SVU-International Journal of Engineering Sciences and Applications (2021) 2(1): 1-8
Print ISSN 0000-0000 | Online ISSN 2735-4571
DOI 10.21608/svusrc.2021.51466.1003

Semi-Automatic Approach for Forming and Processing Laser Sensing Data of Urban Truss

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Abstract There is imprecision in the stage of construction because of manual quality control in the construction procedures. Forming and processing point clouds image of as is truss part with its CAD data are researched to identify and repair the geometric discrepancies and imprecision. Approved suggested technique of processing building model was done.

Instead of manual processing of the 3D models points. BPNN architecture give the best coordinates processing training. It is applied to optimize the points forming process between the input laser scanned coordinates of the as-built model with the output true CAD coordinates. RMSE in x, y, xy, z and space vector R of all processing tasks are computed acceptably.

Keywords BPNN (Back Propagation Neural Network) ; Forming; Laser remote sensing; Processing; Point cloud; Visual Basic.

1 Introduction and Review

Terrestrial laser scanning (TLS) and Photogrammetry are commonly used to obtain points clouds in many remote sensing and geodesy applications [1]. Many scans from different positions have been taken to realize all model faces.

Fig.1 shows flowchart of the laser scanning method for site forming and compare it with two other method including manual CAD system and photogrammetry technology.

Data processing is method of forming a model or three-dimensional shape, for instance meshes, NURBS or solids. Processing of a point cloud refers to deduction of geometric information and data reduction. Furthermore, it is an important process in terms of transferring data into GIS or CAD-systems. However, post-processing is time-consuming process depending on modelling methods and needed levels-of-details [3].

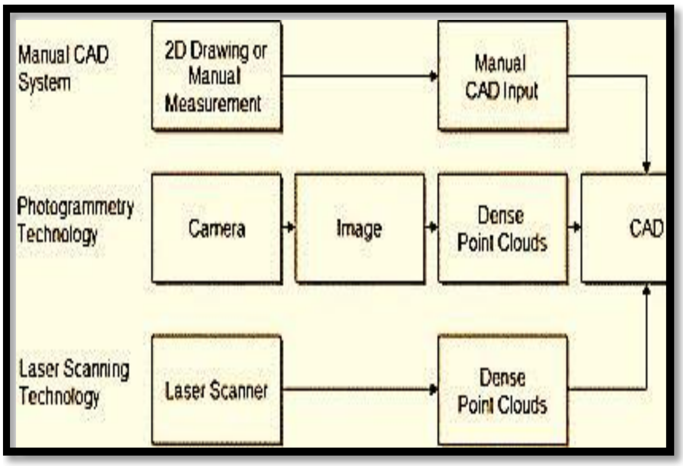

Fig. 1. Flowchart of laser scanning and compare it with manual CAD system and photogrammetry technology [2].

3D data processing is delivered in variety of forms and formats; several 3D geometries are available including cloud of points such as that shown in **Fig. 2,** polygon-mesh **(Fig.3a),** contours, and solid model **(Fig.3b).** Commercial 3D processing tools allow for both 3D surface/solid model creation and standard parts/steel profiles definition by using the best-fit techniques [4,5]. If the intensity data of the laser scanning technique are calibrated, adjusted and processed, the range of the studies will be broadened [6].

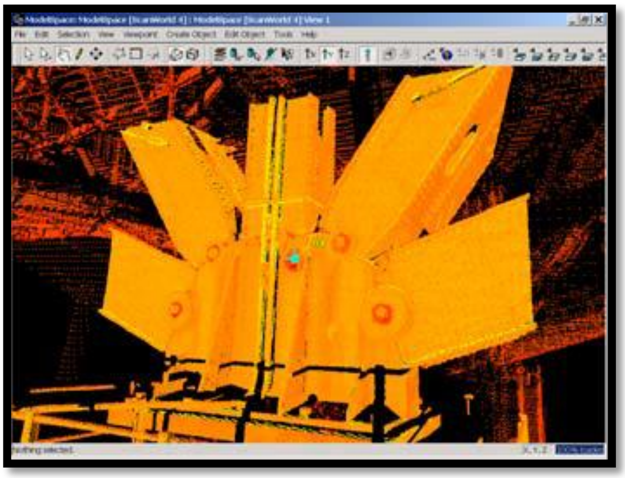

Fig. 2 - Point cloud of high-resolution zone of steel truss members joint.

Received: 14 December / Accepted: 31 March 2021

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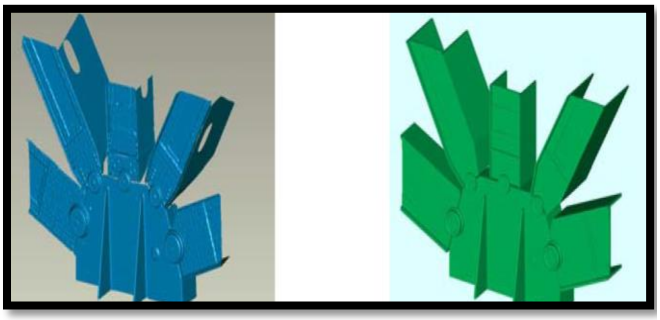


Fig. 3- a, left: 3D polygon-mesh of the steel truss joint. **b**, right: Solid model of the truss joint.

ANN is a scientific method that emulate functionalities of the biological neural networks. In ANN, the patterns are presented to the network via the input layer, which communicates to one or more hidden layers, where the actual processing is done via weighted connections [1]. ANN architecture is based on the concepts of neurons, transfer functions and layers and their interconnections. A back-propagation ANN model was then developed to model the condition state rating [7].

The conservation of some aging structures is an interesting issue faced by many nations [8]. Recently the problem of assessing the condition and working capacity of structures becomes more important. Importance of observing the technical condition of structures is developed to prevent the crisis [9]. There is need of reliable inspection technique that can provide early warning of some types of critical structures [8]. [10] cited that laser scanner that was approved in twenty-eight researches images geometrical and spatial data by laser waves [11].

Researchers existing methods and algorithms can realize automated model identification [12-13]. Terrestrial data collections can be subjective and time consuming [14].

4D range sensor cameras are latest generation of (MESA Swissranger); SR4500 is the highly accurate measuring device. It can be explored for high-precision metric applications for measuring structural errors [15].

Engineering structures are subjected to deformations as result of natural causes. This motivates necessity for a reliable solution system for identifying errors of routine construction [16, 5, 17]. There are numerous methods for determining the errors and deformations. Innovative solutions for rapid and intelligent survey are required in maintenance, repair and rebuild of enormous numbers of structures throughout the world [23].

About 10% of construction rework budget is produced because of delays in errors recognition [2, 18]. Therefore, suitable and precise inspection can save money and can advance construction plans. So, it is of little wonder that structure maintenance and management is facing severe challenges [17, 19].

[20] explored idea of referencing condition rating data (inspection data) to 3D geometric representation of the structure. However, this research didn't suggest a solution for practical issues of digitizing inspection data, and visualization of inspection observations wasn't proposed. Various types of adjustable predefined structure models were presented in [21]. To match laser data to another designed dataset, three dimensions points extraction is a vital stage. In [22] they address the problem of three dimensions points extraction of laser datasets.

So, to overcome on the previous reviewed researches disadvantages and standing in the proposed method; the research is enhancing the processing of the structure inspections data by simplifying the data forming and processing by applying and training them in ANN. Then, comparing between the laser scanned object and the designed CAD object to identify the differences and errors.

2 The Case Study and Data Models

The studied data model can be explored in CAD system as 3D designed model. The case study is a steel truss consists of steel members and joints components in CAD system software are in **Fig.4**.

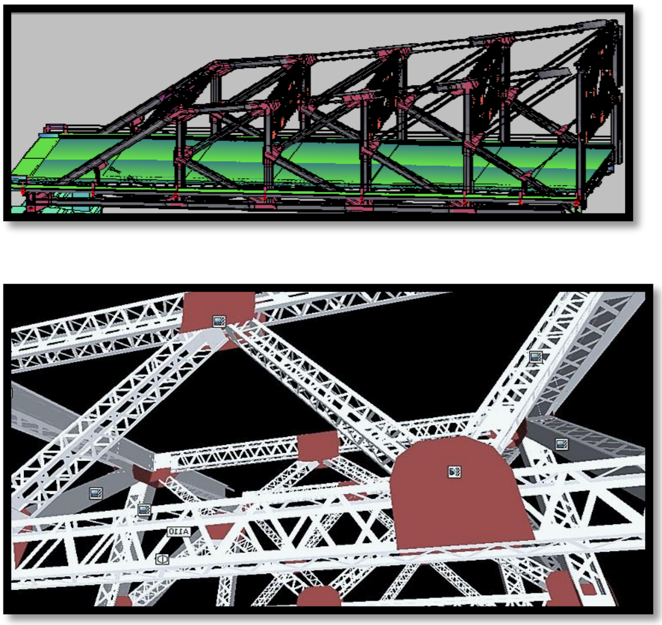


Fig.4. 3D designed models of the steel truss members and joints in CAD software.

The inspector can recognize the studied model, check its maintenance data, and produce real report.

Points cloud of the laser scans of the studied truss are shown in **Fig 5**.

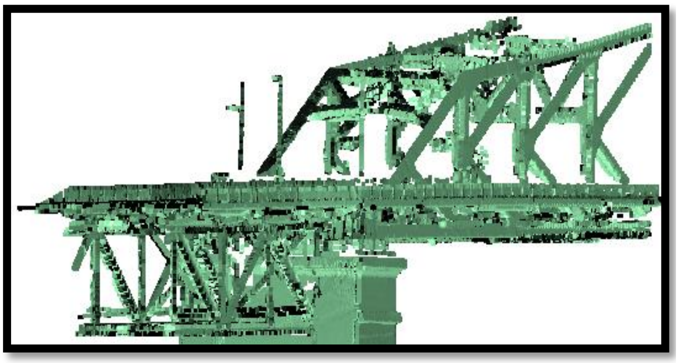


Fig. 5. Point clouds of laser scans of the truss members and joints.

3 Data Visualization

Knowledge of visual presentation of the model data permits the inspector to understand it professionally to create effective choices concerning about the model maintenance data. Checking the materials conditions of the steel truss members are inspected visually from their attached digital images in CAD software, as shown in Fig.6. Then, we can compare visually between the designed CAD model and the as-built model of the truss member, as shown in Fig.7.

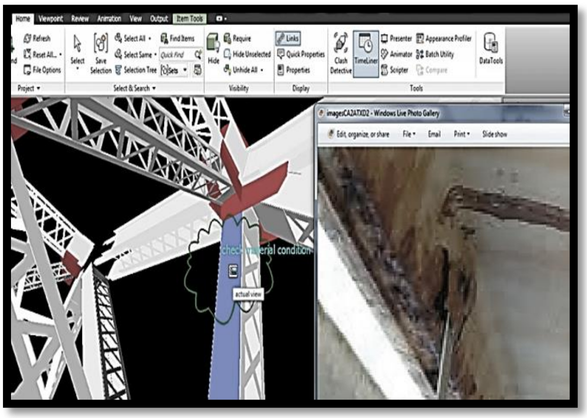


Fig.6. Check material condition of the truss member from its image visually in CAD software.

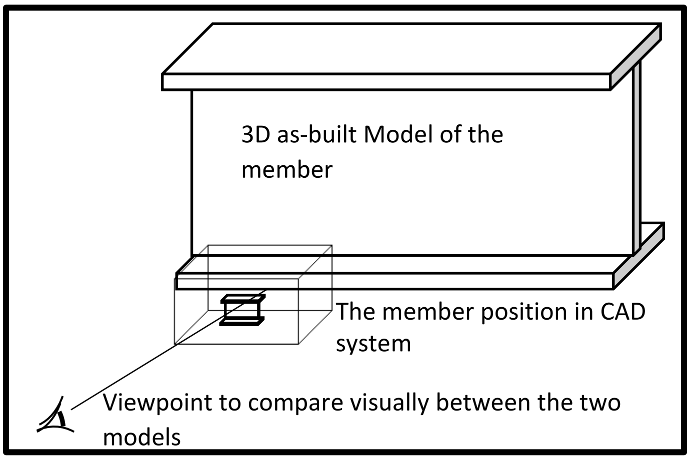


Fig.7. Comparing visually between designed CAD and as-built models of the truss member.

4 Materials and Data Scanning

Steel truss is the model of the case study. Leica laser scanner HDS2500 was utilized to scan the steel truss; its beam spot radius size is 6 mm at 50 m range (http://hds.leica-geosystems.com, last accessed in 2019). The approximate length of the studied part of the truss was 75 m. HDS2500 laser scanner was put at 107 m apart from this part of the truss. This instrument has a long range, up to about 200 m under ideal conditions. With commercially available systems, CYCLONE software program was utilized to control HDS2500 instrument. We applied AutoCAD, Geomagic, RiSCAN, MENNIGMA and LSAR software in modifying, processing, training and assessment of the steel truss models.

5 System Methodology (Processing and Training using BPNN)

To validate the possibility and practicality of the planned methodology, a system is advanced and is discussed in this section. This system is planned to achieve the previous requirements. The reasons of this innovating work are to expect improvement in the processing accuracy with more automation. In BPNN, a least squares algorithm adjusts the connection weights between units to minimize mean square error between the network output and the target output. The target output is known from the training data. There are a range of activation functions to transform the data from hidden layer unit to an output layer unit. Next iteration starts with new set of weights and parameters and the process is repeated till the convergence is achieved, and the adjusted weights are obtained [24]. At this stage, the network is assumed trained.

As shown in Fig. 8. The system starts with the as-built steel truss model thru scanning procedure to produce laser scanning coordinates model of the truss as (DXF or DWG). At the same time, the pre-designed CAD coordinates model of the truss is obtained. Then, the both models (laser scanned and designed CAD truss models) are inserted to Geomagic software program to apply the models processing and alignment.

Then, the resulted laser scanning coordinates of the truss model as input data is trained to designed CAD coordinates of the truss model as network output data, which are compared with the true CAD coordinates of the truss model as target output data using BPNN. That through Modified software (MENNIGMA) to obtain the final processed points of XYZ coordinates of the truss model. In final step, the accuracy assessments of the system are applied in MLSAR software.

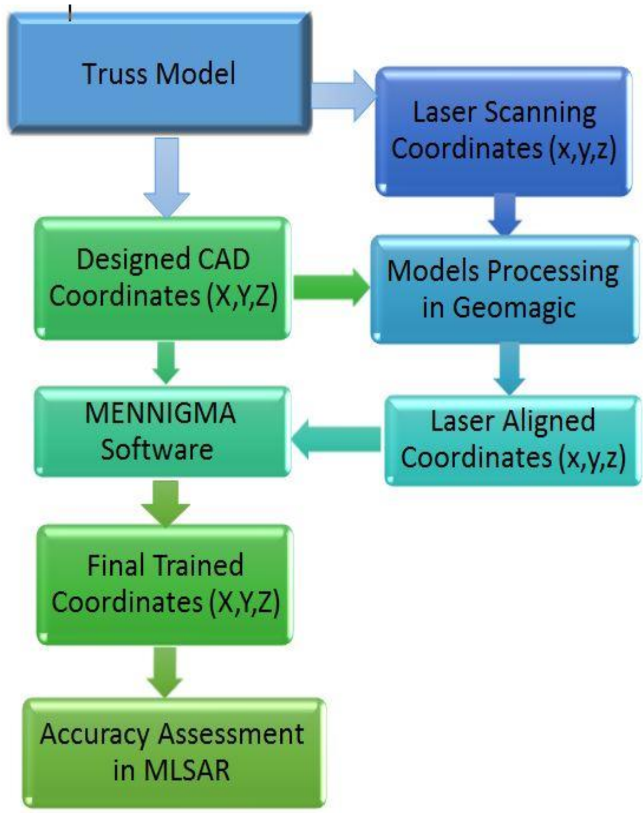


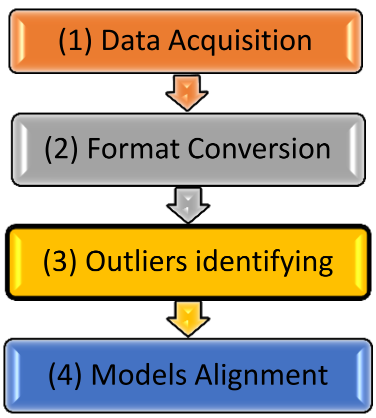
Figure 8- Overview of proposed processing and training system.

6 Data Processing

Data processing is set of modelling and forming processes to create appropriate models to be aligned in the last step. To demonstrate feasibility of the planned methodology; the pattern is advanced in the following section. The steps are presented in Fig. 9:

7 Data Processing Results

The data preprocessing was established the truss models results to be applied at the next steps. These results are:



Fg. 9- Data processing steps.

1- Data Acquisition Result

We started with acquiring the model points cloud from laser scanning by Leica laser scanner for the studied truss part imported in CAD system software (AutoCAD program) as (.dwg & .dxf) formats, as shown in Fig. 10.

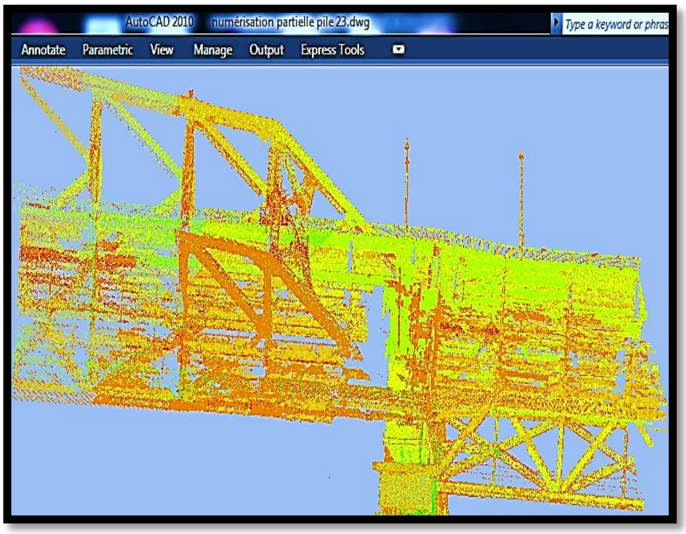


Fig. 10- Points cloud of laser scans of the studied truss in AutoCAD program.

2- Format Conversion Results

The truss points cloud format has been converted from CAD formats (.dwg and .dxf) to Geomagic software format (. wrl), as shown in Fig. 11.

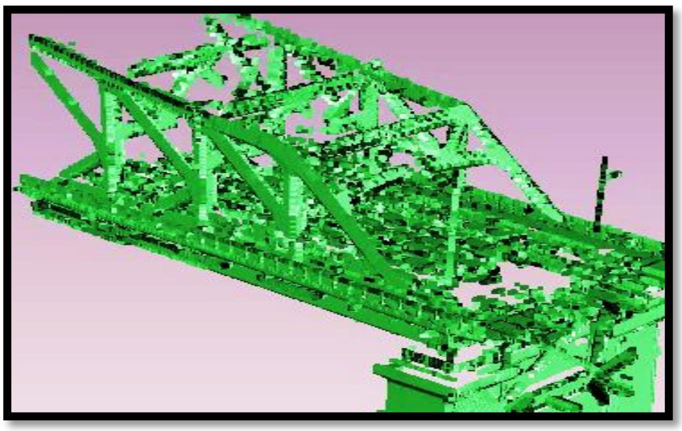


Fig. 11- The scanned truss model in format (.wrl) in Geomagic software.

It is needed to convert the designed truss model to data form equivalent to laser scan, so the CAD truss object was filled by cloud of points in Geomagic software, Fig. 12.

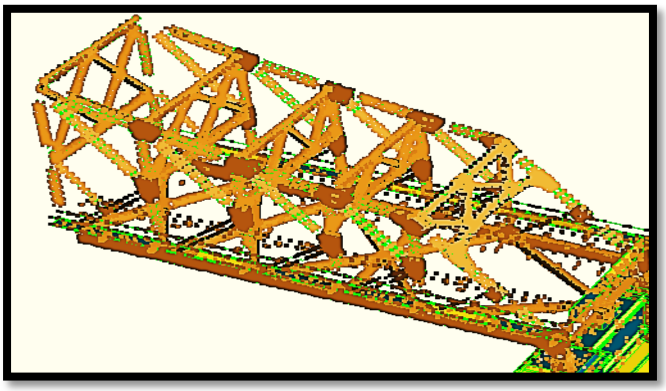


Fig. 12- The designed truss model was covered with form of 3D point clouds in Geomagic software.

3- Outliers Identifying Result

The discovered outliers algorithm in Geomagic program was applied to identify the anomalous outliers points on the studied truss model, based on these points that have distances away from the regular points in the truss model, and noticed in red colors, as shown in Fig. 13.

Fig. 13. The anomalous outliers' points were identified in red colors.

4- Results of Aligning Laser Scanned Model with Designed CAD Model of the Truss

The laser scanned truss model (Fig.14) was aligned in the same coordinate system with the designed CAD truss model by identifying pairs of well-defined corresponding points in the two models to compare and identify geometric discrepancies between them in Geomagic software, as shown in (Fig.14, Fig.15 and Fig.16).

Alignment results of the laser scanned and the designed CAD truss in Geomagic software are shown in Fig.15, and Fig.16, with average distance = 0.19 m, and the standard deviation = 0.12 m, that indicates the deviation of points distances in the overlapping regions of the two models of the truss.

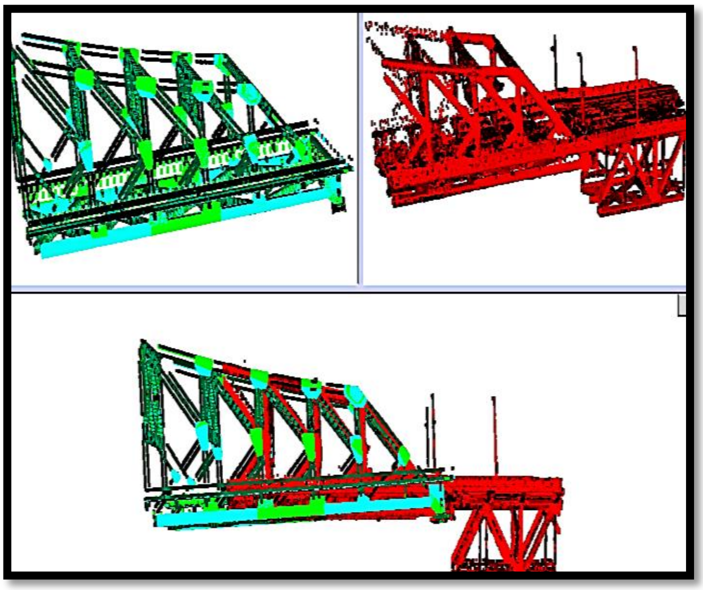


Fig.14 - Laser scanned truss [right], designed truss [left], and the alignment result [below].

The standard deviation is acceptable compared with the data accuracy acquired by the scanner of Leica with specifications (0.13 m ray spot size at 106 m distance), and compared with the approximate length of the studied part of the truss which was 75 m long.

The light columns (inside the ellipse, as shown in Fig.15) were captured in the laser scanned truss model, but these light columns are not included in the designed truss model, and this is considered as geometric discrepancy and error between the two models.

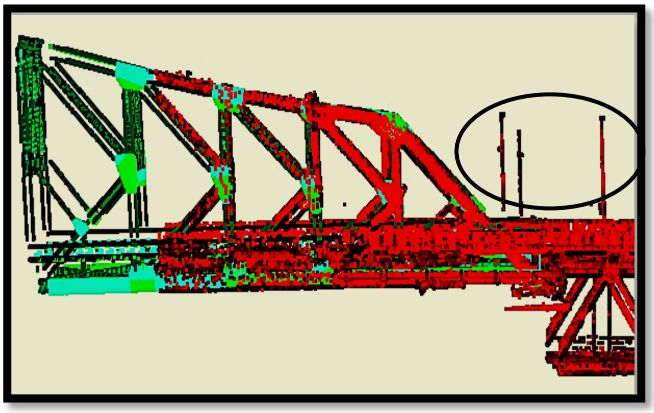


Fig.15. Aligning scanned truss with light columns [red], and designed truss [green] (without light columns).

5- Proposed Processing and Training System Results and Analysis

The proposed system results using RiSCAN, AutoCAD and MLSAR programs were output. After performing the alignment of the two truss models. Places of 17 points of well-defined targets points are chosen and its numbers are distributed in the laser scanned and the designed models, as shown in Fig. 17.

Fig.16. The final result of alignment of the two truss models, standard deviation = 0.12 m.

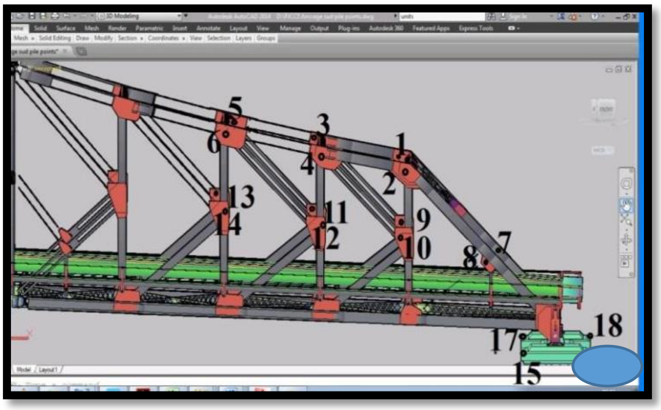


Fig. 17. The targets points numbers and its places in the truss model part in AutoCAD software.

The coordinates of the target's points are determined in the laser scanned truss model using RiSCAN program, and in the designed truss model using AutoCAD program, as listed in Table 1.

The coordinates of the 17 targets points are determined in the laser and designed truss models, as listed in Table 1.

8 Software Development

Softwares were developed by Application Programming Interface (API) which is programmed by Visual Basic VB language to achieve the research objectives.

The first software was named Modified Engineering Neural Network for Interpretation and Generalization of Meta Applications (MENNIGMA). The software is planned to automatically choice network design consistent with the path and location of network errors.

This software begins through single hidden layer with single neuron then regularly adds neurons or adds additional hidden layer in accordance with network error type. A snapshot of BPNN design of the current software (MENNIGMA) is revealed in Fig. 18.

Table 1: Coordinates of the targets points in laser scanned and designed truss models.

Points Number	X-laser	Y-laser	Z-laser	X-design	Y-design	Z-design
1	7.066	-21.448	54.071	-57091.8	3665.68	17668.43
2	27.533	-21.466	54.357	-57666.36	3658.41	18508.57
3	6.952	-31.688	56.18	-57480.72	3738.94	17682.83
4	27.493	-31.419	56.356	-57455.04	3730.18	18522.97
5	6.81	-41.897	58.177	-57873.45	3820.12	18545.69
6	27.265	-41.954	58.681	-57879.615	3799.62	18515.37
7	7.145	-11.884	44.528	-56683.753	3253.85	17659.51
8	27.765	-12.113	44.87	-56671.809	3258.38	18451.2
9	7.125	-21.11	45.364	-57081.178	3290.49	17708.93
10	27.255	-21.411	46.517	-57073.537	3339.53	18465.76
11	8.128	-30.938	47.584	-57462.02	3431.03	17722.58
12	27.524	-31.525	47.585	-57458.080	3393.49	18478.08
13	7.352	-41.697	49.075	-57901.138	3467.23	17734.33
14	27.403	-41.955	49.525	-57877.984	3459.34	18491.61
15	31.225	-9.452	34.859	-56584.494	2889.65	18616.37
17	3.893	-9.224	34.58	-56618.047	2901.08	17518.94
18	3.931	-1.624	34.492	-56318.192	2899.57	17509.76

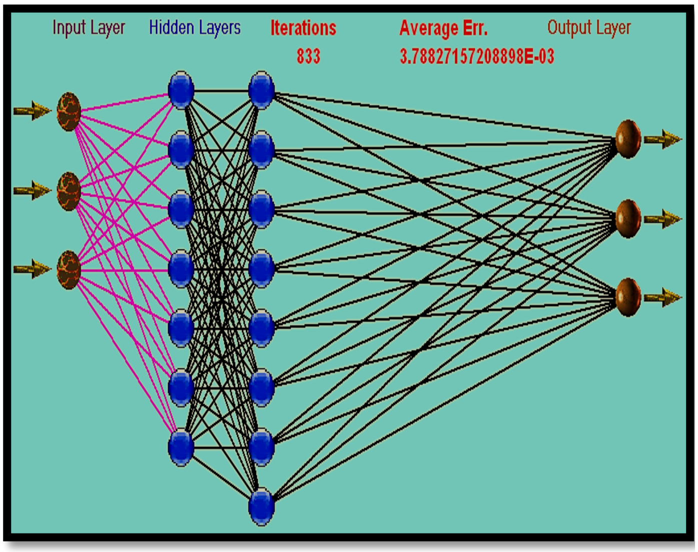


Fig. 18 - The solving process of BPNN Architecture with the current software.

In this approach, set of 3D corresponding coordinates points is firstly identified in the range images of laser points cloud of the truss model (as shown in Fig. 18, and Table 1). Then, these laser points coordinates as input data in the input layer (3 neurons as x, y and z laser coordinates) are trained to the output layer (3 neurons as X, Y and Z) of designed truss model coordinates as network output data (Fig. 18). The output designed truss model coordinates are compared to the true designed truss model coordinates as the target output data, through MENNIGMA as mentioned as before.

Evaluation of the results shows that two hidden layers with [7 + 8] neurons architecture (after 833 iterations, with average error = 3.788 E-3 ≈ 0.004 m) gave the best training and the validation results, as shown in Fig. 18.

BPNN architecture was trained automatically and validated with results. The evaluation of the results shows that architecture gave best training, validation results and least RMS, as shown in Fig. 19. Therefore, this arrangement of BPNN architecture is used to predict the output CAD truss coordinates points from the input laser coordinates points of the truss model. Also, that to optimize data processing between the input laser coordinates data of the as-built truss model with the true designed CAD coordinates. RMSE values are acceptable compared with the dimensions of the truss, as mentioned before.

9 Conclusion

It is concluded that artificial neural network ANN can predict the output CAD coordinates points from the input laser coordinates points. The evaluation of the coordinates training results shows that BPNN architecture gives the best coordinates training.

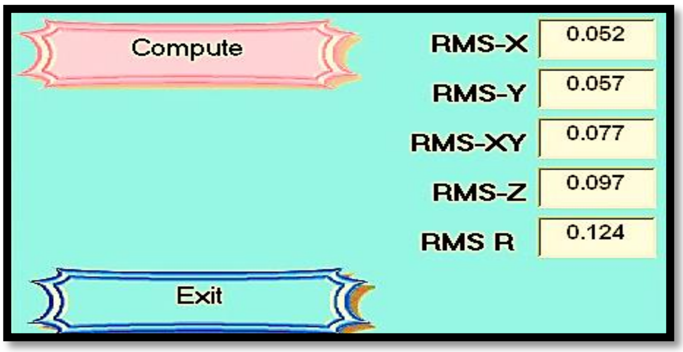


Fig. 19. The BPNN solving process gave least RMS results in MLSAR software.

In addition to optimize the points alignment process between the input laser scanned coordinates of the as-built truss model with the output true CAD coordinates. RMSE values are acceptable compared with the scanning data accuracy.

Developments of two specific purposes software (MLSAR and MENNIGMA) are reliable for data training, evaluation and optimization of the proposed systems performance.

All standard deviations of the alignment process are acceptable; compared with the data accuracy acquired by the scanner of Leica with specifications (0.13 m ray spot size at 106 m distance), and compared with the approximate length of the studied part of the truss which was 75 m long. It is concluded that the desired accuracy and precision for all forming and processing tasks are achieved for the studied truss.

More trying of the advanced portions of the system is recommended and needed to increase the functionalities and usability of the system.

It would be noted that this study is still in development and several features discussed about the requirements are still to be applied and verified. Additionally, we are in the procedure of adapting the system for several applications.

Acknowledgments

Authors acknowledge Prof. Dr. Amen Hamad and data sources for the investigation information.

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