SENSOR DRIVEN MAPPING OF REINFORCEMENT BARS

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Abstract

Non destructive mapping of reinforcement may be needed in concrete elements of old buildings where changes or an extensive maintenance is required. It is needed if reliable design drawings are not available. The mapping will indicate the location of reinforcement bars, their size and depth of cover.

The objectives of the study presented here were to select a reliable sensing tool for detection of the presence of reinforcement bars in concrete, and develop a reliable procedure for the manual and automated mapping of the reinforcement, with this tool.

Different sensors may be used for detection of steel elements embedded in concrete. The sensors include electromagnetic covermeters, microwave (radar) scanners, radiographic systems, magnetic, and electrical devices. The sensor which has been selected for this study was an electromagnetic covermeter. To ascertain a fast and reliable scanning method, the sensor tool has been mounted on the arm of a robot (GMF-S 700) which led it through a predetermined grid of measurement points. An algorithm has been developed and tested for processing the data obtained, and generation of the layout of reinforcement.

The paper discusses the testing of the sensor's accuracy, the manual and the robotized measurement process with the sensor, and the principles of the algorithm for generation of reinforcement layout.

Keywords: Reinforcement bars, Mapping, Sensors, Automation, Construction

Introduction

Reinforced concrete structures have a long economic life - 50 years or more. During the service life of such a structure it may be necessary, sometimes more than once, to re-examine the precise location of the reinforcement, in some or more of its elements. This may happen under the following circumstances:

- When a change in the existing structure is required,
- When the existing structure may be used under excessive loads or other non-routine conditions.
- When ambient weather conditions may, with time, adversely affect the condition of the reinforcement.
- In special situations, immediately after casting, if a mistake in design or construction has been made.

Under all these circumstances, the precise state of the reinforcement - its size, location and condition - must be examined. If the design drawings of some or all of the structural elements are unavailable or unreliable, a physical, preferably nondestructive testing method (NDT), must be employed.

The non-destructive testing method may use sensors which can interact with the reinforcement steel, embedded in concrete. An intelligent procedure for employment of such sensor and interpretation of its readings can yield the necessary reinforcement mapping.

Sensor driven mapping can be done manually or automatically, however, automated mapping is faster, more precise, and more reliable.

The objectives and method of the study

The study which is presented here had the following objectives:

1. To review appropriate sensing devices and select one of them for employment in the mapping process.
2. To develop and test a procedure for a manual mapping. At this stage it was assumed that the reinforcement consists of one layer of bars (or that mapping is done for one layer at a time), and that the bars consist of linear sections.
3. To determine and evaluate a procedure for automated mapping.

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The general method of the study followed these steps:
1. A sensory system has been selected and tested for its accuracy on actual specimens of reinforced concrete.
2. An algorithm has been developed for mapping of the reinforcement based on the data, obtained from the sensor. The robustness of the algorithm, in light of possible inaccuracy of readings, has been tested with the aid of a simulation program.
3. A procedure has been developed for automated mapping, using a robot for the surface scanning.
The procedure focuses here on the layout of the reinforcement, although it can easily address also its depth and cover.

The available sensory tools

The available sensors which can be used for detection of bars can be divided into the following categories:
a. *Electromagnetic covermeters* [1], [3], [4]. The probe of the covermeter generates an electromagnetic field. When this field is disturbed by the bar's presence, an appropriate signal is emitted. The size, location and orientation of the bar can be interpreted from the nature of the disturbance. The cover of the bar may be determined if a suitable calibration can be obtained for the particular size of the bar.
b. *Magnetometer sensory systems* [8]. This method is a passive technique which is based upon measurement of the magnetic field generated by ferrous objects. This technique can provide data about location, orientation and depth. The main shortcoming of this method is it's high sensitivity to magnetic fields of nearby objects. Bar diameter estimate with this method is not reliable.
c. *Electrical sensory systems* [7],[9]. Such system measures the resistivity of the object and is usually employed to determine the thickness of pavement. In some cases this method may also provide information on the location and the depth of steel bars.
d. *Microwave scanners* [5], [10], [11]. This technique employs short pulses of electromagnetic energy which are emitted towards the concrete surface. When a metal obstacle is encountered an echo is returned, and the location of the obstacle can be deduced from the change in the amplitude of the echo and the time elapsed between the emission of the pulse and the return of the echo. The diameter of a detected bar cannot be assessed with this method.
e. *Radiographic sensory systems* [2]. This system uses Gamma rays or X-rays directed towards the area to be mapped. The bars are identified at their actual shape even when considerably removed from the concrete surface (more than 500 mm). The technique requires however extensive safety precautions and must be employed by a staff with a special training in this respect.
It followed from the findings of the literature survey that the electromagnetic covermeter is a preferable mapping device for bars not very deeply embedded in concrete. This device can detect both depth and size of bars, it is simple to operate both manually, and with automatic grippers. The readings, which are given by a digital tool, are easy to interpret.

Selection and testing of the sensory system.

Based on the findings of the literature survey - an electromagnetic covermeter *Profometer 3* (product of Proceq Co., Zurich) has been chosen. The covermeter, shown in Fig. 1 uses three sensing probes - a spot probe for placement of bars, a depth probe and a diameter probe. The concrete surface is scanned by moving the probe close to the concrete surface in a predetermined pattern. The data from the sensor is transferred to a processing unit of the covermeter and a display indicates the proximity of the probe to a reinforcement bar. The spot probe is used to determine the location of the bars, and the diameter probe is used subsequently to determine their size.
The accuracy of the covermeter has been tested with respect to three concrete specimens with known and reliable design drawings. The reinforcement - actual and detected - of one specimen is shown in Fig. 2

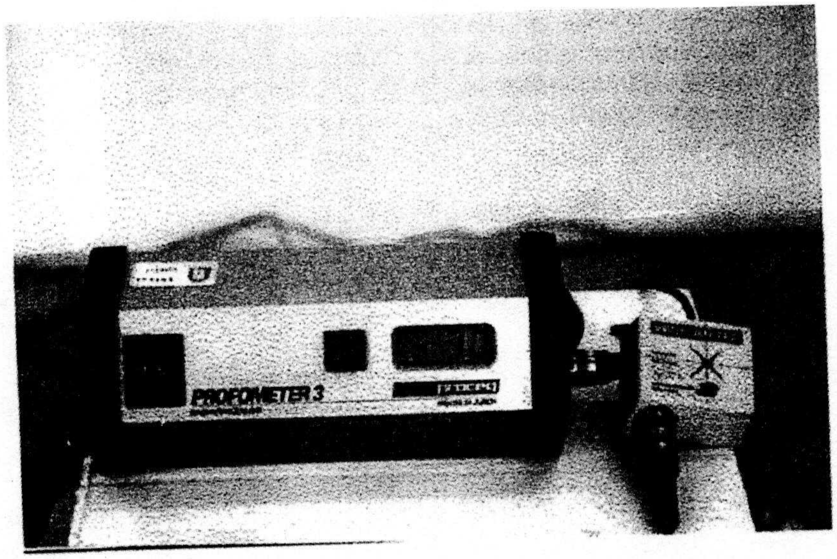

Figure 1 - The covermeter: the control unit (left), and the spot probe (right).

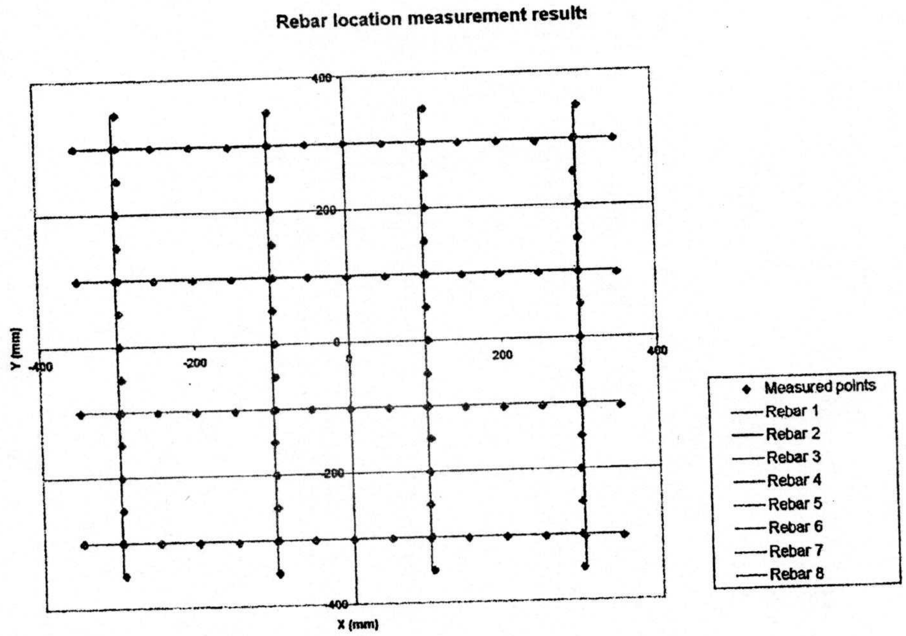

Figure 2 - The reinforcement location - actual vs. detected points

The tolerance of the readings - with respect to the location, depth, and diameter of the bars, is shown in Table 1. It may be seen that the tolerance of location did not exceed 5 mm which was satisfactory in the light of the requirements specified in the Israeli code for reinforced concrete structures [6] which allows a tolerance of up to 5mm. The tolerance was defined here as the maximum deviation between the measured and the actual dimension.

Table 1 - The reliability of the measurements

	Number of readings	Rebar location Tol. (mm)	Rebar location S. D. (mm)	Depth of cover Tol. (mm)	Depth of cover S. D. (mm)	Rebar diameter Tol. (mm)	Rebar diameter S. D. (mm)
Experiment 1	58	5	2.1	1	0.16	4.6	2.4
Experiment 2	48	4	1.7	2	0.87	4.0	1.1
Experiment 3	43	5	1.4	2	1.1	4.4	1.7

The algorithm for manual mapping of reinforcement

The data from the readings of the covermeter, applied manually to the surface of the element to be examined, was subsequently used as an input into an algorithm for mapping of the bars included in the examined area. Each data point was defined by its location (in two-dimensional coordinate system) and depth.

The algorithm had two stages of calculation. In the first stage, subsets of points were identified, using the least square technique. Each set was to represent a different (straight) bar section. The subsets were grouped in a manner that will produce the highest correlation coefficient for each set. In the second stage, the different sections were joined into whole bars.

The robustness of the algorithm was tested by simulation of the covermeter's reading errors. The error at each reading was determined at random by the program, assuming its normal distribution within a defined tolerance range. The results of the simulation procedure, when applied to a model of 3 bars, are shown in Fig. 3.

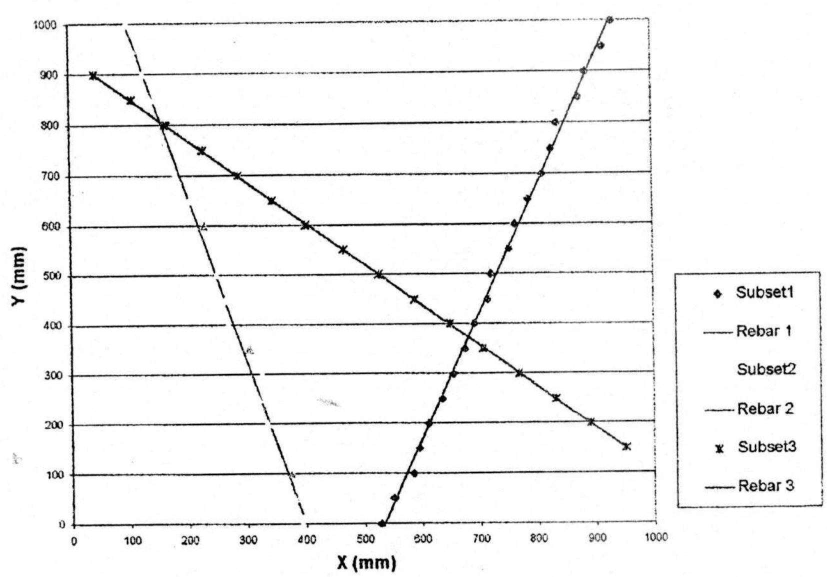

Figure 3 - The results of the mapping algorithm

The reliability of the algorithm has been tested, by increasing the tolerance range of the error from 10mm to 100 mm. The reliability of the algorithm has been evaluated by a simulation that generated tolerances in increasing ranges and testing the precision of the output. The reliability of the algorithm has been tested by introduction of simulated deviations of the measurements from the actual locations of the reinforcement, and a subsequent application of the mapping algorithm.

The error has been generated as a random variable with a normal distribution, within a predetermined tolerance range. The tolerance range has been increased in each simulated mapping experiment. The reliability was still greater than 0.95 (following an F test) in tolerances of up to 60 mm.

Table 2 - The reliability of the mapping algorithm – under increasing measurement tolerances

Measurement Tolerance (mm)	Algorithm Tolerance (mm)
10	6.3
20	11.5
30	21.7
40	30.4
50	33.6
60	38.1
70	50.1
80	51.7
90	70.7
100	83.1

Automatic mapping

Automatic scanning of concrete surface with a robot, has been employed to increase the speed, reliability, and accuracy of mapping. The covermeter has been attached to the robot's arm, and moved by it over the concrete surface to be mapped, following a pre-established grid.

The robot which has been used for this purpose was GMF S-700 with 6 degrees of freedom (3 at the wrist) and an arm 1.580 mm long. It is shown in Fig. 4. The robot can move from one work station to another in order to cover a vertical surface of desired dimensions. Mobile robots with a rectangular arm may be better suited to take probe readings while moving over large, vertical or horizontal surfaces.

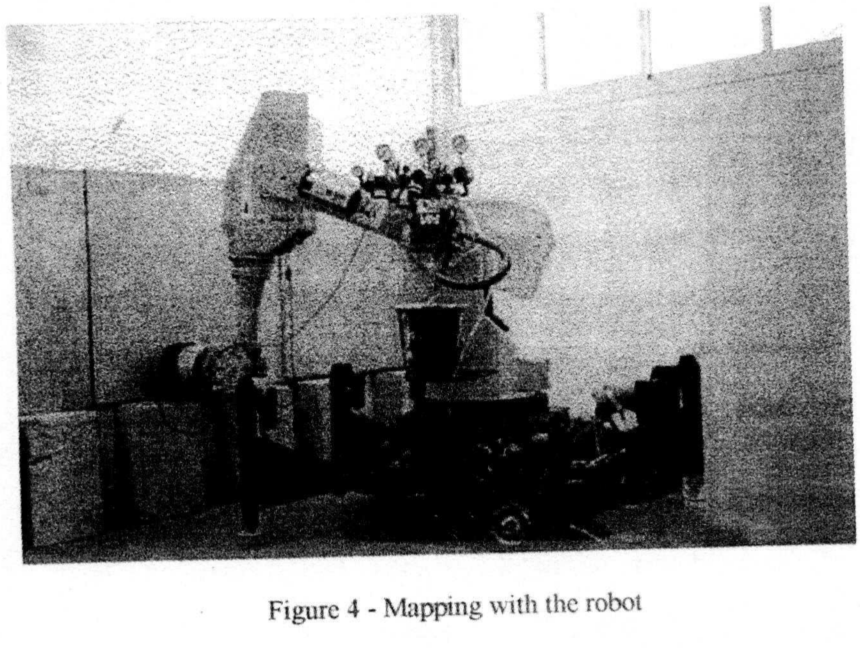

Figure 4 - Mapping with the robot

Mapping was performed, as before, first by scanning the surface and reading the sensor's data, this time by an automated device, and later - generating the reinforcement location pattern. In order to enable the movement of the probe close to the concrete surface, the automated system used an infrared sensor which has been calibrated to keep the probe 5mm. away from the concrete plane. The orientation of the concrete plane in the robot's system has been established by finding - with the aid of this sensor - the coordinates of 3 points on the surface. In this manner the system has been able, to subsequently determine, a 3 dimensional measurement grid for the measurements with the covermeter's probe as close as required to the concrete surface. A measurement has been taken at each point on the grid. Whenever an existence of a bar has been sensed, the recorded data included the location of the probe and its distance from the sensed bar. The grid has been determined in such manner that each bar had to be recorded twice - once on each side of the bar. The location of the bar has been determined from these two readings.

The automated mapping consisted therefore of these steps:

1. Recording 3 measurements of the concrete surface, with an aid of the infrared sensor.
2. Establishment of a 3 dimensional scanning grid for the probe path.
3. Movement of the probe over the grid, and recording sensor's readings.
4. Generating the reinforcement pattern from the grid, with an aid of the mapping algorithm.

The mapping algorithm for automated procedure acted in the same manner as the algorithm for manual procedure, except that it could produce - in a dense grid - several readings for one steel location. An output of an automated mapping, applied to actual concrete specimens is shown in Fig.5.

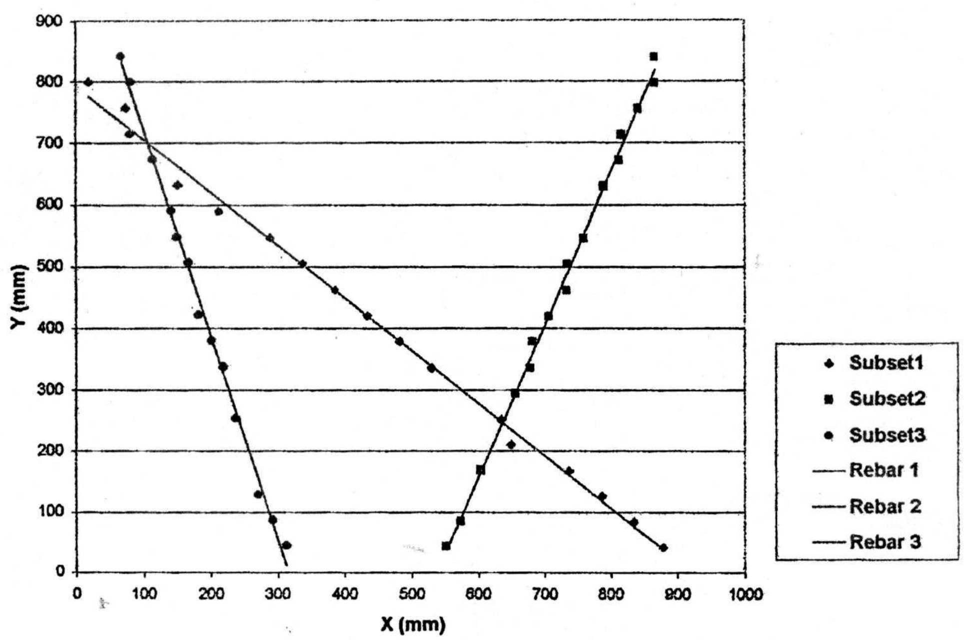

Figure 5: The results of automated mapping

Summary and conclusions

A procedure has been developed for a non-destructive mapping of reinforcement embedded in concrete. An electro-magnetic covermeter has been selected for this purpose. Its performance has been tested on reinforced concrete elements. An algorithm has been developed to determine the location pattern of reinforcement bars, based on data obtained from the covermeter readings. It was found that the accuracy of readings and the precision of the measurement procedure are adequate in light of the required tolerance of reinforcement placement. Mapping was also performed in an automated manner by leading the probe of the covermeter over the concrete surface, with a robot's arm. at a predetermined grid of measurements.

The mapping procedure has been developed for a single layer of reinforcement bars. It can be extended to deal with several layers, by dividing the detected points into layer-sets, depending on their distance from the concrete surface, and mapping each layer separately. It also has to be modified when the bars are closely spaced - at a distance which is less than the grid spacing. These problems have not been addressed here.

The procedure can be made more efficient if a prior information on the nature of the reinforcement is available. In such case scanning can be made more selectively and not to encompass the whole surface at the same density of the grid.

It appears that the automated procedure, employed for mapping, is effective in terms of its reliability and convenient execution. The procedure may be extended and include mapping of cables, water pipes, examination of the physical condition of reinforcement and other uses. A similar procedure may be used, with a different sensor, for examination of underground pipelines and conduits. Robots may have their configuration adapted to different types of surfaces to be mapped.

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