Contract Report STEP 2000/17

Evaluation of Pavement Response Instruments

Authors:
F Vogel
WJvdM Steyn

PREPARED BY:
CSIR Transportek
PO Box 395
PRETORIA
0001
Tel: +27 12 841 2905
Fax+27 12 841 3232

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Authors: F Vogel WJvdM Steyn			
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Abstract:

Instrumentation to measure pavement behaviour during load conditions is a key component of the Heavy Vehicle Simulator (HVS). The present instrumentation system has reached a mature stage of development with respect to displacement measurement. New technologies, alternative measurement technologies or enhancement of the present technologies is considered to improve various measurement parameters. The improvements are aimed at obtaining higher performance, lower maintenance requirements, higher reliability, higher quality and integrity of the data, easier deployment and lower production costs.

The report focuses on aspects such as possible wireless data transmission, standardization and measurement methodologies and sensor technology. Various avenues are explored for the development of sensors while new emerging technologies that could find application in Accelerated Pavement Testing (APT) is also examined for possible development. The evaluation also highlighted the possibility of extending the present sensor technologies by enhancements such as lowering the noise floor of the electronics and smart sensor application.

To complete the overall evaluation of the instrumentation system, the management of the instrumentation system is also considered. This includes aspects such as commissioning of the instrumentation, training of the personnel that has to use the system, technical maintenance, backup and support and the question of upgrading aging or outdated systems.

Keywords:

Data communication, measurements, sensors, displacement sensors, smart material application (SMA), image, image processing, system management, noise reduction, strain measurement heavy vehicle simulator (HVS), Accelerated Pavement Testing (APT).

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Signatures: *Steve Kekwick* **Language Editor**	Steve Kekwick **Technical Reviewer**	*B. Verhaeghe* **Programme Manager**	*A. v.d. Merwe* **Info Centre**

1. INTRODUCTION

The objectives of this STEP project are:

- to investigate the current pavement structure parameter measurement and monitoring methods
- to identify limitations in the current systems, and propose new systems to enable better measurements.

Firstly the various pavement structure parameters of importance to pavement engineers are identified and the current methods by which they are monitored identified. General information regarding each of the identified parameters is also provided.

Secondly the available technologies monitoring pavement structure parameters are identified and discussed.

Thirdly the needs and technologies are compared and proposals made for solutions to the current limitations and some new measurement techniques.

2. REQUIREMENTS

2.1 Introduction

The requirements from a pavement structure viewpoint for parameters that need monitoring and or measurement are summarised in this section. For each of the parameters identified a list of the properties needed is shown.

The parameters identified as of importance to pavement engineers are shown in Table 2.1. while typical data recorded for each parameter are shown in Table 2.2. Where a question mark appears in a row in Section 2.2 it indicates that the relevant information is not readily available or not currently defined.

The parameters listed under "new value" indicate the ideal situation for the specific parameter.

Table 2.1: Pavement structure parameters identified as of importance to monitor and/or measure.

PARAMETER
Elastic surface deflection
Elastic in-depth deflection
Strain (in situ)
Compressive/shear stress (in situ)
Effective material stiffness
In-situ moisture content
Damping coefficient
Plastic (permanent) surface deformation
Plastic (permanent) in-depth deformation

Table 2.2: Typical data recorded for each pavement structure parameter.

PARAMETER PROPERTIES	**'VALUE'**
Identification	e.g. elastic surface deflection
Location of measurement	e.g. surface
Range	e.g. 0,010 – 3,000 mm
Resolution	e.g. 0,010 mm
Repeatability & reproducibility	?
Frequency of measurement	e.g. 80 Hz
Load mechanism (e.g. SL, MSL, DL, MDL) Static Load, Moving Static Load, Dynamic Load, Moving Dynamic Load)	e.g. MSL
Parameter type (mass, length, area, volume, time, force, stress, temperature)	e.g. length
Current system	e.g. RSD
Limitations	e.g. speed of measurement, positioning of beam
Current costs (per system / per measurement)	e.g. R 10 000 per instrument R 0,50 per measurement
Current signal processing	e.g. Labview software
Current DAQ	e.g. National Instruments based
Possible new systems	e.g. use of SMA (Shape Memory Alloys)
Vision / Purpose / Objective	e.g. measure non-contact elastic deflections in 2 dimensions at speed
Other	?

2.2 Parameter data

PARAMETER PROPERTIES	CURRENT 'VALUE'	NEW 'VALUE'
Identification	Elastic surface deflection	
Location of measurement	Surface of pavement in 1 dimension	Surface of pavement in 2 dimensions
Magnitude range	0,020 – 7,000 mm	0,001 – 10,000 mm
Resolution	0,020 mm	0,001 mm
Repeatability	?	?
Frequency	100 Hz (256 points over 2,5 m @ 5 km/h)	3 400 Hz (256 points over 2,5 m @ 120 km/h)
Load mechanism (e.g. SL, MSL, DL, MDL)	MSL	SL, MSL, DL, MDL
Parameter type	Length	
Measurement system	RSD – DC LVDT	SMA-based
Limitations	Location of measurement point, frequency, range, resolution	?
Typical costs	R 10 000,00 per instrument R?? per measurement	?
Signal processing	Labview	Labview
DAQ	National Instruments	National Instruments
Vision	Non-contact measurements at speed in 2 dimensions	
Other	?	?

PARAMETER PROPERTIES	CURRENT 'VALUE'	NEW 'VALUE'
Identification	Elastic in-depth deflection	
Location of measurement	In pavement @ 150 mm intervals	In pavement @ 10 mm intervals
Magnitude range	0,020 – 7,000 mm	0,001 – 10,000 mm
Resolution	0,020 mm	0,001 mm
Repeatability	?	?
Frequency	100 Hz (256 points over 2,5 m @ 5 km/h)	3 400 Hz (256 points over 2,5 m @ 120 km/h)
Load mechanism (e.g. SL, MSL, DL, MDL)	MSL	SL, MSL, DL, MDL
Parameter type	Length	
Measurement system	MDD – AC / DC LVDT	SMA-based
Limitations	Location of modules, frequency, range, resolution	?
Typical costs	R 25 000,00 per instrument R?? per measurement	?
Signal processing	Labview	Labview
DAQ	National Instruments	National Instruments
Vision	Non-contact measurements at speed in 2 dimensions at depth intervals of 10 mm	
Other	?	?

PARAMETER PROPERTIES	**CURRENT 'VALUE'**	**NEW 'VALUE'**
Identification	Elastic strain	
Location of measurement	None currently	Inside pavement layers
Magnitude range	?	0,01 – 10 % (100 – 100 000 με)
Resolution	?	0,01 % (100 με)
Repeatability	?	?
Frequency	?	3 400 Hz (256 points over 2,5 m @ 120 km/h)
Load mechanism (e.g. SL, MSL, DL, MDL)	MSL	SL, MSL, DL, MDL
Parameter type	? length	
Measurement system	?	SMA
Limitations	installation, range, resolution, frequency	?
Typical costs	?	?
Signal processing	?	Labview
DAQ	?	National Instruments
Vision	Non-contact measurements at speed in 3 orthogonal directions.	
Other	?	?

PARAMETER PROPERTIES	**CURRENT 'VALUE'**	**NEW 'VALUE'**
Identification	Stress	
Location of measurement	None	Inside pavement layers
Magnitude range	?	10 – 5 000 kPa
Resolution	?	1 kPa
Repeatability	?	?
Frequency	?	3 400 Hz (256 points over 2,5 m @ 120 km/h)
Load mechanism (e.g. SL, MSL, DL, MDL)	MSL	SL, MSL, DL, MDL
Parameter type	Stress	
Measurement system	?	Stress-sensitive film
Limitations	Installation, range, resolution, frequency	?
Typical costs	?	?
Signal processing	?	Labview
DAQ	?	National Instruments
Vision	Non-contact measurements at speed in 3 orthogonal directions.	
Other	?	?

PARAMETER PROPERTIES	CURRENT 'VALUE'	NEW 'VALUE'
Identification	Stiffness	
Location of measurement	None - indirect	In situ
Magnitude range	100 – 10 000 kPa	100 – 10 000 kPa
Resolution	50 kPa	1 kPa
Repeatability	?	?
Frequency	10 Hz ?	3 400 Hz (256 points over 2,5 m @ 120 km/h)
Load mechanism (e.g. SL, MSL, DL, MDL)	MSL	SL, MSL, DL, MDL
Parameter type	Stress ?	
Measurement system	K-mould, back calculations	?
Limitations	Inaccurate, laboratory based,	
Typical costs	R?	?
Signal processing	Back calculation software	?
DAQ	None	?
Vision	Measure effective stiffness in situ under traffic in various pavement layers	
Other	?	?

PARAMETER PROPERTIES	CURRENT 'VALUE'	NEW 'VALUE'
Identification	Moisture content / density	
Location of measurement	Surface / in depth	Surface / in depth
Magnitude range	0,5 – 50 %	0,1 – 100 %
Resolution	0,5 %	0,1 %
Repeatability	?	?
Frequency	?	?
Load mechanism (e.g. SL, MSL, DL, MDL)	MSL	SL, MSL, DL, MDL
Parameter type	Mass ?	
Measurement system	Nuclear gauge / Strata gauge	?
Limitations	Accuracy, location, low MC range	?
Typical costs	R ? R ?	?
Signal processing	None	?
DAQ	None	?
Vision	Measure in situ moisture content and density for range of non-saturated materials using non-contact measurements	
Other	?	?

PARAMETER PROPERTIES	CURRENT 'VALUE'	NEW 'VALUE'
Identification	Damping coefficient	
Location of measurement	?	?
Magnitude range	?	?
Resolution	?	?
Repeatability	?	?
Frequency	?	?
Load mechanism (e.g. SL, MSL, DL, MDL)	MSL	SL, MSL, DL, MDL
Parameter type	Vibration / mass ?	
Measurement system	?	?
Limitations	?	?
Typical costs	?	?
Signal processing	?	?
DAQ	?	?
Vision	?	?
Other	?	?

PARAMETER PROPERTIES	**CURRENT 'VALUE'**	**NEW 'VALUE'**
Identification	Poisson ratio	
Location of measurement	?	?
Magnitude range	?	?
Resolution	?	?
Repeatability	?	?
Frequency	?	?
Load mechanism (e.g. SL, MSL, DL, MDL)	MSL	SL, MSL, DL, MDL
Parameter type	Deduced from displacement	
Measurement system	?	?
Limitations	?	?
Typical costs	?	?
Signal processing	?	?
DAQ	?	?
Vision	?	?
Other	?	?

PARAMETER PROPERTIES	**CURRENT 'VALUE'**	**NEW 'VALUE'**
Identification	Temperature gradients	
Location of measurement	None	Pavement surface, tyre surface
Magnitude range	None	0° C – 300° C
Resolution	None	?
Repeatability	None	?
Frequency	NA	NA
Load mechanism (e.g. SL, MSL, DL, MDL)	NA	NA
Parameter type	Temperature	
Measurement system	None	Infrared camera
Limitations	NA	?
Typical costs	NA	?
Signal processing	NA	?
DAQ	NA	?
Vision	NA	?
Other	NA	?

3. AVAILABLE TECHNOLOGIES

3.1 Introduction: an overall perspective.

The measurement of pavement behaviour during load conditions to determine various characteristics of the materials used for constructing the pavement is the heart and soul of the HVS. The instrumentation to determine deflection of the pavement, the profilometer, RSD (Road Surface Deflectometer), MDD and CAM (Crack Activity Meter) are well-developed instruments that have proven to fulfil the requirements they were intended for.

The present instrumentation has reached a mature stage in their development with respect to capability in terms of accuracy, resolution, etc. To push the frontiers back would require the use of new and/or alternative technologies to achieve higher performance levels. This could be achieved either through using newer, matured and commercialised technologies, or the research and development of newer technologies and/or materials to achieve that goal.

This viewpoint only examines the possible gains that could be made on a component level. This report also examines he instrumentation as a system and consider the advances that could be made by improving the instrumentation system as a whole. The aim of such an approach will be the improvement of the systems in terms of ease of operation and reliability. The improvement in ease of operation is aimed at getting good quality data (or in some cases better quality) with the same or less effort from the operators.

Reliability in the present system appears to be suspect. The improvement in reliability (less down time) and good (or even better) data with the same or less effort will enhance the productivity of personnel operating these systems. Reliability will not only improve the client's productivity but will also improve the Technology Innovation Centre's productivity (less time attending to client problems to be resolved)

In the case of improving the system, there are numerous mature and commercially implemented technologies that could be adopted as is, or in some cases, with improvements or modifications to serve the purpose better.

In conclusion, the report aims at examining the instrumentation as a system and as individual components in an attempt to highlight improvements and advantages that could be gained from them.

3.2 The HVS Instrumentation System

3.1.1 Introduction

The HVS instrumentation system can be described in brief as an IBM compatible Personal Computer, equipped with a commercial data capturing system comprising of hardware and software. The commercial data capture system (National Instruments) is the interface between the digital world of the PC and the predominantly analogue world of the measuring instruments, converting analogue voltage signals into digital values. The software for controlling the process is National Instrument's Labview that is user programmable. The older HVS4/UCB system used a PC30 data capture card with software written for a DOS operating system.

The instrumentation comprises of the profilometer, Road Surface Deflectometer, Multi Depth Deflectometer and the Crack Activity Meter as well as strain gauges and thermocouples to measure material stress and temperatures respectively. Most of these sensors have electronic circuits called signal conditioners that convert low-level voltages, currents and resistance into higher-level voltage signals less susceptible to electrical interference.

Throughout the instrumentation system, it had become apparent that there is no definitive standard adopted for the individual measuring instruments that constitute the measuring components of the system. In some cases, profilometers were delivered to different customers where the one has an analogue output while another had an Analogue-to-Digital converter on board, delivering a digital output to the computer system.

This has been the result of two factors: the natural tendency of evolution over time and the desire to satisfy the client's needs and requirements that differ in individual cases. This has resulted in a situation where any repair and maintenance on instrumentation systems required a detailed assessment of the system first before advice and assistance can be given.

The discussion to follow is divided into two main categories: the present system and the possible improvements and refinements that can be made to it, and future developments. These improvements and refinements can be lumped together into short term and medium term developments (short term being a 12 to 18 month while medium term constitutes 12 to 48 months). The future developments represent the pushing back of frontiers in various aspects such as accuracy, resolution (smallest changes detectable), speed of acquisition, non-contact and non-intruding measurement methods.

3.3 Detailed technical assessment

3.3.1 System Communications

On a component level, all instruments are connected to the computer system through a network of cables carrying analogue and digital signals. From experience, these cables are in the front line for damage. Any such occurrence leads inevitably to down time of the system. Repairs are complicated as the connectors and cables used contain multiple connections and require relative well developed skills in soldering. Faultfinding is even more problematic as poor quality connections could influence (not disrupt) analogue signals and require a skilled technician to pinpoint the origin of the problem.

There is a case to be made out to consider the elimination (if possible) or the reduction/simplification of the cabling between measuring instruments and the computer system. There are numerous commercially used wireless communication systems available that should be considered as a solution to this problem;

- radio data links (digital and analogue)
- infrared links (mostly digital) and fibre optic (digital and analogue).

3.3.2 Radio Data Links

Radio communication links are already used on the HVS between the wheel carrier and the HVS frame to control and measure loading of the wheel. This technology has the disadvantage that the frequencies allocated for data transmission differs from country to country. From a standardization viewpoint, this would be undesirable (see motivation for standardization – 3.5). Since it is not easy to make radio data link systems easily changeable for other frequencies, it would be advisable to discard this method as a possibility.

Another possible disadvantage is the possibility of interference from other nearby users of the radio spectrum. They do not necessary have to use the same frequency; equipment often emit radio interference. Personal computers are notorious culprits in these respects while other equipment like Citizen Band Radios often are as bad or even worse.

3.3.3 Infrared Data Links

Infrared data communication linking is an attractive possibility. It has no impact on the electromagnetic spectrum and is therefore not subjected to the same legal and regulatory constraints of radio data links. Infrared communication links are not influenced by environmental interference (sunlight and other warm bodies), as they are modulated systems working at a very specific frequency.

They do not require precise alignment (line of sight, direct line, etc) as infrared waves easily bounce off surfaces and the receiver is sensitive enough to pick the transmission up even in the presence of strongly emitting infrared sources (heat).

3.3.4 Fiber Optic Data Links

Although fibre optic cables are not wireless systems, they have advantages that should not be overlooked in this application. The advantages of fibre optic communications are numerous. Some of the advantages that would be desirable in this case are, high immunity to electromagnetic interference, high data throughput, simplicity (single connection), surprisingly high tolerance to wear (repeated coiling and uncoiling) and surprisingly good mechanical damage tolerance due to strengthening in the sheathing materials used.

3.3.5 Other possible methods

The main aim of the exercise is to simplify or eliminate the cabling between the computer system and the measuring instruments. Eliminating cabling would be the ideal but must be seen against the background of the total system configuration. In the event that *all cabling* be eliminated, this would create a challenge to providing power to the instruments. A possible solution would be to convert all the instruments to battery power. Although this is an attractive possibility, it will have to be weighed against battery life, power consumption, cost and maintenance.

If one would allow for cabling to eliminate the disadvantages of battery-operated instrumentation, hybrid systems could be considered where power is supplied through cables while data is transferred through any of the above wireless technologies. The complexity of the cabling is the result of the data communication requirements; this being taken care of by a wireless system would reduce the power cabling to a simple two-wire system.

Standardizing the connectors would mean that any power cable could be plugged in anywhere. At the same time, a reticulation system (a closed loop where power can be fed from either end of the loop) would further enhance the reliability of power supply to all the instruments while still retaining simple wiring.

In the case of a fibre optic communication link, the fibre optic cable and the power cable could be combined resulting in a single cable with the copper cabling providing additional strength and protection to the fibre optic cable.

If cable simplification is deemed an advantage, the fibre optic cable could possibly also be eliminated. In this case, the data is modulated and transmitted onto the same copper cable that carries the current to supply the instruments with power. Another alternative would be to have a three-core cable, two cores carrying the power supply current while the data communication is carried on the third. In all three cases above, the cable is daisy chained (going in to the instrument and going out to the next instrument in a chain of instruments). If the chain is a closed loop, power and communication can take place from either end and any break in the chain (faulty cable) will not disrupt the system in any way.

The main advantage of this system will be the simplification of the wiring system. All connecting wires look alike so that one or two spare cables could be used to substitute any faulty connecting cable in the system resulting in low capital layout, higher reliability and simplified maintenance.

3.4 Maintenance and Reparations

In a complex and diverse electronic system like the one implemented in the HVS finding and rectifying a problem is a daunting task to even the most skilled and intelligent technician. To anyone else, it represents a nightmare. Faultfinding is a time consuming and intellectually taxing task.

Since the system already has a computer system, a self-diagnostic system could be an invaluable tool, even if only to pinpoint the location of the fault. Even more desirable would be the incorporation of a diagnostic program that runs in the background to monitor all functions in the system. The monitoring and early detection of a malfunction (or possible malfunction) could result in preventing unreliable or downright faulty data being logged.

3.5 Standardization

Many of the components used in the instrumentation system are commercial products that are therefore standardized. Examples of this are the interface card used to convert analogue to digital signals, the signal conditioner circuits and the sensors like the LVDT (Linear Variable Differential

Transformers). This is mostly on the component level of the system. If the system level is examined, the same is not true.

Many of the system differs with respect to the interface card used which in turn has a ripple effect throughout the system as this often results in changes to some of the components in the subsystems. The reasons for such changes are two-fold: evolution to better components with higher performance or more desirable characteristics and satisfying the customer's requirements (usually customisation of the system).

In the first instance, such changes are a natural process as a result of technological advances in methods, materials, etc. This is an inevitable occurrence and should therefore be accepted, anticipated and managed. The main criterion for adopting a newer technology is backward compatibility. When newer technologies become available it is almost certain that the technology it replaces will eventually become absolute; it is merely a question of when? By ensuring backward compatibility, the client is assured that the system will not have to be modified to accommodate the new technology.

In satisfying the customer's requirements, one should be careful not to try to be everything to everybody. When a product is standardized, it is also easier for those marketing the product to keep up to date with the features, strengths, weaknesses and limitations. When a client wants a customized feature (either hardware and/or software), this becomes an addition to the standard package and the cost involved in supplying such a feature must be for the customer's account. In the case where demand begins to indicate that there is a market for a certain feature, a development program should be launched to add the feature. This will ensure a disciplined approach to the development of new features and measuring methods.

The advantages of standardization are two-fold. In the first place, standardization will aid in production of the product that lowers production costs. The second advantage is rooted in simplifying maintenance on systems. One of the most effective ways of reducing maintenance costs is to replace a faulty module with a new one. The downtime of the systems is minimized and the faulty module can be returned for repairs by trained personal that knows the product intimately, making repairs quicker and therefore more cost effective.

3.6 Measurement Methodology

The present measurement methodology has proven itself over the years as being acceptable and producing the data required. The methodology is therefore above suspicion but the methods used to execute the measurements could be described as crude, time consuming and labour intensive. The ideal method would require no human intervention and preferably be contact-less.

Labour costs are worldwide a concern. It would therefore be a competitive advantage to have a system that requires minimal and preferably unschooled labour. The most important consideration for automation however is not labour cost but improving the reliability of the data. If a human is required to note readings with pen and paper, mistakes are inevitable.

The automation of the measuring system would require the same interfacing with the control system of the HVS. Even if full automation is not possible due to practical constraints like how to keep the wheel not interfering with some of the instruments, ways to improve the measuring process with no or minimal human intervention should be investigated.

3.7 Reverse Engineering

Since many of the sensors and signal conditioning electronic circuits are commercial units and mostly imported; the cost of these units in the light of an ever-decreasing Rand, makes them more and more expensive, making the input costs towards the systems more costly. Since none of the sensors and instrumentation used at present, is protected by patents or intellectual property rights, the possibility exist to reverse engineer and/or develop the present technology.

This would open up the possibility for a commercial spin off venture with the industrial sector that could supply the local market with an alternative to imported components, providing an opportunity for job creation, saving on foreign currency and an income for the CSIR. Such a local manufacturing facility could also cater for customized sensors and systems that are not readily available locally.

3.8 Sensor Technology

Up to this point, most of the discussion revolved around the present measurement procedures, methods and methodology. In the discussion, it was assumed that the present sensors and methods to measure the parameters required are adequate to good enough. It seems that one of the limiting factors in the present sensors is noise. If the smallest detectable displacement signal is smaller than the noise, the signal will be "buried" in the internal noise of the measurement system. From analyses done it seems that the present sensors system's life expectancy could be considerably extended if the noise in the system could be reduced significantly.

The reduction of noise can be achieved through several mechanisms of which intelligent sensor technology seems to be the most promising. At present all sensors delivers extremely small signal outputs. These small signals are far more susceptible to electrical interference and noise pickup. By placing the signal conditioning at the sensor, the signal transmitted from the sensor is a much higher level that is far less susceptible to noise pickup. If the signal is also converted directly into a digital signal, noise susceptibility is reduced even further.

Newer sensor technology can be categorized into: new and matured (commercially available) technologies and experimental or prototype technologies. The newer technologies commercial available can be adopted and used as it is or it can be adapted to serve the purpose for which they are intended better. Commercialised technology is often developed to serve 80% of the market's requirements. The other 20% are often so wide ranging in requirements that the development needed to satisfy the requirements is simply not worth the investment required.

A literature study on sensing techniques and experimental sensors and materials revealed a host of promising new technologies. Many of them are associated with the development of smart materials. The next section examines the different new technologies and their possible exploration for a new generation of sensors that can be used in the HVS. The discussion is divided into two sections:

- Upgrading, developing and refining present sensors and techniques
- Researching and developing sensors using Smart Material Applications (SMA)

3.8.1 Upgrading, Developing and Refining Present Sensors

Presently, most of the measurements made relate to displacement (distance). It is only the strain gauges (force) and temperature measurements that can be added to the type of measuring instruments used in the HVS. By looking at alternative displacement measurement systems, a whole range of instruments stands to gain from any advances that could be made in this respect. Since the MDD sensors are at present Transportek's competitive advantage over other players in the field of pavement research and development, this is the sensor that needs to be focused on for R&D to gain additional (or at least maintain) advantage in the marketplace. This sensor is heavily dependent on displacement measurement that makes the development in this field an even higher priority.

The present technology of choice for the measurement of displacement is the Linear Variable Differential Transformer (LVDT). There are several other technologies to measure displacement; some giving absolute measurements while most others give relative displacement. In the category for optical sensors, there are LASER, optical grating sensors and fibre optics while ultrasonic (high frequency sound) and microwave (electromagnetic wave devices) make up the rest of the category for displacement measurement techniques. These fallsinto the category of new applicable technologies considered for adoption and/or adaptation.

Each of these technologies has its up and down side and these will have to be considered carefully before development can be considered. It might be necessary to develop two or even more techniques and/or technologies to obtain a selection of displacement measurement technologies each with its niche application to cater for different circumstances in which it must be applied.

Considering alternative measurement techniques, there are two technologies that are under consideration: fibre optic cable and piezoelectric sensors. Both technologies are currently researched and developed on site at the CSIR. The know-how, experience and infrastructure to do application research is readily available and co-operation from a logistic viewpoint, easy to resolve. These technologies are in the category of new technology to be researched and developed. This category is destined for long-term development.

3.8.2 Researching and developing sensors using Smart Material Applications (SMA)

There are new technologies that is aimed at exploiting the unexpected and sometimes most peculiar behavior of a group of materials that is known as smart materials. As the name implies, these materials seems to have some sort of "intelligence" or "memory". Smart materials are those materials that couple mechanical energy or behavior to other energy forms. Examples are piezoelectrics that enable the exchange of mechanical and electrical energy. There are also materials that couple mechanical behavior with chemical, thermal or magnetic behavior. In this discussion, attention is mainly focused on those materials that couple electrical energy with mechanical behavior.

It is outside the scope of this report to give a full account of all these material phenomena. This section will deal only with those SMA applications that are most promising and applicable within the APT (Accelerated Pavement Testing) program. It is this mechanical/electrical coupling that can be exploited to develop new strain sensors for the measurement of strain in road surfaces. What is more important is its unique ability to do the reverse, that is, to induce a strain in the road surface when electrical energy is added to the structure containing the smart material. Two materials had been identified as possible candidates for the development of strain measurement devices: piezoelectrical devices and a smart material called Nitinol that has a very high resistivity for its length, ideal for a good strain sensor.

Another material under consideration is fiber optics. Optical fiber is a thin strand of glass that is capable of carrying light impulses from the one end to the other through a mechanism called total internal optical reflection. This in effect means that a light beam projected into optical fiber, will remain within the fiber as a result of the internal reflective qualities of the fiber. Bending or straining the glass fiber usually results in a change in the behavior of the light beam carried inside the fiber. These changes can be detected and forms the base for the measurement of the mechanical parameter that was responsible for the change in the light impulse's behavior.

The technique of fiber Bragg grating is one that needs to be explored. When an optical glass fiber is exposed to ultraviolet light during manufacturing, it changes the refraction index of the glass. This result in the ability to control, combine and route light within the same glass fiber. These characteristics could be exploited in the manufacturing of MDD's that uses different color light sources for the different depths of measurement. The light is conveyed to the reference point via a bragg grated fiber where minute changes in position of the light source as a result of the road surface deflection will be detectable to a very small resolution.

4. NEW TECHNOLOGIES FOR DEVELOPMENT

4.1 Introduction

There are three technologies that have never been applied locally (except for experimental evaluation) in pavement measurement and are considered technologies that should be extensively evaluated for possible application. These three are:

- Image processing
  - Visual spectrum
  - Infrared spectrum
- Ground RADAR
- Non-contact Ultrasonic measurement

This discussion will briefly look at the general reasons and application of these technologies and the reasons why it is considered for possible application in the field of pavement evaluation and measurement. The main advantage of these technologies is the fact that they are all non-intrusive measurement methods.

4.2 Image Processing

Image processing is one of the most exciting developments of the past few years. Most of it stemmed from NASA's space program where images transmitted from satellites and space exploration vehicles had to be processed. The processing of images had come a long way and is a highly technologically advanced science. The need for image processing was driven by the need to be able to fully utilize the information available. An image taken consists of some few thousand picture dots or pixels. Each pixel represents an information bit. Apart from the individual pixel information available, there is also the relationship between pixels that also contains information. An image therefore represents a vast amount of information. Extracting and deriving the maximum benefit from the information is of cardinal importance.

If one consider how relative easy it is to take an image, freezing a vast quantity of information on the subject under consideration in one single shot, it is imperative that the opportunity be exploited to its full potential. Consider an infrared photo of a subject. Each pixel (say 320 by 400) represents a temperature measurement. If one considers the effort needed to make 128 000 individual point readings, one can only start to appreciate the power of imagery. Apart from 128 000 readings, the picture also tells the story of the relationship between the individual points which reveals a pattern that is practically almost impossible to obtain otherwise.

4.2.1 Visual Images

Visual images can be divided into monochrome (black and white with a grey scale ranging from 0 to 8, 16, 256) and colour images (16, 256, 65536, etc. colours). The same principle applies to the difference in grey or colour as pointed out above. When contrast and brightness is added, the amount of information is compounded by the permutations available, all which contain some form of information.

Extracting the information required from this vast pool of information is a specialized task. Apart from knowing what to look for, there is also the question of the vast storage of information that is yet to be exploited. The research project should be aimed at trying to unlock the as yet unexplored information contained in visual images of pavements.

4.2.2 Infrared Images

Infrared images are visual representations of temperatures at each point covered by the pixel in the image. The temperature differences are depicted as colours to help with the interpretation of the information they contain. If one considers the ease with which 128 000 (or more) temperature readings can be taken with the push of a button, one can only start to appreciate the power of imagery. The information contained in the relationship between individual points and the correlation of patterns contained in those images, unlocks another leap in the quantity and quality of information that can be derived from the image.

Again, knowing what to look for and extracting the required information is one thing. Unlocking the information that can be provided by the image is a challenge that needs to be addressed in a research project. Lots of research has already being done in this regard. The project needs to assess and evaluate the possibilities and their application in pavement research and measurements.

Image capturing and processing is an expensive technology. It is only when the information that can be unlocked from these images has been assessed, can a cost versus benefit assessment be made to determine the cost effectiveness of such technology *in pavement assessment and research.*

4.2.3 Current Infrared Technologies

The current leaders in infrared solutions are definitely FLIR Systems. This is also confirmed by the amalgamation of previously known as Agema Infrared Systems with FLIR Systems. The company specializes in infrared image cameras that loosely appears to be a video camera but is a still image camera with a viewfinder similar to a video camera so that the operator can see the live image (similar to a SLR camera (Single Lens Reflex) where the image is seen through the lens of the camera).

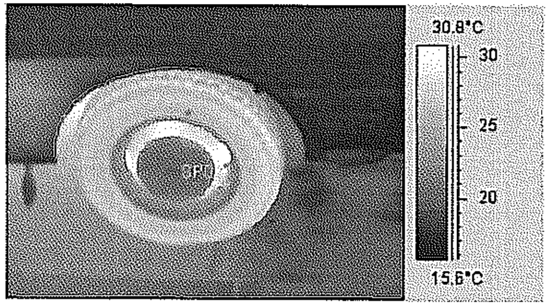
FLIR System's camera is unique in that respect that it uses a patented uncooled detector. Most infrared cameras require the image sensor to be liquid helium or liquid hydrogen cooled to be sufficiently sensitive in the infrared spectrum required. This makes the camera much more transportable, considerable easier to use and less costly to run. The camera also boasts a large variety of features to capture images, voice comments with an image, text annotation and special reporting software to enhance the ease with which data can be reported. In figure 4.1 an example of some pavement related images taken by the FLIR system is shown.

The success of the product is amply demonstrated by the distribution of users (through their dealer and agent network), and the large variety of industries that uses the produce in production, maintenance and research capacity. Some examples are the automotive industry (research), plastics industry (production) and various maintenance companies specializing in preventative maintenance on heavy mechanical equipment in a large variety of industries.

4.2.4 Other Image Technologies

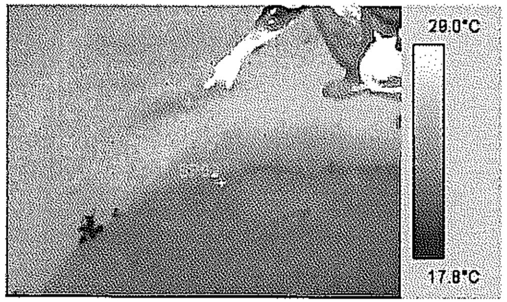
Although the technology and technique described here is not necessarily an image technology, it is closely linked to image technology and therefore deserve mentioning. Pressurex, a product marketed by Sensor Products Inc. is a pressure sensitive film that turns into various degrees of red depending on the pressure exerted at that point. This tone variation due to pressure variation leaves an imprint that visually represents a map of pressure distributions over and area under investigation.

This film is a quick and cheap method to evaluate the pressure distribution of the contact area between the road surface and a tire. The resultant map not only clearly shows the high and lower stress areas in the contact area, but through analysis of the colour intensity of the various areas, it is possible also to quantify the pressures experienced at that point. In a pilot test, one could easily seen that the leading edge of each rubber "block" in the tire's thread pattern, experience higher contract stress than the rest of the "block".



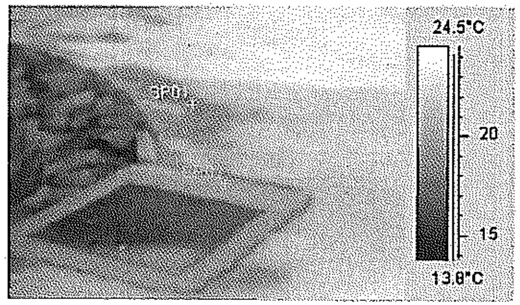
Warm tyre after driving

SPO1 = 26.9 C
SPO2 = 24.2 C



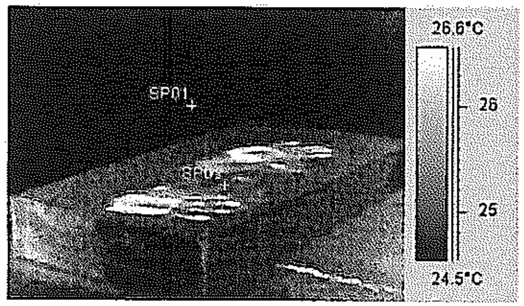
Crack on concrete pavement

SPO1 = 24.7 C
SPO2 = 21.9 C



Moist areas on concrete pavement

SPO1 = 18.3 C
SPO2 = 20.5 C



Increased temperatures due to surface contact on asphalt sample

SPO1 = 22.9 C
SPO2 = 25.2 C

Figure 4.1: Typical infrared photos.

4.3 Ground RADAR

Electromagnetic waves have the ability to penetrate objects and materials without causing damage or change to the materials or objects that is unique. This penetration opens the possibility to examine the secrets, hidden from the eye, of these objects that are unique. RADAR is predominantly used in air traffic control to locate and characterize airplanes even in the most adverse weather.

RADAR has since found most unusual applications one of which is the location of buried objects. Forensic teams of police services, archaeologists, emergency teams, to name a few have used the technology to locate people and objects buried underground. Much of the success of the technology can be attributed to the advances made in signal processing, enabling these systems to construct images from the reflected waves.

The speed with which the images can be obtained, open the possibility of using the technology to obtain information on the layers below the pavement at relative high speed. This means that vast tracts of road could be assessed in a relative short time to determine the condition of the underlying layers in the road. This non-intrusive assessment could be invaluable in the early detection of pavement problems. Being able to be proactive instead of reactive (often resulting in expensive rehabilitation) could have an enormous impact on the condition of roads and the cost of maintenance.

The assessment would entail the study of ground radar and the information that could be gained from the technology. Once this information is available, the possible application in pavement evaluation could be assessed before a decision can be made on the suitability and cost benefit ratio of this technology.

4.4 Ultrasonic Imagery

A very recent development in ultrasonic wave imagery is the development of a transducer that needs not to be in contact with the surface of the object or material under examination. This opens the possibility to apply ultrasonic wave measurements to pavements from a moving vehicle in the same way as envisaged with ground radar.

Once again, the characteristics that can be assessed with this technique needs to be evaluated for suitability and applicability in pavement measurement. Since the wavelengths of the two methods differ, it is expected that the one method will be able to detect features not possible with the other method. Combining the two methods could not only expand the range of characteristics detected, but by combining the two methods, could reveal more than the sum of the individual methods.

It is therefore foreseen that both ground radar and ultrasonic imagery will be evaluated both individually as well as in combination. The results of the evaluation will indicate it this technology and the ground radar and/or a combination of the two, warrant further investigation and/or development.

5. MANAGEMENT CONSIDERATIONS

The instrumentation system of the HVS is a complex system comprising of both hardware (physical components) as well as software. Apart from developing, designing, building and installing the systems, very little if any consideration has been given to the management aspects of commissioning, training, maintenance, backup and support and upgrading of instrumentation systems to clients. Since clients are predominantly situated at considerable distances from the division, particular attention should be given to the logistic and other support that might be required by the client.

The standardization strategy is the first step in the management of the system logistics. Standard components and system configurations ensures a uniformity that aids in fault finding, reparations and upgrading of existing systems. Apart from standardization, there are several other management steps that can be taken to ensure smooth and trouble free operations of the instrumentation.

5.1 Commissioning Instrumentation Systems

Shipping out an instrumentation system for installation over vast distances in surroundings where there is little backup is a process full of risks. Before one attempts to ship and install an instrumentation system, it is imperative that the system is fully tested in its entirety. This means that all hardware and software must be tested as a unit. Every aspect of the system must be tested and it would be advisable to have a fully documented acceptance test for the instrumentation system to ensure that all functions of the systems are working satisfactorily.

The question of calibration of the sensors is extremely important, as the accuracy and repeatability of data coming out of the system will have an influence on the validity of the data generated. Till now, no one has ever questioned the accuracy and validity of the data, but at present there is no defence if any queries or question marks are raised. In the long term, it would be advisable to have a calibration and testing section in the Technology Innovation Centre that should eventually be brought up to ISO Guideline 25 standards. This would give the division excellent ground for defence if any aspect of the system were to be brought under suspicion.

A formally documented acceptance test would also serve as an excellent base for a training course for operators using the instrumentation. This will also give the assurance that measurements taken with the system is executed with the correct procedures that will ensure that all systems are used within the limitations which is part and parcel of any measurement system.

5.2 Training

Although the question of training is addressed in the operating of the HVS, there seems to be no training course or procedure for the use of the instrumentation. Combining the acceptance test and a training course would be a way to ensure that the persons using the instrumentation are familiar with the correct procedures for taking measurements. It is inevitable that users of the system would find methods to speed up or simplify the procedure for taking measurements. These are human tendencies that need to be taken into consideration. Often, these people have excellent ideas that are practical and sensible. The so-called short cuts that are often associated with this can enhance productivity and should not be outright condemned. But it is necessary to examine these procedures to ensure that they operate within the defined limits of the instrumentation systems. Once this is formalised, one has the assurance that the integrity of the data is above suspicion.

Calibration of instruments on a regular bases and recalibration of instruments like strain gages when a machine is moved from one location to another is important to ensure that the sensors and the instrumentation system's data integrity remains intact. Often instruments like temperature taken with two different instruments show a discrepancy. The personal using the instruments should be trained to be suspicious of such measurements and report it back to head office for examination. At present, personnel appear to have a blind faith in the system which can be fatal for data integrity. A simple procedure such as switching on instruments and allowing them to warm up first for at least 30 min seems to be an alien concept at the moment and yet, this is essential for analogue instrumentation (it is in fact more beneficial to leave instrumentation on overnight).

5.3 Maintenance, Backup and Support

Some of the aspects of maintenance have already being addressed in the section about training and in particular, the calibration of instrumentation. Although electronic devices are robust and reliable once they are past the occasional "teething" problems, one has no control over external factors such as fluctuations in power supply voltage, environmental conditions such a humidity, temperature and thunderstorms that brings electrical activities such as lightning strikes, etc. These are often the cause of some electronic component or system to fail and it is often impossible to prevent damage from such factors. When a failure occurs, people are often scared to death about a possibility that they could have contributed towards the failure.

The failure of a small component, often costing only a few rand, can literally cripple a complete system. The complexity of the systems further contributes towards people's hesitance and fear to "touch it" if something goes wrong. This problem can be addressed in two ways: through technology and through training. It is envisaged that the next generation of instrumentation will have software that will continually interrogate the various components in the system. This process will be completely in the background and the operator will not even be aware of it happening until the system detects an abnormality in the system. The software will be complemented by embedded hardware with intelligence to aid in this process. Once an abnormality is detected, the system will need the aid of human intervention to find the cause of the problem.

Training personnel in using the software to find the cause of the problem often leads to personnel having more confidence in their ability to handle a breakdown in the electronic system. The built-in diagnostics to be embedded into the system will be able to instruct the operator to carry out simple tasks such as disconnecting cables or removing and swapping standard modules in the system to help pinpointing the cause of the problem. The software will therefore become an on-site technical support system enabling the system to pinpoint the exact nature of the problem itself.

The standardization of components and subsystems will enable the division to come to the rescue of a client by shipping a replacement subsystem on an exchange bases to replace the faulty one. Since all subsystems are plug-in units, it is a simple matter of removing a faulty subsystem and replacing it with a new one. Where minimal down time is a high priority, the client could keep some spare subsystems in store. Through keeping a history of breakdowns in systems, it would become possible to identify those subsystems most vulnerable and where it is not possible to eliminate or reduce the risk of such breakdown through alternative design, spares could reduce the risk of downtime.

This proposed procedure would reduce the risk of down time in systems located at vast distances from the division and also reduce expenses in travelling to such remote locations to correct problems in a system. The automatic detection of faults at the site by the software would also reduce the costly labour intensive process of trying to do fault finding "at a distance".

5.4 Upgrading Aging Systems

Advances in measurement techniques and technology make the outdating of equipment a certainty that has to be faced. Since standardization and modularisation of equipment is envisaged, this would contribute towards ease of upgrading of outdated systems. Backward compatibility will assure the client that he/she need not to replace their complete system, but merely upgrade those subsystems that are most in need of improvement. In some cases, some alternative subsystems could be offered to the client if they do not have the budget to have all the "latest and greatest" available.

This methodology will also ensure that a new generation of instrumentation need not to be developed, designed and built in one single and massive effort. Improvement in the system will therefore become evolutionary rather than revolutionary. Some of the earlier and less costly measurement systems might be more appropriate for the client. The possibility of upgrading their system should the need arise is a strong selling point in marketing a product. Selling older, more mature technology will also enhance profitability for that product or technology (more units sold for the same development layout).

Since software plays such a prominent role in modern electronic systems and this system is no exception, the capacity to do programming in-house should be pursued. Programming in a technical environment places total different demands on the programmer than that experienced in the IT

(Information Technology) world where software is written for application programs. The technical world demands an excellent background to the hardware and the software. Often the designer of hardware has to make choices between software implementation and less hardware or vica versa. Only a person with an excellent background in hardware design will be able to gasp the trade offs that often accompany such decisions.

It is therefore most undesirable to make use of internal programmers (IT orientated) or outsourcing this to technical expert/programmers. The amount of interaction required between the hardware designer and the external programmer make this process simply uneconomical. The continual development of new hardware and the subsequent software needed for this new product make it imperative that the division acquire this expertise and capacity internally.

6. CONCLUSIONS

A critical evaluation of the present instrumentation system and its configuration led to some important "discoveries" in terms of the present systems weaknesses, leading to the development of a vision for a new generation of instrumentation. It must however be stressed that the new generation instrumentation is not a radical departure from the present system. The new generation system will use the strengths of the old instrumentation system and the evolution will be aimed at reducing the weaknesses of the old generation system.

The most radical departure from the older generation system is the scrapping of the tendency to customize the instrumentation for a client. Instead, standardization of not only components but also system configurations will be pursued. This will have a large impact on the maintenance of systems. Taking into consideration that there is numerous instrumentation systems already installed and in use in the field, backward compatibility will be strictly adhered too. This will enable existing customers to be able to upgrade their systems without major cost or modifications to their hardware or software.

Four important conclusions can be drawn from the evaluation of the instrumentation requirements for APT technology:

- **Displacement Sensing Technology:**

  - Displacement sensing is the core business of the instrumentation system.
  - Since MDD technology is a unique product of this division, the advantage over competitors should be retained and preferably extended.
  - Since MDD technology is largely dependent on displacement sensing, this technology should be furthered as far as possible.
  - Any advances made in displacement sensing will impact on a wide range of instrumentation.

- **Noise Reduction Strategy:**

  - The present instrumentation systems are very vulnerable to electrical interference and suffer from a lot of electrical noise.
  - This noise prevents the sensors used to reach their full capability in terms of resolution.
  - A reduction in the noise from the system could extend the present sensor's life span before they need to be replaced with more advanced and sophisticated sensors.
  - The development of so-called "intelligent" sensors will greatly contribute towards this goal.

- **Modernizing Signal/Data Transfer:**

  - The signal transfer from sensors to the instrumentation systems is at present done exclusively through cables.
  - These cable are a reliability risk and a real nuisance.
  - The MDD's (our main competitive advantage) stand to gain the most from the elimination of cables for data transfer (and even power supply)
  - Elimination or standardization of the cabling between instruments and the main instrumentation cabinet at the computer will result in lower maintenance costs and higher reliability of the system.
  - It will enhance the perception of a modern, advanced instrumentation system.

- **Standardization of System Configuration and Components:**

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  - Customers are predominantly large distances from or location, resulting in a logistic nightmare in the event of breakdowns in systems located away from the division.
  - Standardization will reduce production costs, inventory costs for spare parts and reduce downtime of systems during breakdowns.

- Having spare components in stock would drastically reduce the delivery time of both spare parts in the event of breakdowns and systems to new customers.
- Where customers require additional features in their systems, this can be handled as a consultation project.
- Where more customers are calling for the same extended feature to the instrumentation system, this feature can be developed as an additional enhanced feature for all systems.
- Customers can choose the standard features they require for their particular application. Any extension of their system becomes the delivery of a standard feature/component to their system.

7. REFERENCES

1. Measurement Systems : Application and Design. – Ernst O. Doeblin
2. Frequently Asked Questions about Fiber Bragg Gratings – http://135.145.4.90/corpinfo_faq_fbg.htm
3. Fiber-Optic Strain Measurement – http://www.fisco.com/strain.htm