An-Najah National University
Faculty of Graduate Studies

Developing a Roughness Criterion as a Basis for Performance Measurement of Palestinian Roadway Network

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Dedication

To My Beloved Family with Respect and Love

Acknowledgment

My sincere gratitude and appreciation to my supervisor Dr. Osama Abaza for his kind help, advice and encouragement. I would like to extend my deep thanks to all members of staff at the faculty of engineering and all who helped in this project.

Last but not least my deep thanks for my family for their support throughout my studies.

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Abstract

Well known fact states that a good roadway network has strong and positive relationship with the national economy. Therefore, research is applied in most countries and academic institutions to find a suitable approach to evaluate pavements so as to develop a pavement management system "PMS". The pavement evaluation should be measured objectively and not subjectively. The main objective of this thesis is to develop a machine utilizing roughness criteria as a basis for PMS program. The proposed machine will have the capability of reading the road coordinates. A mathematical model was developed to measure those parameters that form the basis for the software developed for processing the input data.

The serviceability can be determined by the use of the static profile. The new machine determines the road level every 0.64m, and with using rating systems such as the International Roughness Index "IRI", the decision can be made to find out the maintenance strategy needed.

Based on the results obtained in this thesis, the mathematical model developed in association with the machine designed for implementing this model reflects the true coordination of pavement structure from the point of view of performance and road profile.

Chapter One

Introduction

The roadway network in the Palestinian Territories is classified into main, regional, and local roads. Under Israeli occupation, the roads suffered from sever deterioration caused by poor maintenance. The existing roadway network suffers from a lack of fund, poor maintenance activities, lack of experienced and trained staff, shortage of equipment and manpower, an increase in traffic volume, and lack of control on weights of heavy vehicles.

The roadway network is in need of a comprehensive maintenance program in order to keep it functional in a suitable manner. Inadequate institutional structures working in road management in the Palestinian Territories have led to poor maintenance polices, and thus in part to inadequate road condition. The other main factor is the lack of funds.

Since a good roadway network has strong and positive impact on the national economy, the development of a maintenance management system, which can be used to priorities of urgent work, is crucial. Therefore, urgent attention is given to the development and implementation of a maintenance management system.

Regular and reliable information on road condition is essential for proper maintenance management plan. The reliability of data to be collected by an inspection team depends very largely on the techniques being used. Good techniques will lead to a good data and a good maintenance system for the roadway network in the Palestinian Territories.

Current techniques mostly depend on visual inspection, Present Serviceability Rating “PSR”, serviceability and performance measurements. These measurements depend largely on trained personal in this field as well as the limit extent to the coverage of network segments using those techniques. The use of visual inspection practiced locally on project basis with little or no wide scale performance measurement on network bases.

Human evaluation of serviceability of roads is very important for practical purposes and interesting from both the physical and theoretical points of view. Various serviceability indexes associated with the readability of roads have been developed and applied for pavement maintenance, rehabilitation, and design purposes.

There are three major ingredients in the serviceability concept, namely, the static road profile, the vehicle characteristics, and the driver's or passenger's response to the ride character at a given speed. The early investigations on the serviceability of roads mainly focused on relating the distress of a road surface, e.g., slope variance of a wheel path measured by "static" profilometers, to the user's response.

Later, the role of vehicle characteristics in road evaluation was considered, since the response type road roughness measuring systems (RTRRMS) have been put into practice. However, many different explanatory variables have been introduced over time. Most of the previous studies on the serviceability of roads sought explanatory variables, which would correlate well with some rating index of a road given by a panel of raters. The physical reasons for selecting these variables were never made clear. It is necessary to establish the roughness as new criterion for Palestinian Territories in order to evaluate pavements texture objectively and determine the serviceability of roadway network.

The main objective of this thesis is developing equipment to measure roughness (lack of smoothness) in order to examine construction acceptability and long-term evaluation. The equipment should be light in weight and capable of movement over pavement at speeds approaching highway traffic to minimize danger to personal and traffic interference.

In this thesis, the general kind of roughness evaluation machines was studied in addition to rating systems, which were summarized in Chapter Two. The details of the new machine were explained in Chapter Three, and the mathematical model with the electrical parts was categorized in Chapter Four and Five. Chapter Six includes machine testing and evaluation on a selected road section. The output data of this machine is presented in Appendix A, and Appendix B put side-by-side Level Instrument results and the new machine output.

Chapter Two

Literature Review

2.1 Introduction

Rating systems are needed, which provide feed back to the agency on the suitability of the riding quality from standpoint of the highway user, permit orderly scheduling of the pavement maintenance, assist in establishing priorities for reconstruction, and generally help to ensure protection of the substantial investment in the roadway system.

Pavement roughness is generally defined as an expression of irregularities in the pavement surface that adversely affect the ride quality of a vehicle (and thus the user). Roughness is an important pavement characteristic because it affects not only ride quality but also vehicle delay costs, fuel consumption, and maintenance costs. The World Bank found road roughness to be a primary factor in the analyses and trade-offs involving road quality versus user cost. Roughness is also referred to as "smoothness", although both terms refer to the same pavement qualities.

The parameter of longitudinal and horizontal variation of the roughness are wave irregularities, wavelength, amplitude, frequency, speed (vehicle characteristics, tires, seats suspension, body mount, weight…etc), and perception (passenger sensibilities to acceleration, speed, resonance, and mental condition of driver).

2.2 Pavement evaluation

The American Association of State Highway Officials “AASHO” Road Test developed a definition of pavement serviceability and the present serviceability rating (PSR) that is based on individual observation. PSR is defined as "The judgment of an observer as to the current ability of a pavement to serve the traffic it is meant to serve. To generate the original

AASHO Road Test PSR scores, observers rode around the test tracks and rated their ride using the quantitative scale shown in Figure 2.1. This subjective scale ranges from five (excellent) to zero (essentially impassable). Since PSR is based on passenger interpretations of ride quality, it generally reflects road roughness because roughness largely determines ride quality.

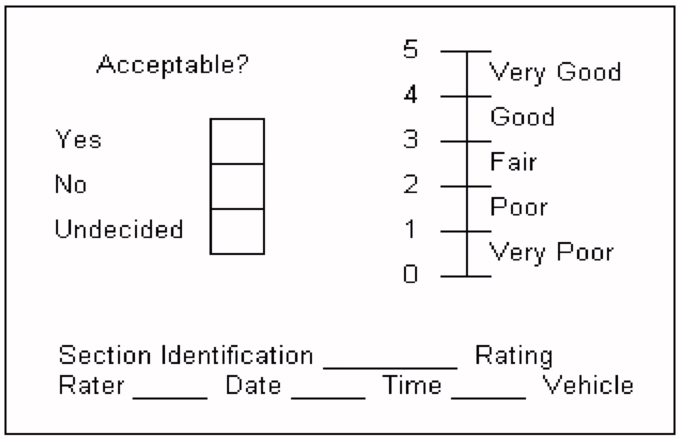


Figure 2.1. Individual present serviceability rating form.

The present serviceability index (PSI) is based on the original AASHO Road Test PSR. Basically, the PSR was a ride quality rating that required a panel of observers to actually ride in an automobile over the pavement in question. Since this type of rating is not practical for large-scale pavement networks, a transition to a non-panel based system is needed. To transition from a PSR serviceability measure (panel developed) to a PSI serviceability measure (no panel required), a panel of raters during 1958 to 1960 rated various roads in the states of Illinois, Minnesota, and Indiana for PSR.

This information was then correlated to various pavement measurements (such as slope variance (profile), cracking, etc.) to develop PSI equations. Further, the raters were asked to provide an opinion as to whether a specific pavement assessed for PSR was "acceptable" or "unacceptable" as a primary highway.

Although PSI is based on the same 5-point rating system as PSR, it goes beyond a simple assessment of ride quality. About one-half of the panel of raters found a PSR of 3.0 acceptable and a PSR of 2.5 unacceptable. Such information was useful in selecting “terminal” or failure serviceability (PSI) design input for empirical structural design equations.

It is interesting to note that the original AASHO Road Test raters opinions were based on car ride dynamics; it is unclear whether such levels are acceptable for trucks.

Pavement performance can then be defined as "the serviceability trend of a pavement segment with increasing number of axle applications" (3). Figure 2.2 further demonstrates this concept.

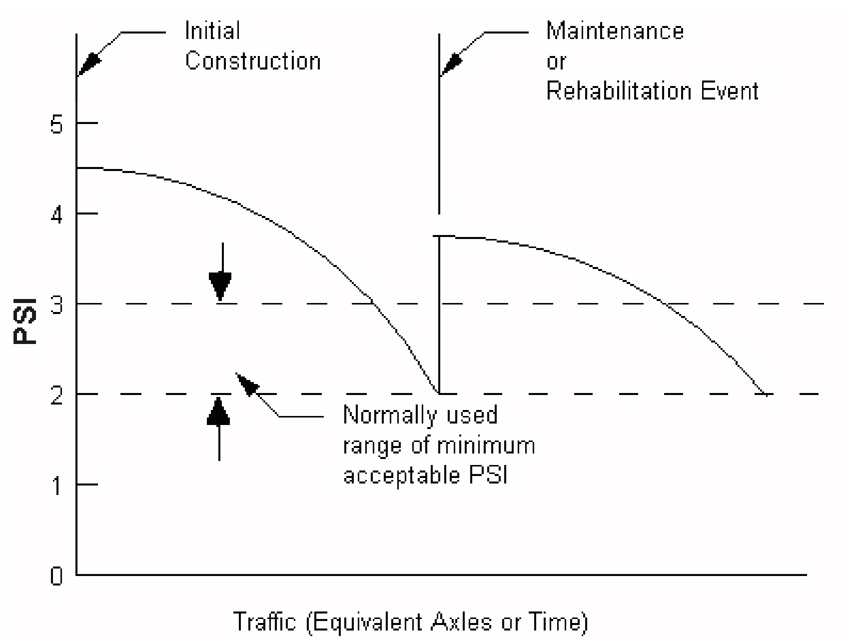


Figure 2.2. Concept of pavement performance using present serviceability index (PSI) (8).

The Present Serviceability Index "PSI" was established from regression equations, which related user's opinions with objective measurements (AASHO slope profilometer) with the extent of cracking, patching, and rutting.

The international roughness index (IRI) was developed by the World Bank in the 1980s (8). IRI is used to define a characteristic of the longitudinal profile of a traveled wheel track and constitutes a standardized roughness measurement.

The commonly recommended units are meters per kilometer (m/km) or millimeters per meter (mm/m). The IRI is based on the average rectified slope (ARS), which is a filtered ratio of a standard vehicle's accumulated suspension motion (in mm, inches, etc.) divided by the distance traveled by the vehicle during the measurement (km, mi, etc.). IRI is then equal to ARS multiplied by 1,000. The open-ended IRI scale is shown in Figure 2.3.

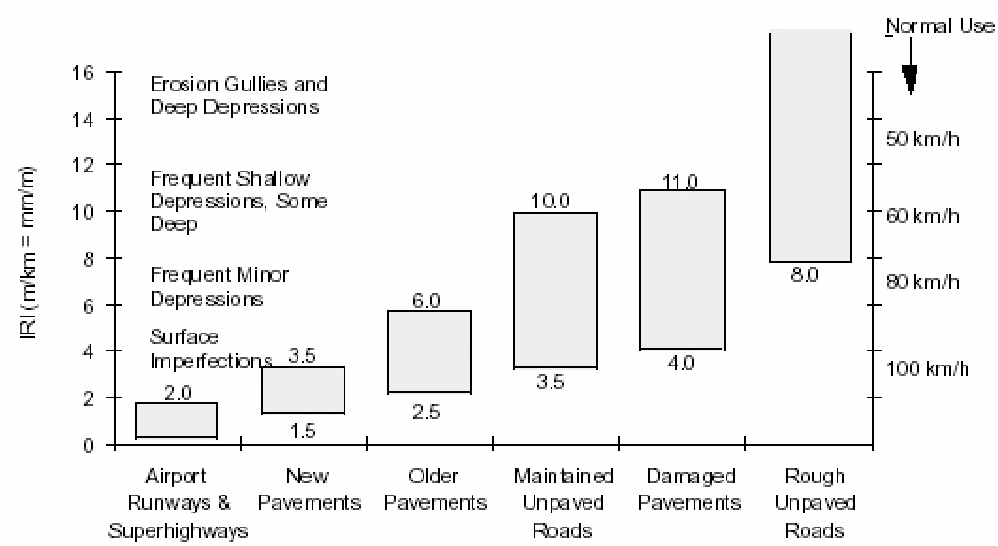


Figure 2.3. IRI Roughness scale (8).

2.3 Correlation between PSR and IRI

Various correlations have been developed between PSR and IRI. Two are presented here. One was reported in 1986 by Paterson(6):

$$PSR = 5e^{-0.18(IRI)}$$

where: PSR = Present Serviceability Rating

IRI = International Roughness Index

Another correlation was reported in a 1992 Illinois funded study (8):

$$PSR = 5e^{-0.26(IRI)}$$

The previous study and correlation used data from the states of Indiana, Louisiana, Michigan, New Mexico, and Ohio for both flexible and rigid pavements. The associated regression statistics were $R^2 = 0.73$, SEE= 0.39, and n= 332 sections. Correlations were highly dependent upon the data that were used.

2.4 Measurement techniques

The equipment for roughness survey data collection can be categorized into the four broad categories shown in Table 2.1.

Table 2.1. Roughness measuring equipments.

Equipment / Technique	Complexity
Rod and level survey	most simple
Dipstick profile0r	
Profilographs	Simple
Response type road roughness meters (RTRRMs)	complex
Profiling devices	more complex

The following discussion with a few modifications was taken directly from the "Pavement Condition Data Collection Equipment" article in the FHWA Pavement Notebook (1989) (8).

2.4.1 Survey

A survey (performed by a survey crew) can provide an accurate measurement of the pavement profile. The use of surveys for large projects, however, is impractical and cost prohibitive.

Figure 2.4 Dipstick

Figure 2.5 Dipstick Operation

The dipstick profiler can be used to collect a relatively small quantity of pavement profile measurements. The Dipstick Profiler (see Figures 2.4 and 2.5) consists of an inclinometer enclosed in a case supported by two legs separated by 305 mm (12 in.). Two digital displays are provided, one at each end of the instrument. Each display reads the elevation of the leg at its end relative to the elevation of the other leg. The operator then "walks" the dipstick down a pre marked pavement section by alternately pivoting the instrument about each leg.

Readings are recorded sequentially as the operator traverses the section. The device records 10 to 15 readings per minute. Software analysis provides a profile accurate to ± 0.127 mm (± 0.005 in.). A strip can be surveyed by a single operator in about one-half the time of a traditional survey crew. The dipstick is commonly used to measure a profile for calibration of more complex instruments.

2.4.2 Profilographs

Profilographs have been available for many years and exist in a variety of different forms, configurations, and brands. Due to their design, they are not practical for network condition surveys. Their most common use today is for rigid pavement construction inspection, quality control, and acceptance. The major differences among the various profilographs involve the configuration of the wheels and the operation and measurement procedures of the various devices.

Profilographs have a sensing wheel, mounted to provide for free vertical movement at the center of the frame (see Figure 2.6). The deviation against a reference plane, established from the profilograph frame, is recorded (automatically on some models) on graph paper from the motion of the sensing wheel (see Figure 2.7 and Figure 2.9).

Profilographs can detect very slight surface deviations or undulations up to about 6 m (20 ft) in length.

Figure 2.6 Profilograph

Figure 2.7 Profilograph output

WSDOT profilograph information

Wisconsin Department of Transportation "WSDOT" uses the California Profilograph to check rigid pavement construction smoothness (8). The measured parameter, called a "profile index", was developed by the California Division of Highways starting in 1956. The goal was to develop a relationship between a calculated index and a subjectively obtained panel rating of road roughness. After a careful survey, the profile index was developed based on 0.2 inch "blanking band" as illustrated below in Figure 2.8.

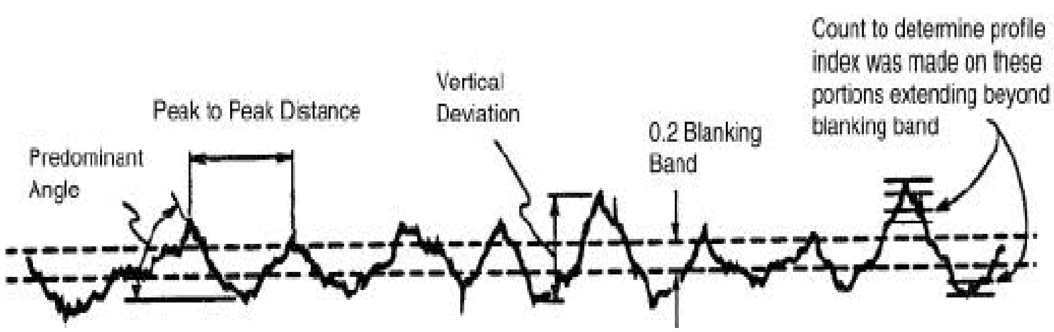


Figure 2.8 Profile index characteristics according to WSDOT.

The blanking band significantly reduced the data analysis effort since only "scallops" (deviations or excursions of roughness above or below zero) that exceeded the blanking band would be significant and have to be analyzed.

WSDOT recognized that the blanking band precluded faulting up to 0.2 inches. Although considered annoying, the vibration caused by this level of faulting did not create accelerations large enough to produce discomfort to the passengers. Thus, the profile index is a count of the inches per mile in excess of the 0.2 inch blanking band. WSDOT specifies the following profile index parameters:

- A daily profile index less than 7 inches per mile. This specification attempts to ensure an overall construction smoothness.
- High points having deviations larger than 0.3 inches shall be ground down so that they do not exceed 0.1 inches. This specification prevents a single large bump from being averaged out over a days' worth of data.

Profile index can be roughly related to other measurements of smoothness and condition. One study showed that for every 2 inches per mile increase in profile index, PSI decreases by about 0.1 (9).

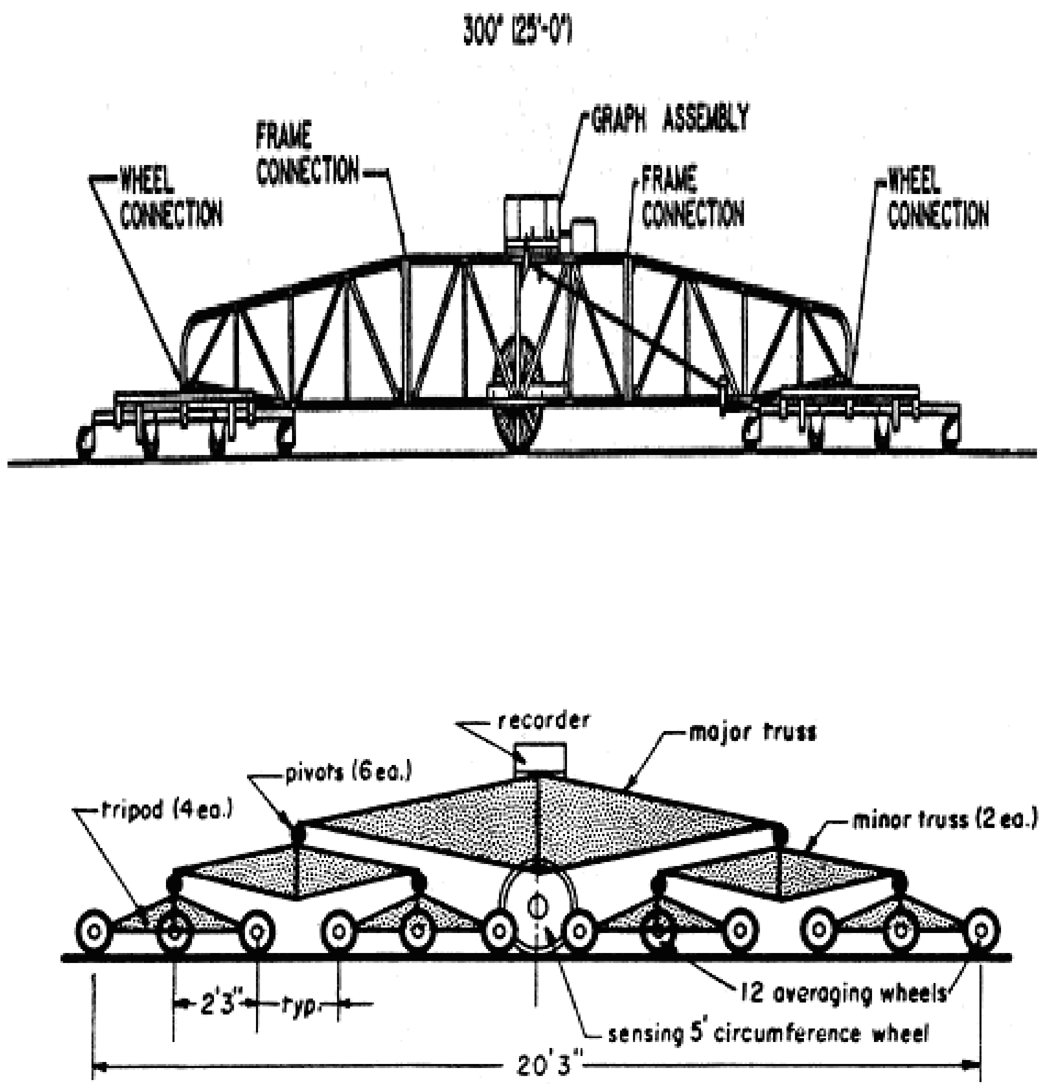


Figure 2.9 California profilograph and rainhart profilograph (side view).

2.4.3 Response type road roughness meters (RTRRMs)

The third category of roughness data collection equipment is the response type road roughness meters (RTRRMs), often called "road meters". RTRRM systems are adequate for routine monitoring of a pavement network and providing an overall picture of the condition of the network. The output can provide managers with a general indication of the overall network condition and maintenance needs.

RTRRMs measure the vertical movements of the rear axle of an automobile or the axle of a trailer relative to the vehicle frame. The meters are installed in vehicles with a displacement transducer on the body located between the middle of the axle and the body of a passenger car or trailer, Figure 2.10 explain the meter position.

The transducer detects small increments of axle movement relative to the vehicle body, Figure 2.11 give details about longitudinal and lateral profile. The output data consists of a strip chart plot of the actual axle body movement versus the time of travel.

The disadvantage of a RTRRM is that its measured axle body movement versus time depends on the dynamics of the particular measurement vehicle, which results in two unwanted effects:

- *Roughness measuring methods have not been stable with time*. Measures made today with road meters cannot be compared with confidence to those made several years ago.
- *Roughness measurements have not been transportable*. Road meter measures made by one system are seldom reproducible by another.

Because of these two effects, profiling devices are becoming more popular.

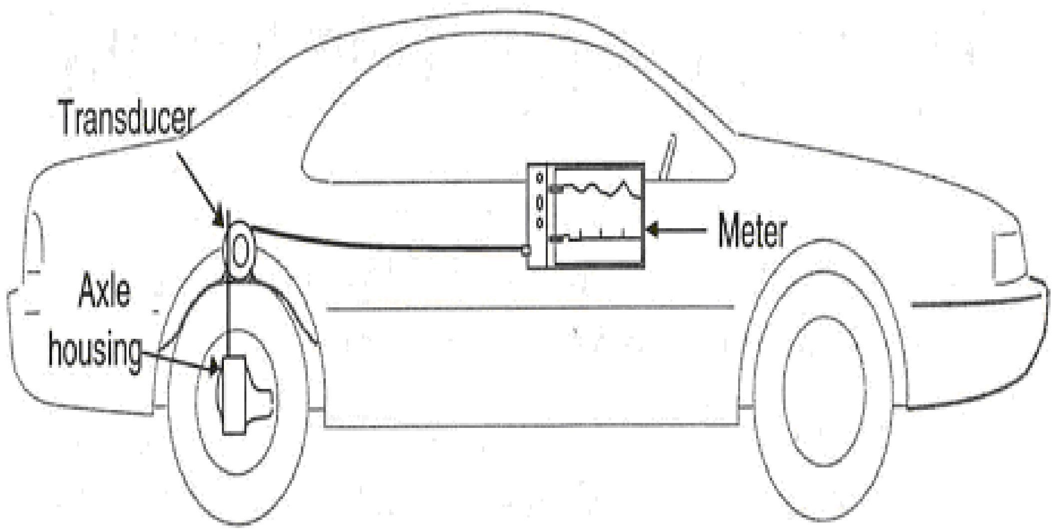


Figure 2.10. A car with a Mays Meter

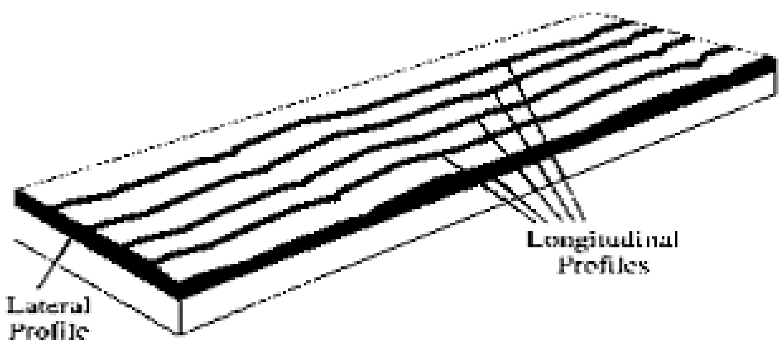


Figure 2.11 Schematic of road surface showing longitudinal and lateral profile.

2.4.4 Profiling devices

Profiling devices are used to provide accurate, scaled, and complete reproductions of the pavement profile within a certain range. They are available in several forms, and can be used for calibration of RTRRMs. The equipment can become fairly expensive and complex.

Three generic types of profiling systems are in use today:

Straight edge. The simplest profiling system is a straight edge. Modifications to the straight edge, such as mounting it on a wheel, result in a profilograph.

Low speed systems. Low speed systems such as the CHLOE profilometer are moving reference planes. The CHLOE is a long trailer that is towed at low speeds of 3 to 8 kph (2 to 5 mph). The slow speed is necessary to prevent any dynamic response measurement during the readings.

A few agencies still use the CHLOE to calibrate their RTRRMs.

Inertial reference systems. Most sophisticated road profiling equipment uses the inertial reference system. The profiling device measures and computes longitudinal profile through the creation of an inertial reference by using accelerometers placed on the body of the measuring vehicle to measure the vehicle body motion. The relative displacement between the accelerometer and the pavement profile is measured with either a "contact" or a "non-contact" sensor system.

The earliest profiling devices used a measurement system in direct contact with the pavement to measure profile. Several contact systems have been used, and are still in use today. The French Road Research Laboratory developed the Longitudinal Profile Analyzer (APL) in 1968.

Systems used today in the United States are frequently installed in vans, which contain microcomputers and other data handling and processing instrumentation. Older profiling devices are usually contact systems, while the more recently manufactured devices use non-contact sensors.

The non-contact systems use probes, either acoustic or light, to measure differences in the pavement surface. For instance, the South Dakota road profiler simultaneously collects three ultrasonic profiles, one for each wheel path and one for the lane center. These profiles are used to calculate (by computer) a mathematical measure of roughness and an estimate of rutting at specified intervals along the roadway.

A hybridized South Dakota road profiler combines the three ultrasonic sensors with two laser sensors, one for each wheel path, for simultaneous measurement of the same roadway by two different sensor types under identical conditions; see Figure 2.2 and Figure 2.13. Integrated analysis units, as pictured in Figure 2.12, can continuously collect a wide variety of data at highway speeds such as:

-Transverse profile/rutting
-Grade, cross-slope
-Pavement texture
-Pavement condition or distress
-GPS coordinates
-Panoramic right-of-way video
-Pavement video & feature location

Figure 2.12. South Dakota road profiler & integrated analysis vehicle interactive (van-mounted).

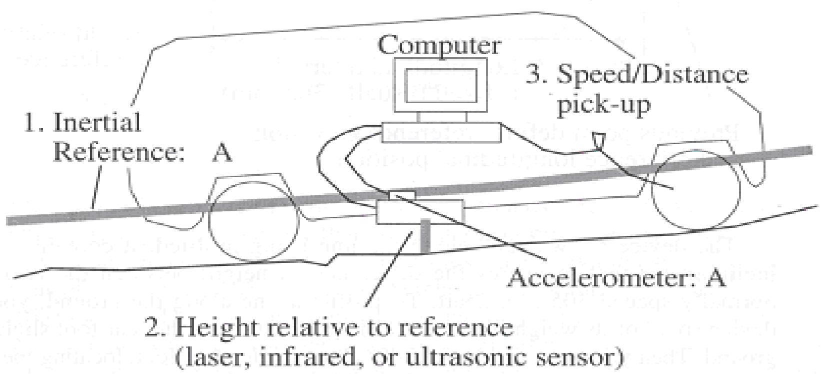


Figure 2.13 Schematic of road roughness Profilometer Van.

2.4.5 Non-contact lightweight profiling devices

A new generation of lightweight non-contact profilers have emerged for construction quality control and quality acceptance purposes. They are much smaller and lighter than the network level profilers, providing the benefit of use immediately after hot-mix asphalt (HMA) construction and much sooner than would be possible with the network level devices on new Portland Cement Concrete (PCC) pavements.

However, they have operating speeds ranging from 8 (13km) to 25 miles (40km) per hour, which makes it impractical for high speed and large road network data collection. These non-contact profilers (see Figure 2.14) require a one-to two-person operation, some are battery powered, others have gasoline engines.

Figure 2.14 Non-contact lightweight profiler & non-contact sensor

The basic system consists of an accelerometer, a non-contact sensor distance measuring instrument, a graphic display, an IBM-compatible PC, with a graphics printer. Inputs from the accelerometer and non-contact sensor are fed to the system's on-board computer, which calculates and stores a user selected smoothness index, and capable of storing as much as 13,000 miles (21,000km) of data. Pavement profile data points, taken every inch, are averaged over a running 12-inch (305mm) interval and stored as profile points every 6 inches (152mm), or every inch, if required. The results can be viewed on-screen or output to the printer.

The longitudinal measurements are independent of variations in vehicle weight, speed, extremes in temperature, sunlight, wind, and pavement color or texture. They can also calculate different smoothness indices using the same data. Some of the emerging profilers include the Lightweight Profiler T6400, manufactured by K.J. Law; Liteweight Inertial Surface Analyzer (LISA), manufactured by Ames Engineering; and the Lightweight Profiler, manufactured by International Cybernetics Corporation; Surface Systems Inc. Pathway Services, Inc. also manufacture lightweight profilers. The profilers cost is from approximately $45,000-$60,000 depending on the manufacturer.

2.4.6 Portable laser profiler systems

For road network data collection, the Multi-Laser Profiler (MLP) provides a vehicle mounted system that automatically collects integrated road condition data by recording laser profilers of the road surface at highway speed, see Figure 2.15.

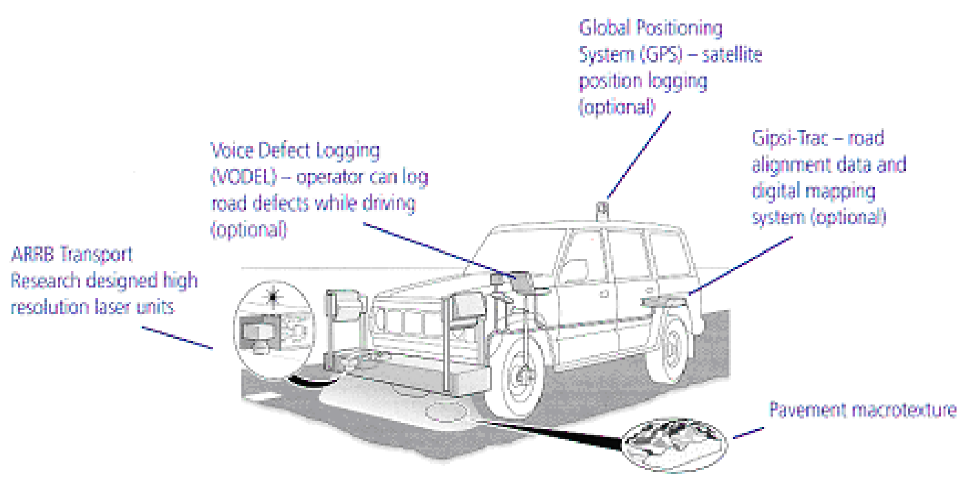


Figure 2.15 Multi-Laser Profiler Vehicle

It is very useful for monitoring large road networks. The speed of operation ranges from 18 miles (29km) to 75 miles (120km) per hour. The

MLP requires a two person operation and comes with an on-board computer system and a range of software for data acquisition and analysis tasks.

It simultaneously measures surface smoothness in IRI, rutting depth, and macro texture in both longitudinal and transverse profiles. The inertial sensors compensate for suspension and tire characteristics. It surveys up to approximately 370 miles (600km) of road per day at intervals as close as two inches (50mm) for smoothness rutting and approximately 1/4 inch (6mm) for texture.

Portable laser profiler systems contain many other sensors and modules not required for pavement smoothness measurement. Among these optional features of the system include a global positioning system, a road alignment data and digital mapping system, and a voice defect logging which allows an operator to log road defects while driving. These optional features provide framework data for asset management. Trigg Industries, Inc., and Pathway Services are among the manufacturers of the MLP.

The cost is approximately $75,000 depending on the manufacturer. Smaller, less expensive portable devices, such as light weight profilers are better suited for quality control in road construction.

An emerging automated portable laser profiler measurement system is the ROSAN as shown in Figure 2.16. The ROSAN stands for Road Surface Analyzer. Originally designed by FHWA, the ROSAN serves as a vehicle mounted portable system for measuring longitudinal pavement profile depth at highway speeds, preferably over 30 miles (48km) per hour. This system is suited for measurement of texture and smoothness. The texture measurements are performed at a 0.25mm (0.010inch) sampling interval and are limited to a speed of 15 miles (24km) per hour. The ROSAN system relies upon software to register these measurements. The ROSAN requires a vehicle with a step bumper.

The entire package, excluding the notebook computer, fits in a wheeled protective case. The ROSAN can be purchased as a complete system from Surfan Engineering for approximately $50,000. The operators attend a 2 ½ day training to learn the operation of the ROSAN. At this time, FHWA's Eastern Federal Lands is its main user.

Figure 2.16 Rosan system

2.5 Summary of measurement devices

A summary of the most commonly used roughness data collection devices, their measurement principles, relative costs, relative degrees of accuracy, and current and projected future use is contained in Table 2.2.

Table 2.2 Roughness data collection equipment.

Roughness Data Collection Device	**Principle of Measurement**	**Relative Initial Cost**	**Relative Data Collection Cost (Network)**	**Relative Degree of Accuracy**	**Approximate Decade of Development**	**Extent of Current Use**	**Projected Extent of Use**
Dipstick	Direct Differential Measurement	Low	Impractical	Very High	1980s	Limited, Used for Calibration	Same as Current Use
Profilographs	Direct Profile Recordation	Low	Impractical	Medium	1960s	Extensive for Const. Acceptance	Same as Current Use
BPR Roughometer	Device Response	Low	Low	Medium	1940s	Limited	None
Mays Meter	Vehicle Response	Low	Low	Medium	1960s	Extensive	Decreasing Continuously
South Dakota Road Profiler	Direct Profile Recordation	Medium	Low	High	1980s	Growing	Rapidly Increasing
Contact Profiling Device	Direct Profile Recordation	High	Medium	Very High	1970s	Limited	Decreasing
Non-Contact Profiling Device	Direct Profile Recordation	High	Medium	Very High	1980s	Medium	Increasing Continuously

Finally, it should be emphasized that there is several equipment using a geometric reference, such as viagraph and the AASHTO slope profilometer (low speed), the British High speed profilometer, the French Analyserur de profile enlong (Longitudinal Profile Anlyser), APL unique, and GM profilometer (for research purpose).

But, as an illustration of the financial resources required, the British High Speed Road monitor a high speed profilometer measuring. Longitudinal profile, macrotexture, and other parameter costs approximately US $775,000 for purchases and US$ 2,300 to 3,000 /day for survey service. The APL trailer with its data processing units costs approximately US $50,000. Its performance is 150 km/day at a cost of US $ 30/kilometer inspected.

Chapter Three

Methodology

3.1 Introduction

To meet the purpose of this thesis, a mathematical model was formulated and a machine was developed to adopt this model. Both will have an output that measures parameters leading to an assessment of the International Roughness Index (IRI). This index will be utilized to give a reflection of the road condition for maintenance purposes.

3.2 Description

The new equipment consists of a main steel arm connected to two perpendicular steel arms, each one moves on tandem wheels. Three sensors were used in this equipment; the first reads the horizontal distance using a photocell, similar to that of a computer mouse, every wheel cycle moved on the road will indicate a distance of the wheel diameter (0.64m).

The other two sensors will be fixed between the tandem tires and the perpendicular steel arm measuring the angle every (0.64m) distance continuously as shown in Figure 3.1.

This new machine will have the ability to determine road levels for a specific distance of 0.64m, the specified distance can be reduced to less than 0.64m according to the manufacturing and accuracy needed. The Electrical Engineering Department at An-Najah National University assisted in assembling the electrical parts and software program.

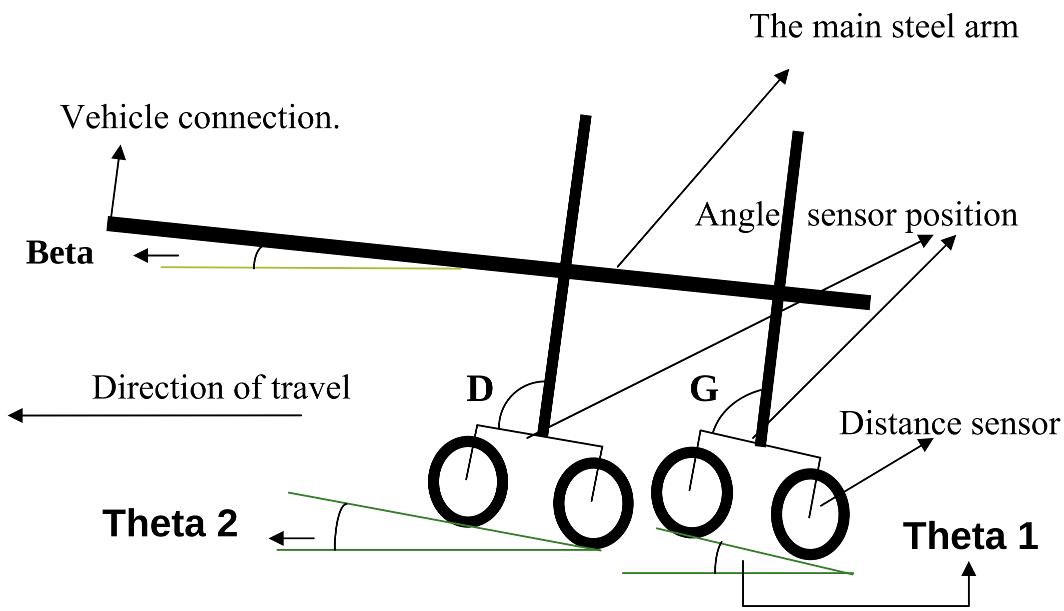


Figure 3.1 Schematic diagram of the proposed machine.

3.3 Methodology

The mathematical model is based on the analogy presented in Figure 3.1. The parameters shown are described here:

Beta (B1): describes the vertical angle (slope) of the vehicle (equipment) before testing. It is an initialization, which will be calculated at the start of measuring only. It can be obtained by using the pendulum method (a weight when settle free will point to the direction of gravity).

Theta1 & Theta2: road angles (slope) that indicate to the road roughness.

G & D: sensors angles and they will be measured every (0.64 m) along the road continuously.

A mathematical model utilizing those parameters is developed to measure road roughness based on IRI.

It is important to note that the model and machine is developed to lead to an outcome that could be used and linked to known criteria for the evaluation of pavement surface, which is in this case the International Roughness Index.

Chapter Four

Mathematical Model

4.1 Introduction

This equipment (body & power supply) must be connected with a vehicle. The output of the sensors (G1,2,3…Gend. & D1,2,3…Dend.) will be recorded and stored on a portable computer every (0.64m) distance, linked with the equipment during testing. Then it shall be coded to a computer program and translated to a road roughness or coordination (road profile).

4.2 Mathematical Model

- G & D: sensors angles and they will be measured every (0.64 m) along the road continuously.
- Beta (B1): describes the vertical angle (slope) of the vehicle (equipment) before testing.
- Theta1 & Theta2: road angles (slope) that indicate to the road roughness .

The first calculation of static condition utilizes equation:

Theta 1 = -90 + B1 + G1 ……………………equation (1).

Theta 2 = -90 + B1 + D1 ……………………equation (2).

When the vehicle starts moving for a distance of 0.64m, (G1 & DI) sensor angles will change to another set of values (G2 & D2) as shown in Figure 4.1. The forward road angle (Theta 3) can be calculated using equation (3).

Theta 3 = Theta 2 + G2 - D2 …………equation (3).

In the same way, when the vehicle passes the next distance of 0.64m distance, Theta 4 will be calculated.

Theta 4 = Theta 3 + G3 – D3 …. …….equation (4).

Theta 5, Theta 6, Theta 7, will be also calculated accordingly.

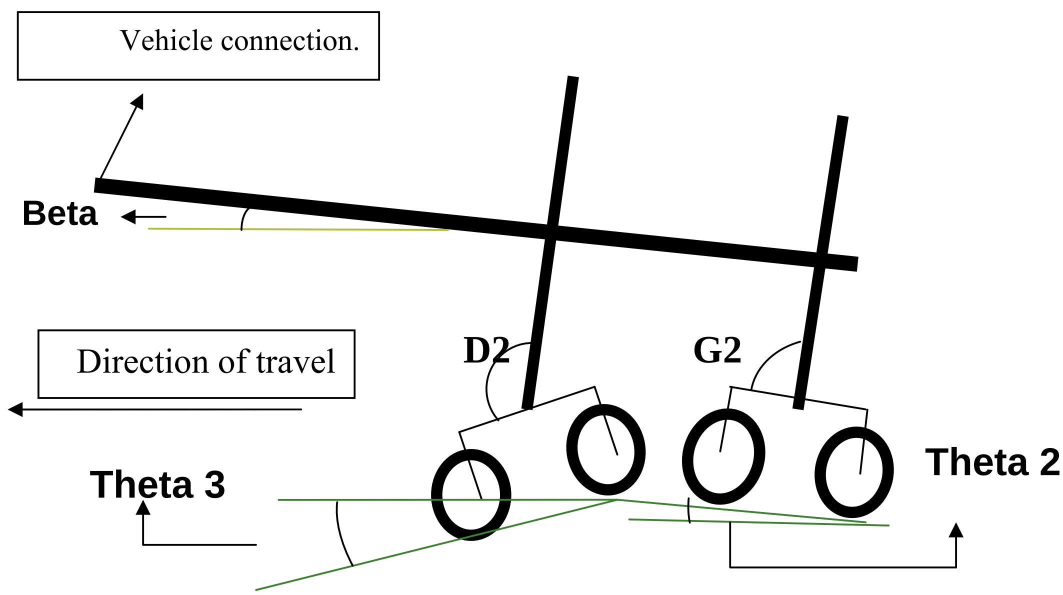


Figure 4.1 Schematic diagram of the proposed machine-next instant.

Finally, we can calculate the levels of the road surface by using the following equation:

Y= sin (Theta)*(0.64) ………………… equation (5), and recording all the coordination (Z & Y) of the road profile as shown in Figure 4.2.

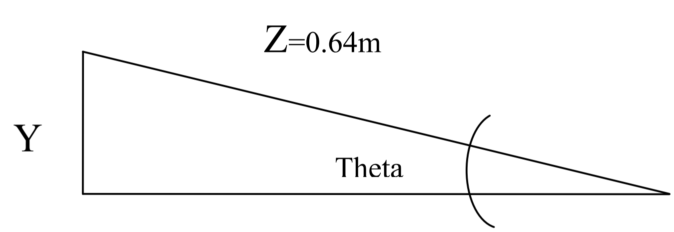


Figure 4.2 Schematic diagram describing Y & Z relationship.

Y is the level of the pavement surface every specific distance along the road section.

Z is the specific distance (0.64 m) traveled by the machine.

The new vertical distance (Y) will be added to the previous vertical distance (Y) and recorded continuously, then it will be plotted and will formulate the road profile, see Figure 8 in Appendix E.

Chapter Five

Technical Specifications

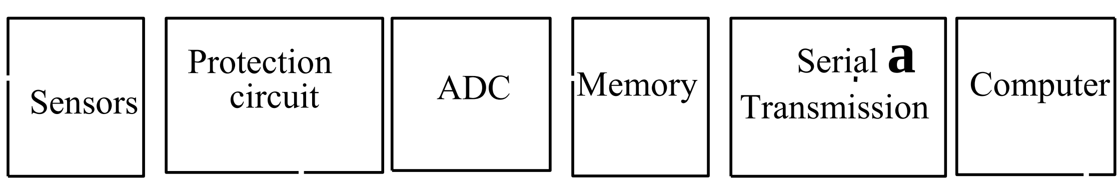
5.1 Introduction

The electrical parts were assembled through a graduating project at the Department of Electrical Engineering at An-Najah National University (2).

5.2 Hardware

The block diagram bellow describes the steps of acquiring data from the sensor and to the last step that is representing data by the computer. The sensor is a variable resistor; the protection circuit includes circuits to prevent noise and circuits to prevent high voltage.

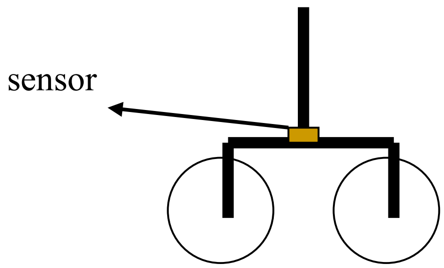
The analog to digital converter is necessary to make the data suitable to the pic, the pic has analog to digital converter internally. Then the serial transmission done by the max232, after that the computer which includes the equations and the high level software.

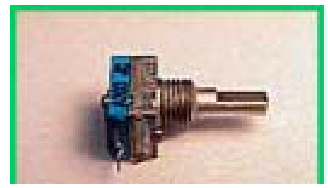


Two types of sensors were used:

1- Potentiometer: It is used to measure the angles Gama1 (D) and Gama2 (G), as shown in Figure 5.1 and Figure 5.3.

Rotating potentiometer is used to transfer the movement of the rotating arms.



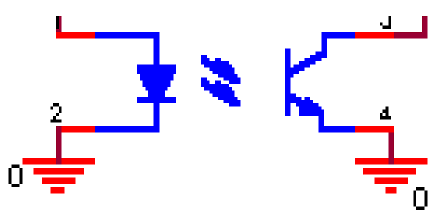


Rotational Potentiometer

Figure 5.1 Sensor (Rotational Potentiometer).

2- Photo sensor: It is used to measure the distance crossed by the vehicle. It is set on the machine wheel as shown in Figure 5.2.

When the piece of rubber cuts the light emitted by the diode, it changes the output voltage of the transistor.



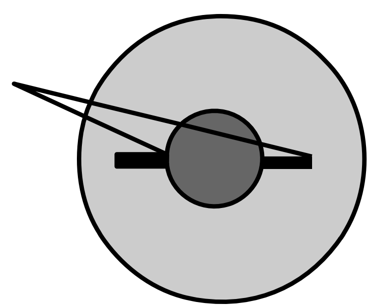


Photo sensor

Vehicle wheel

Figure 5.2 Photo sensor & position on the vehicle wheel.

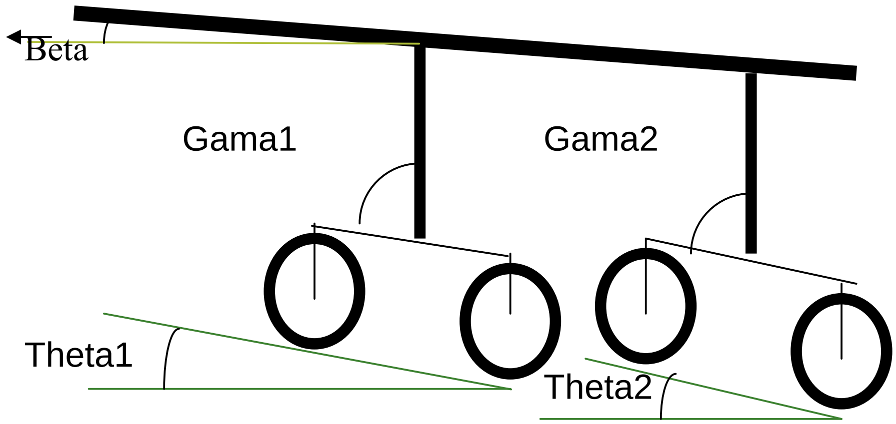


Figure 5.3 Schematic diagram of the proposed machine.

The Pic is a microchip, it supplies 8 bit general purpose microcontroller and it contains the analog to digital converter, memory and serial transmission components. Two components are used to build the protection circuit.

1- Zener diode: It is used in parallel to prevent voltage over 5V (PIC Vcc).

2-Capacitors: They used in parallel to prevent noise.

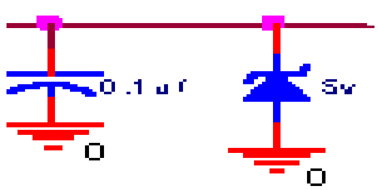


Figure 5.4 Zener and capacitor.

PIC 16F77 was chosen for the following reasons:

1- It is very fast.

2- It has suitable memory.

3 -It has multiple channels.

4 -It has analog to digital converter (built in).

The following parts were used:

1-Input channels: two pins of input channels are connected to the potentiometers.

2-Analog to digital converter: 8 bits ADC is used, the results are stored in the memory then they are framed to be transmitted.

3-Interrupt Pin: It is connected to the photo sensor to set a counter. Another interrupt pin is connected to start/stop push button that is responsible for starting transmission to the computer.

4-memory clear pin: It is connected to the reset push button.

5.3 Data transmission

Data is transmitted serially to/from the computer using TX and RX pins. The computer stores the data in a buffer to be read and analyzed by the visual basic program. Serial transmission and reception has to be configured by the micro programming. The complete circuit is shown in Figure 5.5, and the Micro Programming Flow Chart is shown in Figure 5.6.

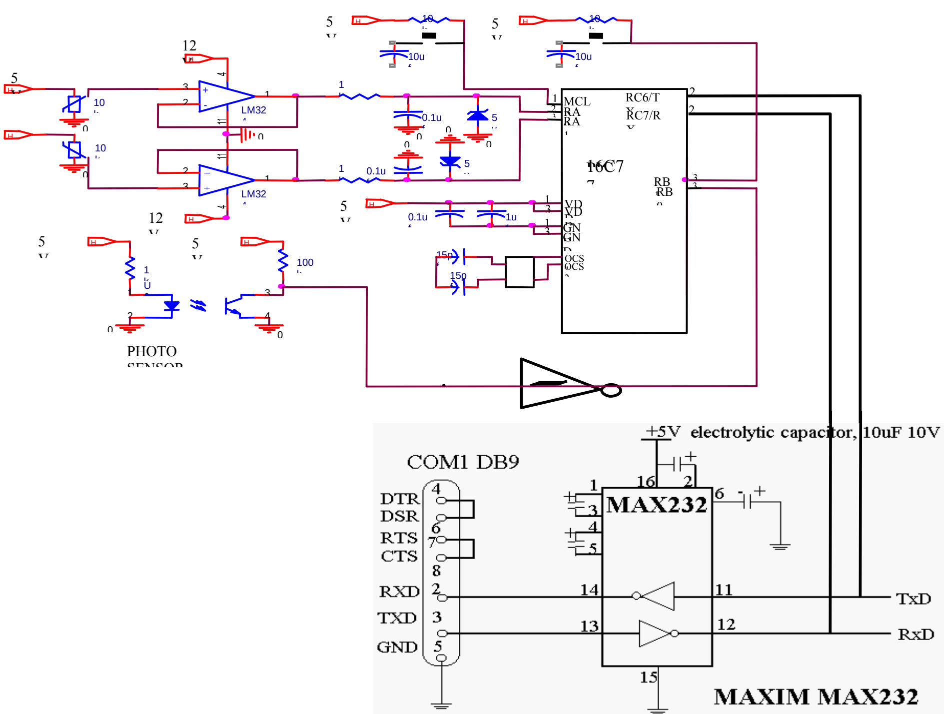


Figure 5.5 Complete circuit.

5.4. Software - Micro Programming

PIC 16F77 has its own instruction set and commands. PIC allows the use of subroutines and functions.

Registers and variables must be configured and defined before using, e.g., ADCONO is configured as 8 bit, external clock rate etc.

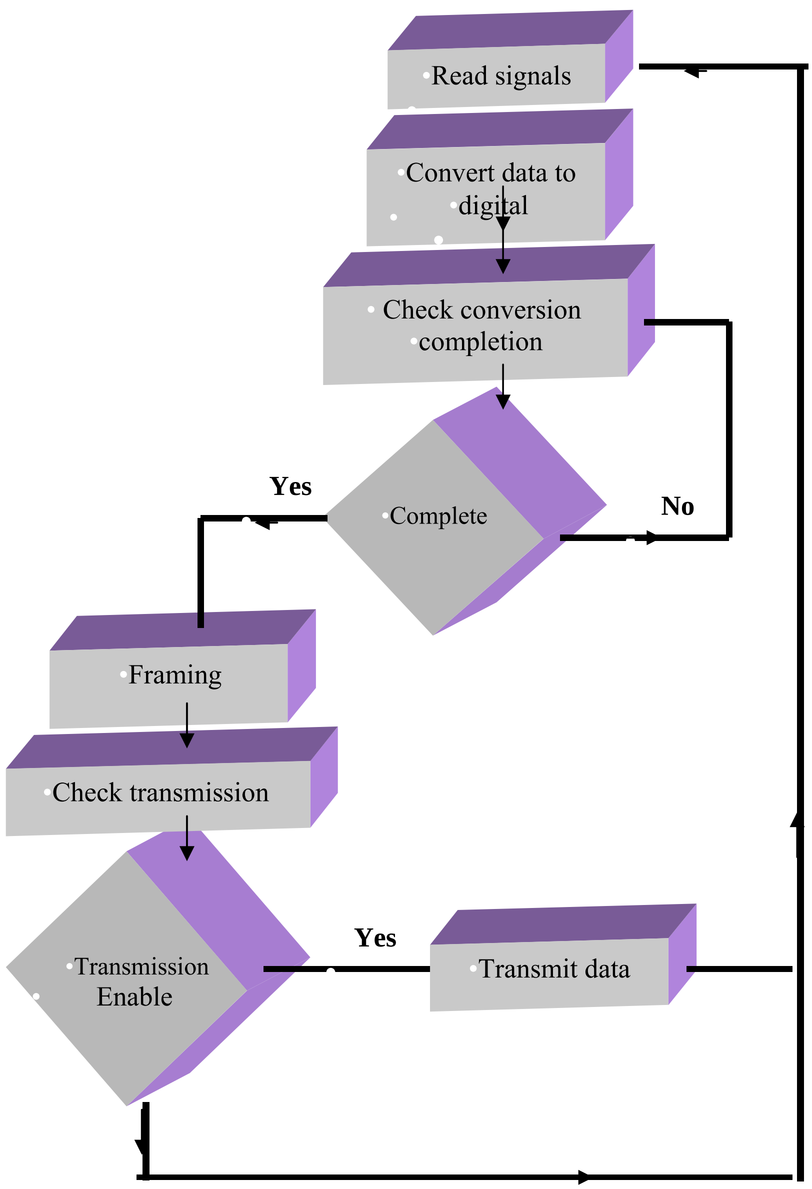


Figure 5.6 Micro programming flow chart.

5.5 Visual Basic program

This program is responsible for receiving and transmitting data from/to the PIC, analyzing the received data to find the angles and the distance, doing some mathematical operations, storing final values in a data base, and it contains peripheral options like drawing and instruction window. Figure 5.7 presents the Visual Basic Program.

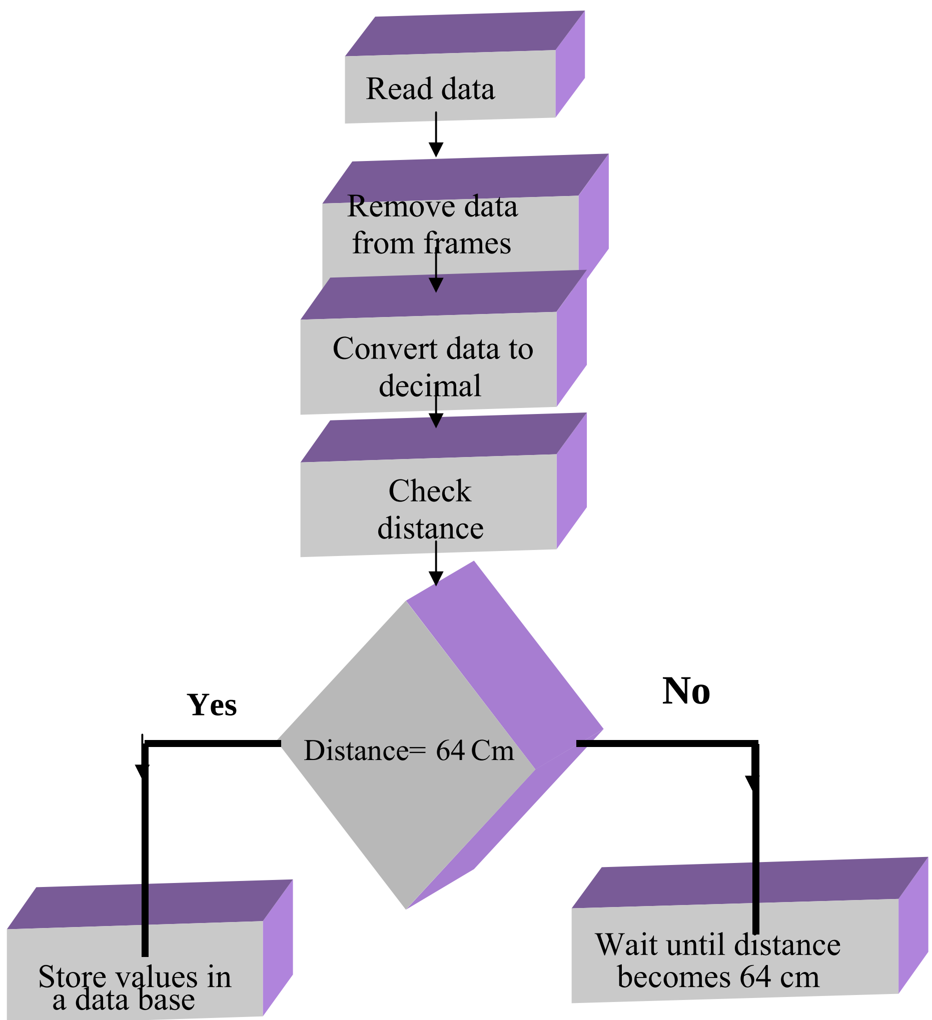


Figure 5.7 Visual basic program.- flow chart.

Chapter Six

Model Verification

Machine Testing & Evaluation

6.1 Introduction

A section of (1 km) from Sanor-Meselieh Road, which is a new constructed road has been inspected. The actual level was determined every 20m by a Level Instrument with accuracy of plus or minus one centimeter. The elevation was then plotted by AutoCAD software, as shown in Appendix B and Chart 1 in Appendix E.

6.2 Machine output

Table 6.1 shows the output data, which is the measured road elevation every 0.64m up to down recorded and followed with next column. This table is a part selected from Appendix A.

Table 6.1. A Sample of Machine Output*.

Measured Level every 0.64m				
358.52	358.28	358.00	357.68	357.50
358.51	358.27	357.99	357.68	357.49
358.51	358.27	357.98	357.67	357.49
358.50	358.27	357.98	357.67	357.49
358.50	358.26	357.97	357.66	357.48
358.49	358.26	357.96	357.66	357.48
358.49	358.26	357.95	357.65	357.47
358.48	358.25	357.94	357.65	357.47

*Complete data is shown in Appendix A.

The new machine output of the inspected road section is recorded in Appendix A, and plotted in Chart 3 as shown in Appendix E. The result was the same as Level Instrument result. The differences vary from 1 cm to 3 cm in some points only. For example, Table 6.2, which is selected from Appendix B, illustrates the difference between the actual road level

357.55m, which is presented in the second column, and the measured level 357.54m, which is presented in the third column at station 1+040; the difference is 1cm.

Table 6.2. A sample of both machines results*.

Road Station (m).	Actual Level (m).	Measured Level (m).	The Differences (m).
0+920	358.52	358.52	0.00
0+940	358.35	358.34	0.01
0+960	358.23	358.24	-0.01
0+980	358.05	358.05	0.00
1+000	357.82	357.79	0.03
1+020	357.67	357.65	0.02
1+040	357.55	357.54	0.01
1+060	357.42	357.42	0.00

*Complete data is shown in Appendix B.

6.3 Machine testing and calibration

Both types of measurements are categorized in Appendix B. The first column is the longitudinal distance, which was traveled by the new machine every 0.64m. The second column is road stations. The third column is the actual road level every 20m. The fourth column contains elevations every 0.64m, which was measured by the new instrument, and the last column is the elevation differences between every two sequenced measured levels.

Table 6.3 is a part selected from Appendix B. It explains the new machine results and Level Instrument results in respective columns.

Table 6.3. An illustration of both machine results and elevation differences*.

Distance (m).	Road station (m).	Actual level (m).	Measured level (m)	Elevation differences(m)
0.00	0+920	358.52	358.52	
0.64			358.51	0.01
1.28			358.51	0.00
1.92			358.50	0.01
2.56			358.50	0.00
3.20			358.49	0.01
3.84			358.49	0.00
4.48			358.48	0.01
5.12			358.48	0.00
5.76			358.47	0.01
6.40			358.46	0.01

*Complete data is shown in Appendix B.

Finally, the International Roughness Index “IRI” was calculated, which equals the total accumulative elevation differences divided by the total traveled distance. It was found that IRI = 6. See Appendix B, and Table 6.4.

Table 6.4. IRI Calculation results*.

Distance (m).	Measured Level (m)	Elevation Differences(m)
934.4	358.11	0.01
935.04	358.12	0.01
935.68	358.12	0.00
936.32	358.13	0.01
936.96	358.14	0.01
937.6	358.15	0.01
938.24	358.16	0.01
938.88	358.16	0.00
939.52	358.17	0.01
940.16	358.18	0.01
940.8	358.19	0.01
941.44	358.20	0.01
	Total Elevation Differences (m) =	5.97
	IRI = 5.97 m / 0.941 km =	6

*Complete data is shown in Appendix B.

The inspected road is a new construction and the pavement surface condition is good. Therefore, PSR = 4 using visual inspection.

That was a subjective measurement, but now it is possible to use the new machine to evaluate the pavement surface condition objectively. IRI = 6 indicates that the road surface is in good condition according to Figure 2.3.

6.4 Statistical analysis of machine output

The measured and the actual road levels with the differences between them are presented in Appendix C. The statistical analysis was done to determine the machine accuracy corresponding to the Level Instrument. The different values were presented in the last column as shown in Table 6.5. This table is selected from Appendix C.

Table 6.5. Actual and measured level with the differences*.

Road station (m).	Actual level (m).	Measured level (m).	The differences (m).
0+920	358.52	358.52	0.00
0+940	358.35	358.34	0.01
0+960	358.23	358.24	-0.01
0+980	358.05	358.05	0.00
1+000	357.82	357.79	0.03
1+020	357.67	357.65	0.02
1+040	357.55	357.54	0.01
1+060	357.42	357.42	0.00

*Complete data is shown in Appendix C.

The t–distribution analysis method is preferred because of unknown variance and the number of the tested points was more than 30. Using Microsoft Excel Program, all variables were determined, the average value (μ) equals -0.00179 m and the standard deviation (S) equals 0.0205 m, see Appendix C. The probability of having a difference of more than 1 cm can be obtained using the following probability form:

$P\ (t_{n-1} › X – \mu / (S / \sqrt{N})$

Where X is the variable and it is equal to 1 cm, $n-1$ is the degree of freedom, and N is the sample size or the tested number of points.

$P\ (t46 \ › (.01- (-.00179)) / (.0205 / \sqrt{47})) =$

$P\ (t_{46} \ › 3.94) = \%\ 00.5$ using Table A.4 (10).

The probability of having a difference in elevation smaller than 1 cm (plus or minus) is 99% by two tail t-distribution.

Chapter Seven

Conclusions and recommendations

Conclusions

The new machine is an accurate device to measure road levels and it has the following capability:

1- The operation time to perform surveying works is less than Level Instrument and can gather more information about road elevations (profile).

2- Using this instrument will minimize human mistakes while measuring road levels.

3- Use of this instrument is not complicated, it is light in weight, and capable of moving over pavement at speeds approaching traffic speed to minimize danger to personal and traffic interference.

4- Current techniques mostly depend on visual inspection, which depend largely on trained personal in this field as well as the limit extent to the coverage of network segments using those techniques. The use of visual inspection is practiced locally on project basis with little or no wide scale performance measurement on network bases. The new machine is considered an objective measurement to evaluate the pavement surface condition, and determine road roughness for the roadway network in the Palestinian Territories according to the International Roughness Index “IRI” criterion.

Recommendations

It is recommended that this new machine is further developed and applied for all Palestinian road projects for both acceptance purposes of new pavement construction or for pavement evaluation measurements.

This machine is considered multipurpose for both survey purposes as well as roadway elevation. It is easy to find the roadway network coordinates, which assist in geometric design. It is also useful to find out the proper pavement strategy based on the International Roughness Index “IRI”. It is recommended for both situations.

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جامعة النجاح الوطنية
كلية الدراسات العليا

تطوير معيار الخشونة كأساس لقياس آداء رصفات شبكة الطرق الفلسطينية

إعداد
مأمون عوني محمود الغالية

إشراف
د. اسامة اباظة

قدمت هذه الأطروحة استكمالا لمتطلبات درجة الماجستير في هندسة الطرق والموصلات بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

2003

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الملخص

من المعروف عالميا ان شبكات الطرق الجيدة لها ارتباط وثيق بالاقتصاد الوطني، لذا تعمل المؤسسات البحثية والاكاديمية في غالبية دول العالم على تحسين اداء هذه الطرق من خلال تقيمها لاداء الرصفة وبهدف تطوير انظمة ادارة الرصفات. ان تقييم الرصفات يحتاج الى قياس موضوعي غير قابل للتأويل.

هدفت هذه الدراسة لتطوير نظام آلي بالاستعانة بمعيار درجة اداء الرصفات كاساس لبرنامج نظام ادارة الرصفات. ان النظام الالي والمقترح قادر على قياس احداثيات الطرق باستخدام نظام حسابي تم تطويره لهذا الغرض وبهدف قياس هذه المتغيرات بدءً من برنامج الحاسوب وانتهاءاً بقيم تحليل المدخلات. ولتحسين خدمة الاداء الطرق يعمل الجهاز المطور على اخذ قياسات لتحديد مستوى الطريق لكل 46سم وذلك باستخدام نظام التقييم العالمي للرصفات IRI. وبناءً على المعطيات يمكن للجهاز ان يعمل على تقييم الرصفة وطرح سياسات تتعلق باعمال الصيانة المطلوبة. اثبتت نتائج هذه الدراسة بان النمط المقترح والمطور يعكس وبصورة واقعية الوضع الحقيقي للطرق وادائها.