distance sensor with an analogue output signal produced by the German company Micro-Epsilon Messtechnik. According to the producer, sensor is appropriate for monitoring and positioning of cranes, measuring the liquid level in a tank, measuring motion of the conveyors and positioning [7], see also Fig. 1.

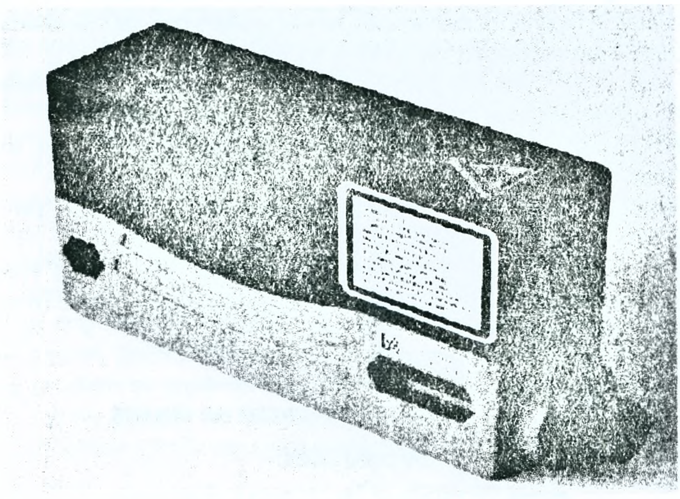

Figure 1 -Sensor optoNCDT ILR 1030-8 by the Micro-epsilon company.

The sensor operation principle is based on the measuring of the pulse propagation time (time-of-flight technology). The sensor sends a short (5 ns) pulse which is reflected from the object being measured and is then detected by the sensitive element of the sensor. Distance of the object is derived from the pulse flight time to the object and back. As a source of pulse is used a laser diode (Class 2) with a wavelength of 660 nm and beam divergence 1 mrad. Pulses of length 5 ns are repeated with a frequency of 250 kHz. This technology should minimize the impact of the scanned surface, properties of the material as well as the impact of lighting object and should thus always provide reliable and consistent data.

The sensor has an analog output 4-20 mA, the measurement range can be set in so called learning mode. In addition to the analog output, also single switching output is available. Its switching level again can be set in learning mode of the sensor. Values can not be entered exactly, only on the basis of the actual measurement. Effective measurement range is limited by the color of the target surface. For dark surfaces the effective range is more than half of the light ones (see Fig. 2).

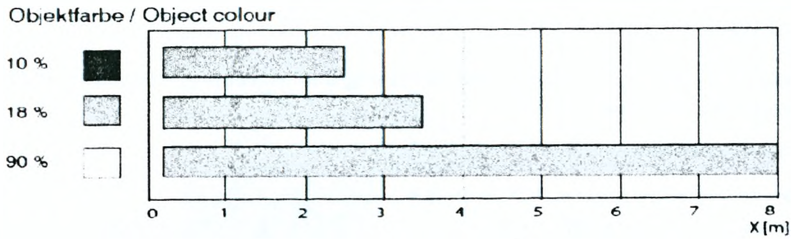

Figure 2 - Measuring ranges of the sensor for different colors of objects.

Table I -Technical Parameter

Measuring Range	0,2 ... 2,5m [a]
Linearity	±20 mm
Resolution	1 mm
Repeatability	<5 mm
Response time	10 ms
Operation temperature	-30° ... +50°C Protection class IP 65
Power Supply	10 - 30VDC, class 2
Weight	90g
Dimensions	25,8 x 54,3 x 88 mm (with connector 102)

a) for black surface, up to 8 m for white

III. MEASUREMENTS WITH THE SENSOR

Technical parameters of the sensor are completed in Tab. 1. We measured the metrological properties of the sensor according the EN 60 770 standard. We performed 3 sets of measurements for increasing and 3 for decreasing values, then following properties were calculated:

A. Inacuracy.

Maximum positive error was at 10 % input and its value is 0,5 %. Maximum negative error is at 90 % input and its value is -0,9 %.

B. Measured error

Maximum positive difference from an average is at 10% input and its value is 0,28 %. Maximum negative difference from an average is at 90 % input and its value is -0,58 %. Measured error is 0.58 %.

C. Non-linearity (terminal based)

Line connecting end points has a slope -0,003796 and offset 0,279630. Maximal deviation of average values from this line is at 90 % input and the value of non-linearity is -0,37 %.

D. Hysteresis

Maximum difference between the increasing and decreasing measurements is at 90% input and its value is 0,7 %.

E. Non-repeatibility

Non-repeatibility value is 0,75 at 85 % input.
We also measured additional sensor-specific properties of the device.

F. Size of the laser spot

We measured diameter of the measuring spot in various distances. Real diameter of the spot was difficult to measure due its high intensity which enlights also the surrounding, especially for small distances. It explains also paradox that spot decreases its diameter with increasing distance. For larger distances the intenzity of the spot is lower and measurement is more precise so we are able to measure just the spot itself and not the secondary lighted area. Results of the measurement are in Tab. 2

G. Influence of the surface color

Measurement on the 100 cm range show almost no dependance of the measured range on the color of the measured object. Results of the measurement are summarized in Tab.3.

H. Power consumption

When powering the sensor from the 12 V DC source (exact value 12,45 V) we measured current consumption 98,9 mA in steady state.

I. Dynamic properties

We measured dynamic properties of the sensor at the step change of the input distance. Distance was changed by the shutter in the laser beam line from the 50 to 100 cm using a position servo. Change of the output value was measured by the oscilloscope as a voltage across the measuring resistance. Measured response time was in the range 10-12 ms, once up to the 14 ms. Response time is not depending on the change direction.

TABLE I. SPOT DIMENSIONS

Distance [cm]	spot dimensions [mm]
50	4,8 x 4,8
100	4,8 x 4,8
150	2,4 x 4,8
200	2,5 x 4,4
250	2,5 x 4,4
300	2,5 x 2,5

TABLE II. COLOR SURFACES

color	current
D=100cm	[mA]
white	6,62
yellow	6,62
[illegible]	6,62
green	6,61
[illegible]	6,61
black	6,61
black foam	6,61
mirror	6,62

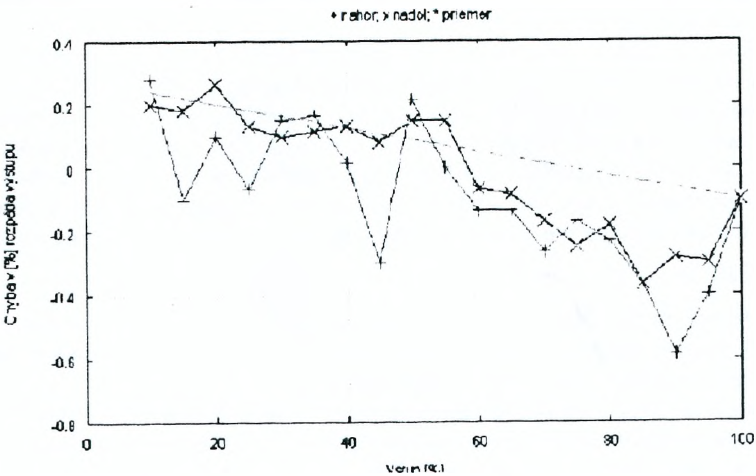

Figure 3 - Measured error of the sensor.

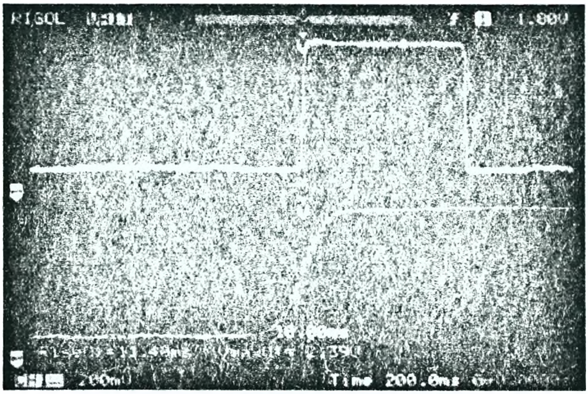

Figure 4 - Dynamic response of the sensor on the step change.

VI. MAP CREATION

For the purposes of the mobile robotics we tried to use this sensor for as a source of data for map creation. For this experiment, we mounted relatively light-weighted sensro on the positioning RC servo head. We were rotate the sensor in the range of 0 to 180 degrees with increments of 1 degree. The servo gear characteristics are unfortunately not quite linear. Then we converted measured value of the current by the 10-bit A/D converter (0-1023) with an input range of 0 to 5 V. Current of 4-20 mA was converted to a voltage using a 233 ohms resistor. Sensing range was for practical reasons limited to 0-200 cm.

Then we created a model room in which the robot has to move (see Fig. 5). The measurement was carried out statically from the point with coordinates [0,0]. During the measurement we exploited three different surface materials . The segments AB and EF white plastered wall , in the section DE ceramic tiles in the remaining sections of BD , FH and JL chipboard . Created model allows as to test several problematic parts - the intern corners ABC, CDE and EFG as well as outer corners BCD. Also we tested the behaviour of the sensor for holes (e.g. window, door, ...) GJ – see Fig. 6.

V. RESULTS

During the measurement the mobile robot with rotating sensor was placed at the point O. Readings with 1 degree increments were plotted in polar coordinates (angle in degrees, distance in cm) on the following diagram.

During the measurement we observed that too fast moving head results in delayed measurements. When faster movements occur the higher the variance of the measured values due to vibration throughout the head Experimental results proved the measured dynamic properties of the sensor and shows that it is impossible to perform a single measurement faster than each 10-12 ms.

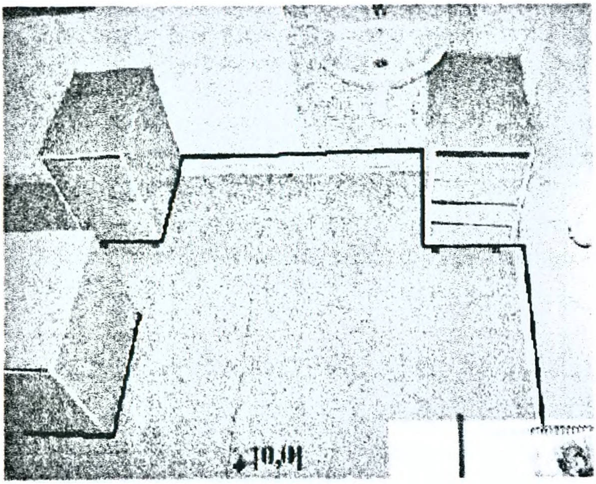

Figure 5 - Photo of the measured room model.

Measurements shows that the approximate time required for full scan in the range of 0 to 180 degrees with a resolution of 1 degree takes about 2,1 seconds. It doesn't seem to be appropriate for mobile robot, but relatively long time is balanced by the reliable and accurate measurement, which don't need to be repeated. Sensor can be also exploited for faster measurements with a possible compensation of dynamic errors or for measurements with more than 1 degree of resolution.

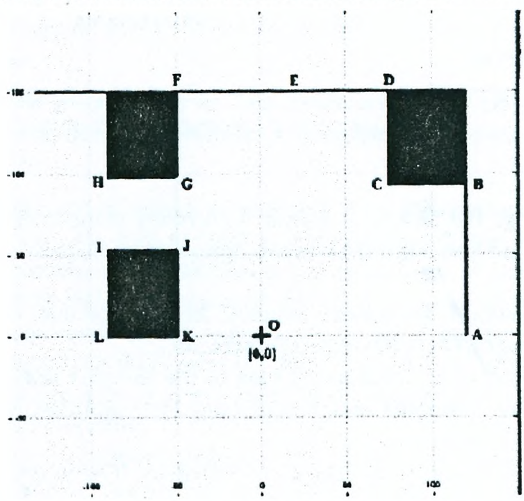

Figure 6 - Dimensions of the room model

VI. CONCLUSIONS

The present sensor ILR 1030-8 is a very promising component for robotics. After correcting the positioning head allows relatively precise distance measurements, it is robust and reliable. Its use is enforces its low weight (which can be further reduced by removing the sensor case). Its approximate price is around 280,-€.

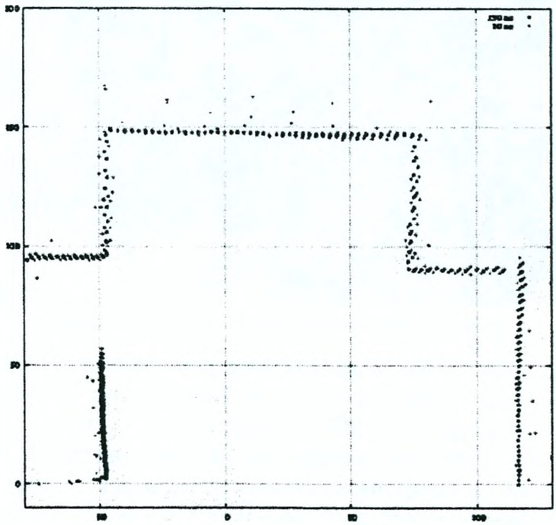

Figure 7 - Results of the measurements.

ACKNOWLEDGMENT

Above experiments were performed thanks to the company Micro-Epsilon Messtechnik, Czech division. We appreciate their helpfullnes when lending the sensor device.

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LANGUAGE OF DESIGN OF MODEL OF BEHAVIOR OF COMPLEX SYSTEM

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Abstract – The paper deals with creating a complex pattern of behavior controls technical system based on the use of the formal language of design. Which provided visualization used in the model of concurrency control system behavior and the possibility of action sequences (the track) with the performance. The resulting pattern of behavior may be useful in the verification and validation of the control program of the technical system.

Keywords – pattern of behavior, a process, asynchronous parallel processes, multiprocessor control system, the graph model of behavior.

I. INTRODUCTION

One of the urgent tasks of software development - is the creation of programs for complex technical systems, such as robot control systems. Of the total list of works carried out in the solution of this problem in the early stages of design, it is possible to allocate the task of creating a model of the future behavior of the robot control system. Perform extensive quality indicators such work can be substantially increased if the design of the management model to use formal language that allows to visualize the execution trace, organization and interaction of parallel processes, using a multiprocessor system.

Besides, complexity of modern control systems demands to provide application of the multiuser operating mode over the project. That provides possibility of simultaneous work on the project to several groups of the independent developers united by one ultimate goal.