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Digital Mapping of Urban Arterial Roads Pavement Conditions

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Abstract: This paper explores integrating Geographic Information System (GIS), Computer Vision (CV) and Artificial Intelligent (AI) using cellular phones to evaluate and manage pavement conditions. It enables non-expert users to assess and maintain pavements effectively. The study develops CV-based mapping and a knowledge-based system for distress detection and management. Statistical regression models predict pavement sustainability. Finally, this approach empowers users to make informed maintenance decisions.

Different cameras resolutions ranging from 0.2 to 16 MP were used to build an intelligent framework system to evaluate and manage pavement conditions with suitable maintenance works by non-expert users. A CV based system was developed for pavement surface mapping using cellular phones. A macro scale mapping of pavement surface conditions in the presence of flexible pavement distresses was developed by cellular phones with normal based configuration and various camera resolutions of arterial roads in Irbid city, Jordan.

GIS layers were built for pavement conditions with various parameters, rating, distress types, severities and repairs options based on Global Position System (GPS) determination for distresses locations. The developed GIS System was established by integrating a set of computerized programs as a part of GIS software. New parameters were introduced to the system to expedite the pavement distresses classification, detection, management, and maintenance process, taking into account distress types, severities and geometrical measurements.

A knowledge-based system (KBS) for pavement maintenance was also developed. It took into consideration distress type, severity, and pavement conditions. A criterion for images enhancement processes based on image processing technique for pavement distresses detection and management was developed. Surface measurements, pavement conditions as well as decision-making tasks have been supported and considered for all distress types.

The developed statistical regression analysis models for pavement sustainability, serviceability and condition prediction utilized a set of extracted resulted measured variables of Pavement Condition Index (PCI), Present Serviceability Index (PSI) and Sustainability Index (SI) from various sources. They were conducted for the collected actual data with the values of (84.8, 2.988 and 0.6057) respectively. Regression results were statistically significant for all models with normal probability plots near a straight line.

Keywords: Portable Cellular Phones, Computer Vision (CV), Geographic Information System (GIS), Artificial Intelligent (AI), Knowledge-Based System (KBS).

1 Introduction

Reading is the entrance to all sciences, since reading is one of the most human means to discovery, learning and communication. Also, reading is considered of the most essential methods to develop knowledge, self-creative capabilities, sense and cognitive study. Reading is the process of customizing students how and what to read. The most important objective of reading is to prepare and enable students scientifically and cognitively to get the knowledge by their own, and to be effective as thinkers and creators, so as to enter and compete creatively and creatively in the real world. Reading is the key to the door of reason because whomever reads puts God Almighty's directives in His Holy Book into practice, making it the lamp of knowledge with numerous advantages for our present and future. Reading is another crucial component for the development of a child because it fosters abilities, creativity, intelligence, and innovation. Reading also helps the child build a closer relationship with language as a medium of expression and a way of thinking.

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All countries over the world focus on the transportation sector and give it great attention due to its involvement in the development and production lines. The importance of highways or roads grows up while the area of any country increases with highly growing of population and technological development.

Roadways contribute to a high-level development of all countries in the world by providing suitable links between people and their merchandise in every movement. Highway Pavement is the building block of roadways; as a structure of a road, consisting of number of layers. Flexible pavement structure is the most widespread type of pavement.

Structural and functional failures of pavement mainly resulted from many critical factors including traffic, environmental, human, materials, construction, and others that lead to many distresses in its structure. Therefore, the sustainability of pavement serviceability should be improved and conserved with many using of correlations, relations, methods and models for pavement maintenance and pavement conditions prediction using several modern technologies and techniques.

Pavement condition data is a massive data that needs several rating systems for pavement condition predictions and repair actions in a timely manner. In Jordan, periodical schedules and programs of highways are focusing on Pavement Condition Index (PCI), Pavement Serviceability Index (PSI) with pavement sustainability and roughness. These indices are the most common types of pavement indices in rating systems.

Conventional methods of distresses data collections require time and sometimes aren’t safe, whereas; other integrated methods aren’t portable and not accurate. However, data collection, planning, presentation, decision-making, budget allocation and follow-up procedures are usually performed manually. Spatial mapping as a tool would help in decision making integrated by the usage of GIS for pavement condition management such as route distress types, severities, and suitable repair works.

Integration of GIS systems along with Artificial Intelligent techniques depending on knowledge-based system with special relations and links to achieve the required pavement performance and help non-professional users in pavement conditions planning and decision-making processes. The development of digital mapping using new technologies, automated and expert processes for urban arterial roads pavements would have a critical significant effect and impacts on decision making, management assessment and pavements evaluation.

This research used portable cellular phones with different camera resolutions in data collection process supported by image processing, vision systems and artificial intelligent systems as expert system to extract useful pavement conditions information and decision-making tasks of the urban arterial roads for routine maintenance.

The main aims of this work were to investigate the feasibility of macro scale mapping of pavement surfaces conditions; by integration of GIS, CV, and AI; using portable cellular phones with different cameras resolutions. It could build an intelligent and integrated framework to evaluate the flexible pavement conditions when the non-expert users use it and concerned on developing new scheme for PCI data collection using cellular phone images. Further, to develop a maintenance road information and management system by the integration of GIS, CV and AI and exploring a new approach in the domain of flexible pavement conditions, serviceability, and performance for future.

This work is anticipated to have a significant effect on decision making management, assessment, and evaluation. It has the potential to give semi-automated detection of distress types, severities, and repairs options by integration of developed system utilizing cellular phones, GIS, CV, and AI as an effective tool for pavement condition data collections.

2 Literature Review

Monitoring or surveillance process gives a general vision of pavement sections performance with accurate information of their rehabilitation and repair requirements. The key in monitoring is making the best evaluation of pavement condition in the presence of different anomalies by doing various surveys for data acquisition and condition rating purposes to perform the physical characteristics of pavement condition serviceability and age for long lasting life period.

Digital mapping system and computer vision systems are the most effective methods with full ability and capacity for pavement distresses monitoring and collection that used for pavement distresses identification with the brightness terminology and images characteristics related to the surrounding area under different conditions [1]. Mobile mapping systems used for pavement performance improvement with certain regulations and applications by recording pavement conditions information in accurate real-time situations and data of pavement distresses [2].

Pavement management system (PMS) is an essential tool of pavement assessment as a set of activities related to pavement planning, design, construction and rehabilitation with certain requirements and models with the most cost-effective treatment categories [3]. Ferreira et al. [4] studied the international pavement management performance with several models. They showed that PMS had many advantages, especially best prediction of pavement performance with certain obtainable historic datasets and better chance of perfect decisions of pavement management.

PCI is one of the most important techniques for pavement management. It is needed for pavement management with structural integrity and surface controlling; ultimately the performance of pavement conditions by investigating distress type, quantity, severity in asphalt pavement surface with suitable M&R periodic works [5]. PSI and International Roughness Index (IRI) are management indicators used for predicting the serviceability and the roughness of roadways pavements in a certain ride quality as numerical scales [6].

In transportation perspective, pavement sustainability represented as an indicator of various pavement segments, called sustainability index. It is a dependent variable set as a function of several independent variables such as PSI, PCI and others. This relation leads to strength and efficient sustainability of pavement condition prediction and performance management in multi dimensions [7]. Various computerized programs can be used for pavement structures sustainability analysis and functional pavement behaviors studying for different joint plains [8].

The integration of PMS into GIS with CV has many advantages such as, ability of integrating spatial data with specific analysis in various fields, moderating with external software and specific programs to access several layers from different data collection, and analysts can rapidly select associated layers. In addition, safe, economical, and accurate road data pavement conditions could be extracted based on the integration operation between PMS, GIS, CV and GPS in accurate manner [9, 10, 11, 12 and 12].

Norela et al. [14] showed an overview of expert systems (ES) development in asphalt pavement management system in highways. They found that ES has significant benefits over the traditional computerized programs and models. Also, they investigated ES as an efficient tool in different pavement problem solving in an accurate, analytical, and strong domain of pavements knowledge-based systems.

Zhou et al. [15] sophisticated that different statistical models, standards, and criteria were developed for asphalt pavement distresses detection and classification. They found that those criteria were examined on several pavement distress images, for extracting certain measurements and specific features of road surface distresses, include type, severity, and various numerical quantities.

CV, Image Processing (IP) and mobile devices can be integrated with each other. The integrated helped in pavement performance prediction by extracting distresses features and information from their images using image processing techniques to get the best indication of pavement condition with high quality prediction and assessment [16].

In this research work, CV Cellular-based system integrated with GIS, GPS and KBS was developed and used for the first time according to literature and authors' knowledge. It could be used in order to collect distress information, analyze maintenance data, and perform decision making through a semi-automated mobile system.

3 Research Methodology

3.1 Experimental Work for Data Acquisition

Portable cellular phones with various cameras resolutions were used for roads distresses data acquisition and collection to automate the extracted measurements of the distresses images as well as the roads pavement identification, evaluation, and prediction processes. Roads distresses images were captured from the field for different arterial roads using portable cellular phones cameras setup arrangement with different resolutions. Road distresses were located, identified by its types, severities and repair options from images using the visual vision perspective, quantified, featured, and analyzed for surface measurements and parameters determination.

3.2 Experimental Setup

To secure the orientation and field of views of portable cellular phones cameras as well as their geometrical dimensions and position that are fixed on the normal base configuration; a special shelf was manufactured for cellular phones cameras setup and installed over the trunk of a mobile vehicle. Images of arterial roads for actual distresses of different resolutions were mapped using a normal base cameras configuration of known positions from GPS mobile application while the truck is in motion mode. Calibration distresses images were also captured for scale computation purpose using some distresses with pre-measured dimensions. Figure 1 shows the truck and the manufactured shelf used for cellular phones cameras set up to hold four cameras.

Fig. 1: A manufactured shelf of cellular phones cameras set up.

3.3 Data-Acquisition Digital System

The developed Data-Acquisition Digital System was used to collect pavement condition images to evaluate its potential in detecting accurate surface measurements in the field of the road network. Four types of portable cellular phones with different camera resolutions (Nokia XL, Samsung Galaxy Note3, Samsung Galaxy S-duos and I-phone 6) were used to collect road distresses data. The used system represents a modern semi-automated data-acquisition digital system. Hundred-forty images for five urban arterial roads in Irbid city were captured using actual distresses data. Automated measurements were extracted from the mapped scenes to develop different statistical models for different pavement distresses. Figure 2 shows sample images of flexible pavement distresses captured by Samsung Galaxy Note3 cellular phone. Actual measurements for all road distresses were also extracted for the purposes of calibration and validation. Measured variables extracted from images of the data acquisition digital system included distress parameter such as length, width, area, PSI, SI, density, deduct value (DV), corrected deduct value (CDV), PCI, the standard vehicles accumulated suspension motion and the distance travelled by the vehicle using the highest resolution phones, i.e. IPhone 6. In addition, image processing techniques were applied on distressed images to extract the automated measurements after performing the suitable enhancement processes to the images.

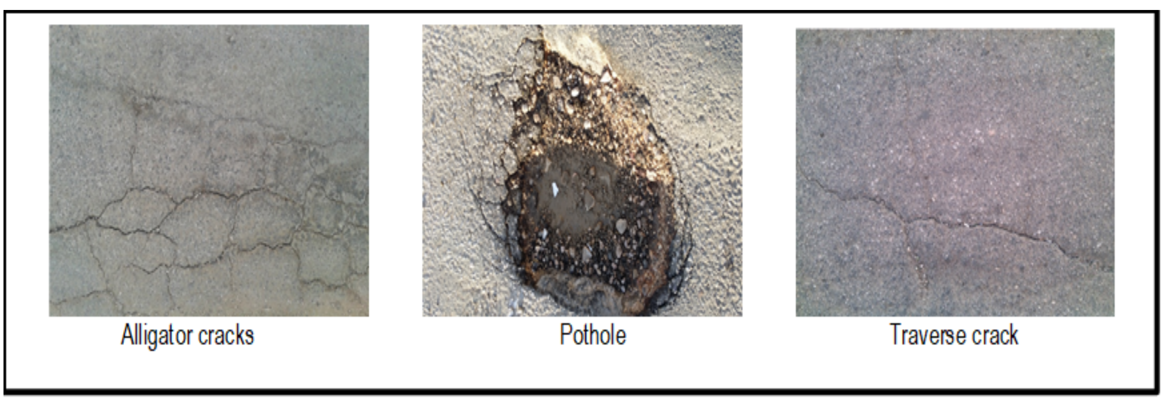

Fig. 2: Actual flexible pavement distresses images captured by Samsung Galaxy Note3 Camera from the field.

Mapped images were digitized and converted to suitable digital format ArcMap software. AutoCAD Irbid city base-map was converted using Data Conversion Tools into GIS map. Data projection and scaling were satisfied for GIS map to get the best properties and characteristics for many features such as dimension, areas, directions, and shapes. Features and useful information extracted from road maps were linearly transformed from real three-dimensional (3-D) word into two-dimensions (2-D) to be suitable as GIS layers. Arterial urban roads with their associated extracted distresses and their GPS locations were laid out to be used as GIS layers. Figure 3 shows the studied arterial urban roads with the points on the tracks pointed to the locations of the 140 images of distresses locations.

Fig. 3: Arterial roads with locations of captured images of distresses in Irbid city.

3.4 Software Development

To perform and conduct this research, computerized programs were needed to capture distresses images, digitize all critical points, measure, and quantify the parameters, determine the causes and the proposed repair works for eliminate the problem and represent the outputs in an automated manner without human intervention for making the best decisions. The distresses' data were handled and sorted by determining their type, description, severity, and quantitative amount for each roadway. GIS database converted the surface pavement distresses into physical inputs, authenticating their location and quantity using specific spatial data and coordinates systems. Each road had a certain layer in a table of contents with specific separated attribute table in GIS that described all urban arterial roads information. It was identified and performed with various real information, knowledge and indices observed from the field survey. All possible information and inputs were determined, inserted, and tabulated in GIS with the resulting outputs. Figure 4 shows the layout of the roads with their distresses' locations as layers in GIS software.

Studied layer included: PCI, IRI, PSI, SI, distress types for all arterial roads, Irbid-City base-map, etc.

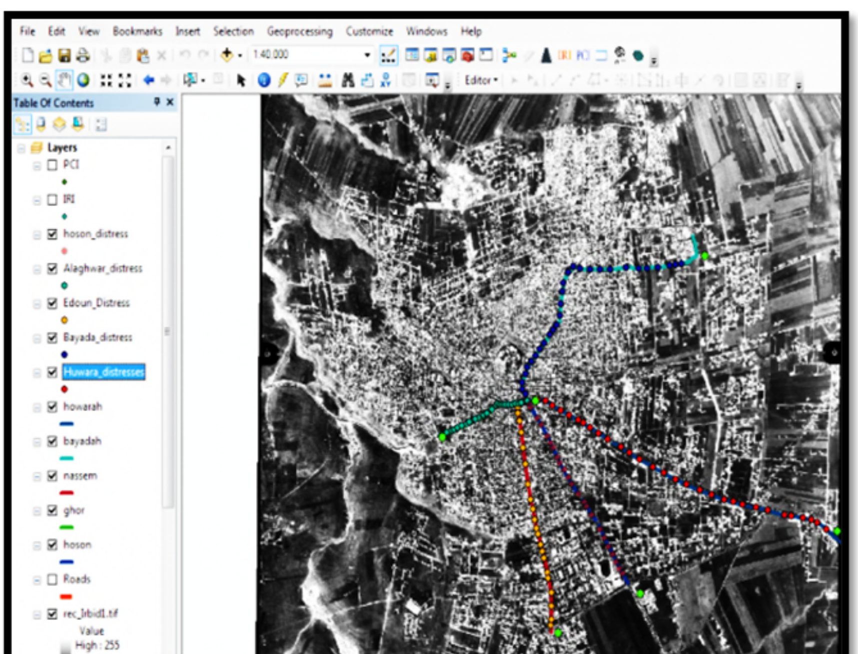

Fig. 4: Roads and distresses layers in GIS.

The modern technologies submit many applications and software that can be used for many purposes in different fields, to get the suitable assessment and management strategies in an accurate, easily, and right way. GIS, CV, PCI, KBS and AI software were developed using several programming languages to achieve study goals. Distresses' locations, types and severity were displayed through the vision of their images depending on the extracted elements, to apply the most applicable management approach for all roads. It was satisfied by the visual process between distresses images, computer sight and device. The integration was achieved when the user inserted his information then, the system will explain the conditions for pavements with all types of flexible pavement distresses with certain checking and rating. A new updating of GIS software version was achieved when the programs integrated in each other for pavement transportation sector requirements.

3.5 Integration of GIS, GPS, CV, and AI with KBS in a Modern Unit System

A schematic strategy planned on the urban arterial roads' pavement distresses in this study. It was focused on the integrity of all programs and technologies in one unit system to develop and create new GIS software. Figure 5 shows the schematic diagrams of building new systematic program in the study work. Sequencing and correlating techniques were calculated and enforced on roads pavement distresses images to extract many various parameters were helped in pavement performance, condition evaluation and prediction.

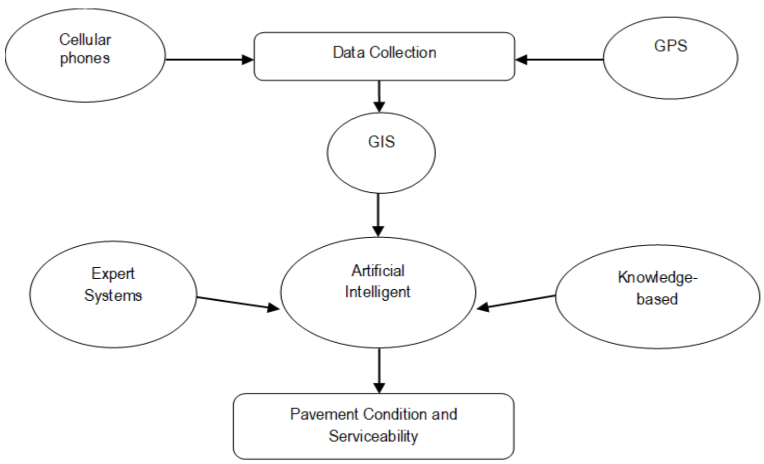

Fig. 5: Schematic diagram of new systematic unit system in study work.

Portable cellular phones and GPS applications are used to describe pavement conditions with the presence of different types of distresses, spatial information, and digital images, which inserted in GIS software as GIS layers. The interference between GIS and CV appeared in an integrated related GIS system when the hyperlink process activated. All roads' distresses were hypered automatically in GIS layers, once the urban arterial roads and the distresses points had been chosen. The integrity of the whole system building needs a flexible pavement distresses maintenance and management program to achieve the aim of the integration. The maintenance program was held in a merge unit system in GIS by forming automated series of roads distresses statements were inserted in a KBS system with their types, severity and the suitable maintenance repair work in a sequence system. An expert system was represented and integrated into GIS software; to provide the best artificial intelligence with knowledge-based information techniques to the whole system without a great human effort. Figure 6 shows the integration of the technologies in GIS software.

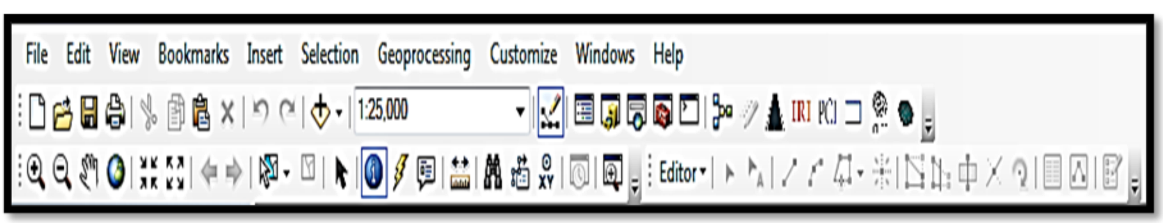

Fig. 6: The integration in GIS software.

3.6 Image Enhancement Techniques as IP Implementation

Sequencing and correlating techniques were enforced on roads pavement distresses images to extract many various parameters helped in pavement performance, condition evaluation and prediction. Urban arterial roads pavement distresses images were modified and edited with critical amendment of properties and characteristics using MATLAB software to get the most acceptable and accurate information from the images, for different parameters and variables.

Images enhancement applied on all roads' pavement distresses images with different processes and methods using MATLAB software to improve the quality of the images, reduce the noising of the images and get the most accurate information and measurements for calculating parameters and variables can be used in the analysis. Figure 7 shows image processing techniques applied on cracking distress.

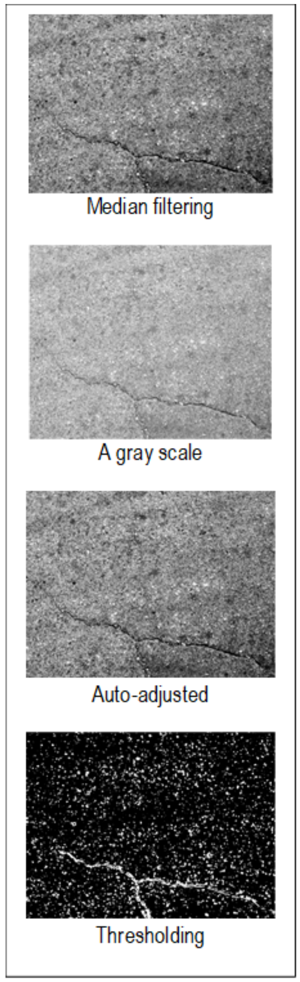

Fig. 7: Image processing techniques for cracking distress.

3.7 Statistical Analysis

Linear regression analysis (LRA) was applied on both data groups; the actual collected distresses data points of the five urban arterial roads and the automated data points of distresses measurements after images enhancement techniques stratification. Various analyses conducted from different extracted parameters and measurements with certain calculations in each data groups using Statistical Package for the Social Sciences (SPSS) software to get the best prediction and performance of roads pavements sustainability for serviceability and condition. Sustainability Index (SI) models and PCI models were built for both data groups in this study.

4 Results and Discussion

4.1 Descriptive Analysis

SI models were built for each urban arterial road with an accurate regression analysis with considering of PSI parameter. The summary of the actual collected data descriptive analysis for the overall roads is obtained for the inserted variables; PSI (X) and SI (Y). Several statistical parameters and indicators got from the analysis. The mean of the variables X and Y was 2.9877 and 0.6058 respectively. The standard deviation was calculated for each variable with 0.18839 for SI (Y) and 0.93498 PSI (X). For the automated data, the mean of the variables X and Y was 4.5714 and 0.9514 respectively. Also, the standard deviation was 0.58939 and 0.07120 for X and Y respectively. Also, PCI models were developed for the data groups of roads with the effects of IRI parameter.

4.2 Regression Analysis

SI regression analysis models were developed for each urban arterial road. The summary of the regression models and their indicators for the actual and the automated data of each road are respectively presented in Tables 1 and 2. From the results shown and after the accurate comparison between both data groups of roads, it can be discussed that all roads in both groups are good overall significant for prediction with these small p- values in statistically significant models. The SI models of all roads in the actual data group have perfect predictors with high values of R-square ranging between 88 to 98 %.

Table 1: A summary of roads statistical analysis results for actual distresses data.

Road	SI -model	P-value	F-value	R-square	Adjusted R-square
Al-Huson	SI = -0.121 + 0.228 PSI	0.000	513.494	95.7%	95.5 %
Al-Aghwar	SI = 0.01 + 0.201 PSI	0.000	1222.936	97.8%	97.7 %
Edoun	SI = 0.02 + 0.199 PSI	0.000	303.230	92.9%	92.6%
Hakama	SI = 0.036 + 0.194 PSI	0.000	575.638	95.4%	95.2%
Huwara	SI = -0.013 + 0.206 PSI	0.000	223.283	88.9%	88.5%

Table 2: A summary of roads statistical analysis results for automated distresses data.

Road	SI -model	P-value	F-value	R-square	Adjusted R-square
Al-Huson	SI = -3.694 + 8.671 PSI	0.000	475.146	95.4%	95.2%
Al-Aghwar	SI = 0.5 + 0.1 PSI	0.000	1.051E16	100%	99.8%
Edoun	SI = 0.436 + 0.113 PSI	0.000	513.139	95.7%	95.5%
Hakama	SI = 0.372 + 0.127 PSI	0.000	421.502	93.8%	93.5%
Huwara	SI = 0.489 + 0.102 PSI	0.000	494.200	95.6%	95.4%

SI and PCI models were developed for all actual and automated data points of overall roads. SI model for the overall roads actual data observations was formed as the following:

$$\mathbf{SI = 0.014 + 0.198\ PSI} \qquad (\mathbf{R^2 = 96.6\%,\ R^2\ adjusted = 96.55\%}) \qquad (1)$$

The independent variable had a numerical value as a coefficient used in SI model formation. The PSI (X) had a value of 0.198 and the constant had a value of 0.018689, which represents the βo value in SI model. From the ANOVA, the p-value for the regression was 0.000 which means that the linear regression equation has good overall significant for predictions with the small values which was zero, with statistically significant model. F value from the F-test was 3891.625 for the regression. In addition, the resulted R-square from the regression analysis was 96.6%, which indicated that the independent variable explained about 96.6% from the variability of the dependent variable SI, with statistical relation. This value showed that the model was perfect with the best predictor chosen and followed the linear regression analysis. The R-square value indicated that the SI variable could change by 96.6% from the effect of the independent variable. In addition, the adjusted R-square was 96.55% for the model. Both p-value and R-square values showed how well the linear regression equation fits the sample data of the roads. The gathering of all roads' observations got the best model accuracy, power, and prediction with high level of linearity rather than each one alone. In addition, SI model for the overall roads automated extracted data was developed using the results of the regression analysis variables coefficients to get the best prediction of the sustainability of all roads pavement with the considered of independent variables. It was formed as the following:

$$\mathbf{SI = 0.408 + 0.119\ PSI} \qquad (\mathbf{R^2 = 96.7\%,\ R^2\ adjusted = 96.66\%}) \qquad (2)$$

PSI variable had a numerical value as a coefficient used in SI model formation was 0.119 and the constant had a value of 0.408, which represents the βo value in SI model. From the ANOVA, p-value for the regression was 0.000 which means that the regression equation has good overall significant for predictions with the small values which was zero, with statistically significant model. The F value from the F-test was 4020.478 for the regression. In addition, the resulted R-square from the regression analysis was 96.7%, which indicated that the independent variable explained about 96.7% from the variability of the dependent variable SI, with statistical relation. This value showed that the model was perfect with the best predictor chosen and followed the linear regression analysis. The R-square value indicated that the SI variable could change by 96.7% from the effect of all independent variables. The adjusted R-square was 96.66% for the model. Both p-value and R-square values showed how well the linear regression equation fits the sample data of the roads. From the statistical regression analysis for all roads, several SI models resulted with different statistical factors that play an important role in roads pavement sustainability evaluation, serviceability, and prediction with certain influential factors. PCI-IRI models for both data groups were analyzed and developed based on reference data. There were followed the power relation and formed for the actual and the automated data respectively as the following:

PCI = 87.0559 * IRI -0.434397 **(R^2 = 58.6%)** (3)

PCI = 94.5802 * IRI -0.373113 **(R^2 = 54.9%)** (4)

The value of R2 of the actual and the automated were 58.6% and 54.9% respectively with .000 p-values, which means that the regression equation has good overall significant for prediction with the small values with statistically significant model.

4.3 Normal Probability and Residual Plots

The normal plots show a line along the points, explaining that an assumption of normality is reasonable for the data groups. Also, the residual plots for the models show identical form of points around the line that mean the models fit the data in a good way. Figures 8 and 9 show the normal probability plot and the regression standardized predicted value of SI model for the actual collected data.

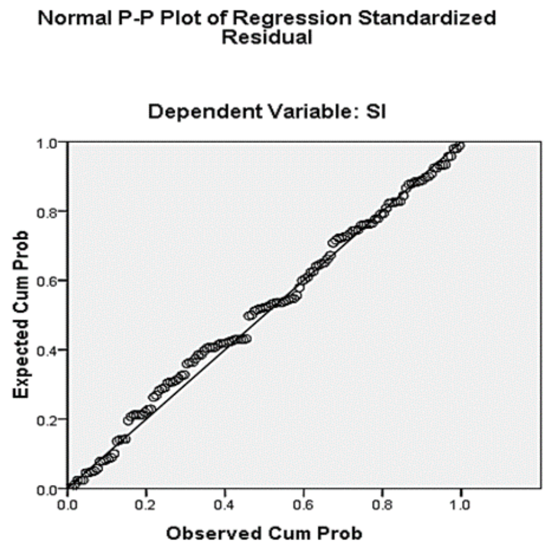

Fig. 8: Normal probability plot of the standardized residual for predicted SI model of the actual data.

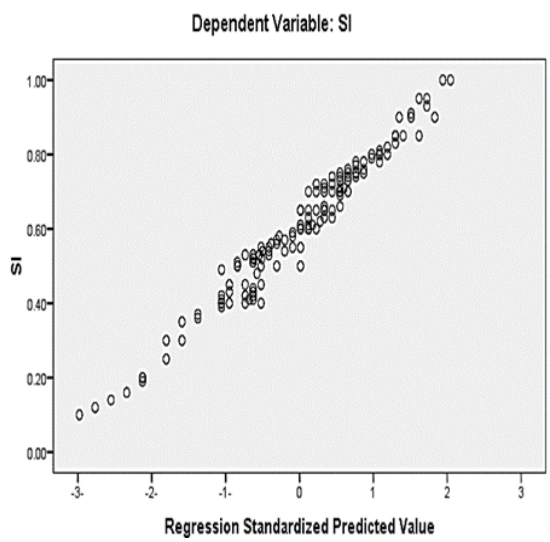

Fig. 9: Regression standardized predicted value with SI response model.

5 Conclusions

The implementation of this work was aimed at making a digital mapping of urban arterial roads pavement conditions evaluation using modern technology. This study is the first digital mapping of urban arterial roads of pavement conditions analysis by integration of new technology; especially using the portable cellular phones in Jordan transportation sector. No previous studies have been conducted on pavement conditions evaluation and their predicted performance in the integrity of different modern technologies with certain analysis in Arab nations.

An automated integration unit system from several modern technologies for urban arterial roads pavement conditions evaluation and serviceability performance prediction was developed. It gained potential impacts in pavement evaluation field, distresses detection with severity levels and proposed repair works.

Data collection for pavement distresses images using portable cellular phones demonstrated rapid, less cost and modern technology compared to manual data acquisition.

The integration of GIS, GPS, CV, and AI with KBS has been proven to be an available tool for pavement conditions evaluation where it was computed, evaluated, and predicted using SI and PCI models with high correlation coefficients.

Portable cellular phones cameras resolutions and image processing enhancement of pavement distresses affect the precision of the extracted distresses features, properties, parameters, and measurements. However, critical differences were found between the real-actual and the automated extracted data measurements.

The findings from this study support pavement serviceability, conditions evaluation, prediction, maintenance, assessment, and management with strong SI models for each road and overall. All SI models followed linear analysis with high R-square values; 96.6% and 96.7% for both the actual and automated data group respectively with high correlation coefficients between SI and PSI parameters with collinearity in the models. In addition, PCI models for both data groups followed the power mathematical relation with 54.6% and 54.8% values of R2 for the actual and the automated respectively. The measured variables of PCI, PSI and SI for the actual data collected were (84.8, 2.988 and 0.6057) respectively. However, this study is essential for the pavement sector in the transportation world. It can be applied to different roads in other countries to gain the best pavement serviceability and conditions performance. It is worth widening this kind of research in the transportation field to improve roads pavement quality.

6 Recommendations

The results of this study led to the critical conclusion that the integration between GIS, CV, AI, ES with knowledge-based could be efficiently applied in digital mapping of the urban arterial roads pavement conditions evaluation and performance prediction. This work is the first in studying roads pavement conditions evaluation and prediction association of the integrity of variants new technology. This prospective can be operated if further research is pointed toward the following jobs: Perform pavement conditions expression analysis of urban arterial roads on all governorates of the kingdom, provide alternative for pavement conditions evaluation using Artificial Neural Network (ANN), provide and suggest independent variables to examine the possibility of association between the variables and their effects on the SI variable and its models, expand the use of digital mapping of pavement conditions evaluation and prediction with advance technologies and statistical analysis into high level of roads and types as; a key improvement of roads pavement treatment with minimum risks and hazardous impacts in transportation sector and spread adaptable image capturing procedure to minimize the risk and hazard over fieldwork procedure.

Conflicts of Interest Statement

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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