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A New Approach Based On Image Processing for Measuring Compressive Strength of Structures

Mehmet Baygin[1], Suat Gokhan Ozkaya*[2], Muhammed Alperen Ozdemir[3], Ilker Kazaz[4]

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Abstract: The compressive strength factor in civil engineering is a very important parameter used to determine the performance of structures. The stability of structures can be tested with this parameter which is used to measure the performance of concrete under different loads. This parameter, which should be determined for the safety of the structures, is usually based on experimental analyses performed in the laboratory environment. In this study, a new approach to compressive strength measurement in civil engineering is proposed. With this approach, which is based on image processing, measurement of compressive strength parameter of concrete samples taken from structures is performed. For this purpose, images of concrete specimens with different strengths are taken and these images are divided into two groups as training and test set. Then, image processing algorithms are applied to these images and the compressive strength of concrete specimens is calculated. It has been determined that the approach suggested in the test runs performed with an error rate of about 1-2%.

Keywords: *Artificial Neural Network, Compressive Strength, Image Processing*

1. Introduction

Today, almost all of the buildings consist of reinforced concrete structures. One of the main factors in measuring the performance of these structures is the strength of concrete [1]. Especially earthquake and environmental conditions affect the structure of these structures over time. In order to measure these effects, various experimental works are carried out on the concrete with laboratory or on-site examinations. In this view, the performance of reinforced concrete structures is evaluated [2, 3].

One of the most important parameters used for performance measurement in reinforced concrete structures is the compressive strength [3]. The compressive strength is basically defined as the strength of concrete under certain loads to show that it is not broken. Various factors such as water / cement ratio, water quality, aggregate particle size and shape, cement properties, properties and quantities of chemical additives and environmental conditions are very important factors in construction. Many different methods are used in order to determine the compressive strength parameter, mainly laboratory experiments [4].

Depending on the developing technology, there is a constant innovation in the field of civil engineering. The development of measurement techniques is one of these innovations. One of the works carried out for this purpose was the measurement of the size of the cracks formed on the concrete samples. In this work, where micro fractures were measured, electron microscopy was used to display cracks. The images obtained from the microscope were examined by an image processing algorithm and the dimensions of the micro cracks were measured on the samples [5]. In another study carried out on the subject, the measurement of the air voids between the aggregates used in the concrete was carried out by image processing. In this work, these air voids affecting the compressive strength of the concrete were determined and the state of the void ratio between the air voids was observed. [6].

Nambiar et al. [7] have proposed a method to measure the effect of air voids in aerated concrete on the concrete density and strength in a given study. In the method, a camera connected to an optic microscope and image processing software are used. The distribution of the air voids on the density and strength parameters is presented in detail with the proposed method. In a study similar to this subject, characterization of elastic and time-independent deformations of aerated concrete was performed by image processing. A sample taken from the concrete is taken through a microscope connected camera and transferred to a computer for image processing. The samples used in the experiments were 28 days and the range of deformations was determined according to the pixel density obtained from the image processing. A block diagram summarizing the experimental setup used in this method is as shown in Fig. 1 [8].

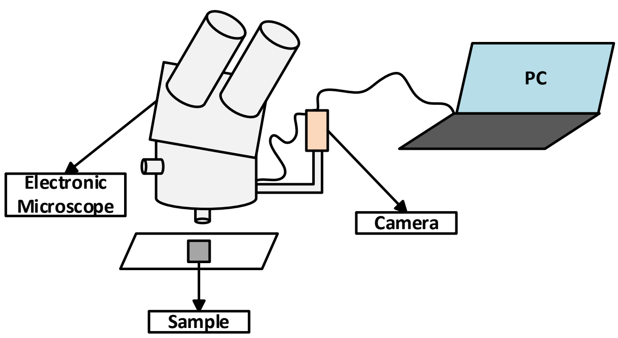

Fig. 1. Experimental setup of proposed method in literature [8]

Image processing technology is often used in many engineering disciplines to detect faults and problems [9, 10].

[1] *Computer Eng., Ardahan University, Ardahan – 75000, TURKEY*
[2] *Civil Eng., Ardahan University, Ardahan – 75000, TURKEY*
[3] *Civil Eng., Igdir University, Igdir – 76000, TURKEY*
[4] *Civil Eng., Erzurum Technical University, Erzurum – 25700, TURKEY*
* *Corresponding Author: Email: suatgokhanozkaya@ardahan.edu.tr*
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One of these studies proposed an automated inspection system that detects concrete cracks in the tunnels. In the proposed approach, the detection of cracks in cross, horizontal, vertical and complex structures has been performed by using image processing techniques. In addition to the image processing, the Dijkstra graph method was used to determine the type of crack. The approach proposed in this study is confirmed by laboratory and on-site experiments, and a block diagram summarizing the study is as shown in Fig. 2 [11].

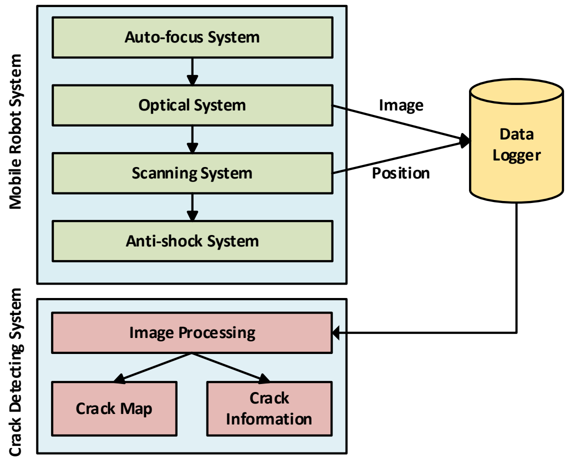

Fig. 2. Experimental setup of proposed method in literature [11]

In a study conducted for the measurement of concrete strength, 10 samples were produced using C20 class concrete. Eight of the samples were subjected to laboratory tests and the remaining 2 samples were subjected to image processing techniques. In the laboratory experiments it was measured that the samples had a strength of 28 MPa. When the results obtained by image processing are examined, it is observed that the porosity of the reinforced concrete samples is less [12]. In another work related to the subject, concrete compressive strength is measured by image processing and artificial neural networks. Arithmetic mean and standard deviation information are extracted from the pixel data of sample images taken through a camera. This data is then given as input to an artificial neural network and the compressive strength parameter of the concrete is estimated. Experimental studies demonstrate the correctness of the proposed approach [13]. Basyigit et al. [14] has used images to predict the concrete classes in their work. For this purpose samples with different compressive strengths were produced and laboratory studies were carried out on these samples. It has been found that aggregate and cement matrix percentages can be obtained in the concrete with the proposed approach, and compressive strength can be determined depending on these values.

In this work performed, image processing based concrete compressive strength parameter measurement process is done. In the second part of the study, the compressive strength parameter was investigated. The proposed method is presented in the third part of the work and the experimental results are given in the fourth part. In the fifth and last section, the results obtained from study were evaluated.

2. Compressive Strength

Compressive strength is a very important parameter used to measure the durability of reinforced concrete structures. The measurement of this parameter, which is traditionally based on laboratory and on-site measurement experiments, has a rather heavy and challenging process.

The measurements in the compressive strength measurement are basically divided into two groups, destructive and non-destructive. These groups are examined in sub-sections.

2.1. Destructive Measurements

This measurement technique is usually based on analyses performed in a laboratory environment. The samples obtained from the construct are placed in the concrete crushing machine in the laboratory environment and subjected to the crushing process. In this process the concrete crushing machine can load the samples at different compressions. At this point, it is possible to determine the point at which the sample used in the test process can withstand the maximum. A sample image of the compressive strength test performed in a laboratory environment is presented in Fig. 3.

Fig. 3. An example of destructive measurements method

2.2. Non-Destructive Measurements

In non-destructive measurement technique, analysis is made by in-situ measurement process without damaging the structure. This technique of measurement involves different techniques in the literature. Although these methods provide significant advantages over time, they can require costly measurement tools. An exemplary image of this measurement technique is as shown in Fig. 4. In addition, destructive and non-destructive measurement techniques are summarized in Table 1.

Fig. 4. An example of non-destructive measurements method

Table 1. Measurement methods [15]

Methods	*Destructive*	*Non-Destructive*	*Precision*
Schmidt Hammer	*X*	√	*Weak*
Pull-Out Test	*X*	√	*Weak*
Penetration Test	*X*	√	*Good*
Ultrasonic Test	*X*	√	*Good*
Embedded Sample	√	*X*	*Good*
Core Sample	√	*X*	*Good*

In this proposed approach, an image processing based approach to non-destructive measurement techniques is proposed. Sample images taken via a camera are pre-processed using image processing software and the results are given as input parameters to artificial neural networks designed in the scope of the study. The compressive strength parameter is obtained from artificial neural networks. The most important advantage of the proposed approach is time and cost.

3. Proposed Method

In this study, a non-destructive measurement method was developed for the determination of the compressive strength parameter which is an important issue for civil engineering. Image processing and artificial neural network methods are used in the proposed approach. The concrete samples with different strengths obtained in the study were evaluated in two different groups as training and test. These samples used in the experiments are prepared in the laboratory environment and have a waiting period of 28 days. The purpose of this waiting period is to ensure that the concrete gains strength. A block diagram summarizing the proposed approach in this framework is as given in Fig. 5.

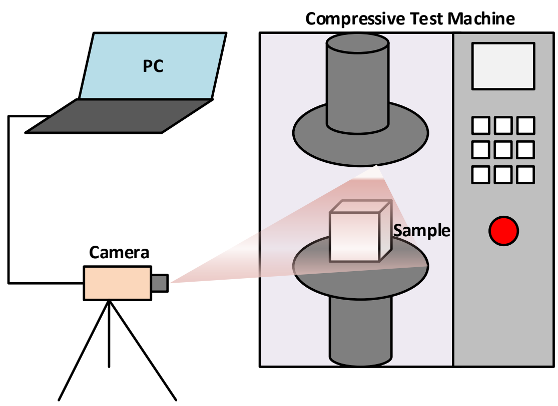

Fig. 5. A block diagram of proposed approach

In the approach suggested in the study, first concrete samples were prepared in the laboratory environment. These specimens were subjected to a 28-day waiting period to gain strength. The samples obtained at the next stage of the study were divided into two groups as training and test set. 80% of the samples were used for training and 20% were used for testing. These specimens, which are reserved for training and testing, can be taken through a camera.

At the next stage of the work, these specimens were subjected to a compressive strength test in the laboratory environment. As a result of these tests, the compressive strength of each sample is obtained. In the next stage, the images of the previously obtained samples were subjected to the image processing approach suggested in the study. Image clipping is applied to image processing and redundant images in the remote sample are removed. Later, these images were converted to gray color space. Standard deviations, arithmetic mean and median information were extracted from images converted to gray color space. The arithmetic average is obtained by dividing the sum of all the p0ixel values by the number of rows and columns, while the median value is the median of the pixel values ranked from small to large. The expression of the standard deviation obtained in the study is given in Equation 1.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \tag{1}$$

In the proposed approach, these parameters obtained as image processing result are obtained separately for training and test set. After completion of these procedures for training and test clusters, the samples are subjected to a compressive strength test in the laboratory environment and the compressive values obtained are recorded for use in artificial neural networks, the next stage of the study.

At the next stage of the system, artificial neural networks are being trained. In this process, the standard deviation, arithmetic average and median values obtained from the images of the samples used in the training set are used to enter the network. The output values of the network are compressive strength parameters. In other words, a neural network with 3 inputs and 1 output was established. The training parameters of artificial neural network designed in the study are presented in Table 2.

Table 2. Artificial neural network parameters

Parameters	*Values*
Input Layer	*3*
Output Layer	*1*
Hidden Layer	*10*
Learning Rate	*1xe*$^{-5}$
Goal	*1xe*$^{-8}$
Iteration	1000

As can be seen from Table 2, 80 data were used for neural network training. Once the intended purpose of the designed artificial neural network has been achieved, the design has been recorded for use in testing operations. An image showing the development of the artificial neural network in this frame and a flow diagram summarizing the steps of the operation are shown in Fig. 6 and 7, respectively.

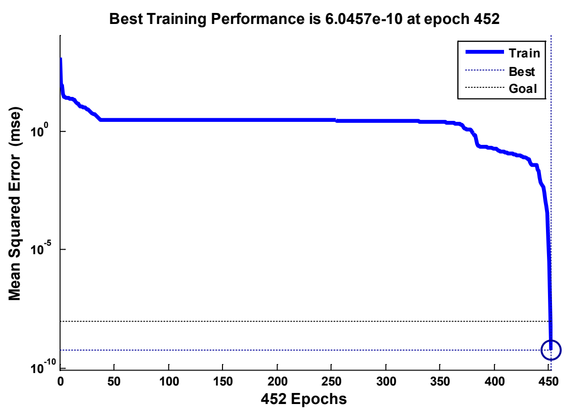

Fig. 6. Artificial neural network training performance

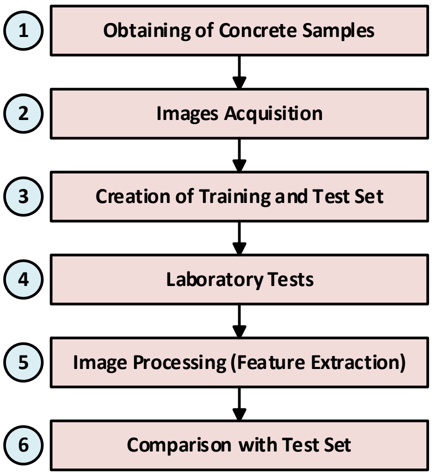

Fig. 7. The proposed approach

4. Experimental Results

In this study, compressive strength, which is an important parameter used to measure the performance of structures in civil engineering, is determined by using image processing and artificial neural networks. The samples used in the study were taken through a camera and the feature extraction process was performed by image processing algorithms. These properties were also introduced to the artificial neural networks designed in the scope of the study and the system was trained. At the end of the study, the samples collected for the test set were evaluated and the correctness of the proposed approach was provided. An image of the laboratory environment in which this study is performed is given in Fig. 8.

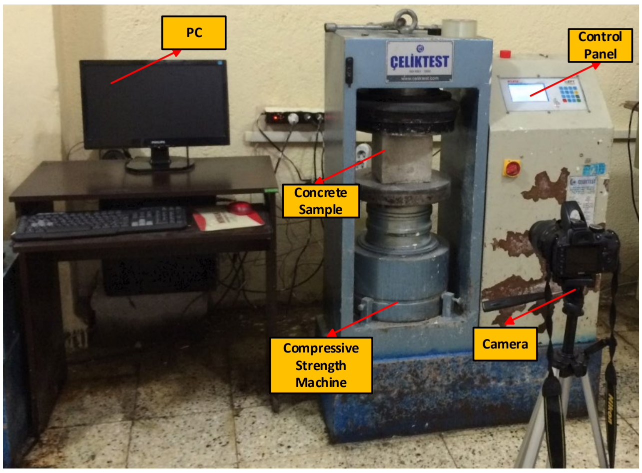

Fig. 8. The experimental setup

The proposed approach is basically composed of two parts. The first is to obtain the standard deviation, arithmetic mean and median information from the samples with image processing. The specimens used in the study have different compressive strengths, and images of some of these specimens are presented in Fig. 9. In addition, the information obtained from these samples is given in Table 3.

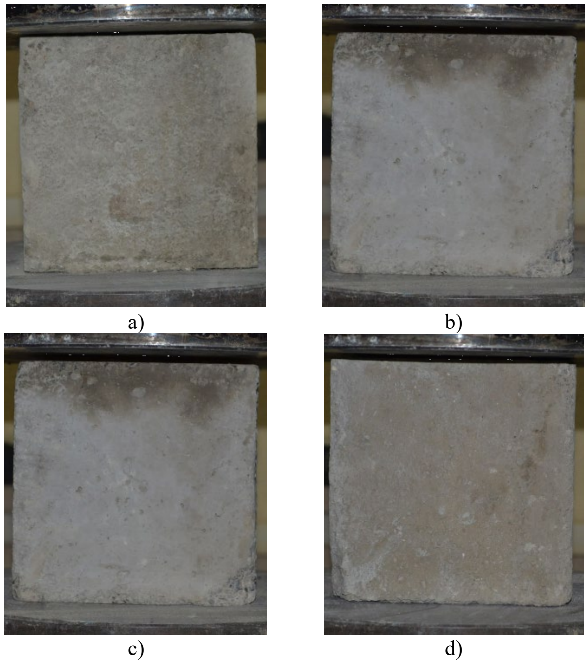

Fig. 9. Examples from training set

Table 3. Sample training data

	Parameters	*Samples*			
		S1	*S2*	*S3*	*S4*
Input	Standard Deviation	*0.0079*	*0.0101*	*0.0061*	*0.0094*
	Arithmetic Mean	*0.4796*	*0.4723*	*0.4724*	*0.4287*
	Median	*0.4980*	*0.5059*	*0.4784*	*0.4431*
Output	Compressive Strength (MPa)	*40.44*	*41.38*	*31.60*	*45.17*

In this paper, 80 training and 20 testing data were used. These specimens used in the study have different strengths. Standard deviation, arithmetic mean and median values of these samples are presented in Table 4. In the study, estimated compressive strengths obtained after the evaluation on the test specimens, the actual compressive strengths obtained in the laboratory environment and the ratios of these two values are given in Table 5.

Table 4. Sample test data

Samples	Test Parameters		
	Standard Deviation	Arithmetic Mean	Median
S1	*0.0076*	*0.4533*	*0.4549*
S2	*0.0174*	*0.4493*	*0.4706*
S3	*0.0078*	*0.4815*	*0.5020*
S4	*0.0097*	*0.4654*	*0.4824*
S5	*0.0107*	*0.4937*	*0.5137*
S6	*0.0100*	*0.4906*	*0.4941*
S7	*0.0071*	*0.5086*	*0.5294*
S8	*0.0040*	*0.4419*	*0.4549*
S9	*0.0074*	*0.4538*	*0.4648*
S10	*0.0044*	*0.4877*	*0.4980*

Table 5. Experimental test results

Samples	Test Results (MPa) Laboratory Test (LT)	Prediction Values (PV)	LT/PV
S1	*30.68*	*30.44*	*1.007*
S2	*42.35*	*41.48*	*1.020*
S3	*37.08*	*36.20*	*1.024*
S4	*28.44*	*28.24*	*1.007*
S5	*31.62*	*32.22*	*0.981*
S6	*37.40*	*36.84*	*1.015*
S7	*21.32*	*14.80*	*1.440*
S8	*37.90*	*38.60*	*0.982*
S9	*39.16*	*38.78*	*1.009*
S10	*25.81*	*26.20*	*0.985*
		Total	***10.47***
		Ratio	***1.047***

5. Conclusions

In this study, image processing and artificial neural network based prediction of compressive strength method is developed. For this purpose, concrete specimens prepared in the laboratory environment were taken and compressive strength were determined after subjected to compressive test. Afterwards, the images taken from the samples were examined with an image processing algorithm and standard deviation, arithmetic mean and median values were obtained. The obtained values were trained by the artificial neural network designed in the study and verification of the system was made with test data. In the experimental studies carried out, it was found that the proposed approach works with an error rate of about 1-2%.

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