PRECISION SYSTEM FOR MAPPING TERRAIN TRAFFICABILITY, TRACTOR-IMPLEMENT PERFORMANCE AND TILLAGE QUALITY

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ABSTRACT

A novel data acquisition and differential global positioning system had been integrated on–board a Massey Ferguson 3060 agricultural tractor for real-time mapping of terrain trafficability, tractor-implement performance, and tillage quality with geographical location. Mapping terrain trafficability had to be done on a separate field sampling operation with the instrumented tractor and the mounted soil penetrometer-shearometer unit before the start on any field operations. Mapping of tractor-implement performance with the instrumented tractor and built-in transducers had to be done while running the tractor and implement for the intended field operation. Mapping of the tillage quality had to be done with the instrumented tractor and the towed soil surface profile digitiser on a separate field sampling operation immediately after completing the tilling operations. The instrumented tractor being the rover, received both the location coordinate signal from the satellite and the broadcasted differential correction signal from the near by set-up base station at the field site. The complete data acquisition and differential global positioning system on-board the tractor was capable of measuring, displaying, and recording in-real time the tractor's position, soil penetration resistance and soil shear stress when mapping terrain trafficability; the tractor's position, pitch and roll angles, traveled speed, actual speed, fuel consumption rate, drive wheel slippage, drive wheel torque, PTO shaft torque, drawbar force, tilling depth and three-point hitch forces when mapping tractor-implement performance; and the tractor's position, soil surface profile, and soil tilt index when mapping tillage quality. Spatial variability information could be extracted from the generated maps to assist the tractor driver in the decision process of optimising the field operation of the tractor-implement. This paper describes the design, integration, and configuration of both the hardware and software for the respective field measurements, monitoring and mapping.

Keywords: *Data Acquisition System, DGPS, Precision Farming, Terrain Trafficability, Tillage Quality, Tractor-Implement Performance*

INTRODUCTION

Great deal of attention in precision farming has been focused on reducing chemical and fertiliser costs and increasing crop yield while ignoring the fact that there are other inputs contributing to the high total production costs. Tractors have been the prime power unit for land preparations, crop upkeep operations, and transportations in the crop production industry in Malaysia. Majority of the farmers contracted out most of the field operations due to the high initial and maintenance costs of tractors and implements. The charges made by the contractor to the farmers for tractor field operation services are made on the basis of field size. The farmers had their tractor field operations done by the contractors without realizing the quality of work they received for the given service. On the other hand, the contractors gave the services to the farmers without realising that the tractor-implement combinations they used were not properly set-up at the up-most optimum conditions. As a result, the contractors had to put more labor and fuel to run the tractor-implement in the field in an inefficient condition while the farmers had to put extra expenses for the over charge rates and the poor work quality given by the contractors due to the used of inefficient tractor-implement. The profit margin for the farmer could be severely affected if the field operation cost escalates too high. Typical cost associated to the land preparations and field maintenances alone accounts about 20 to 25% of the total production cost for paddy cultivation in Malaysia [1]. Thus, significant profit improvements would be possible in any crop production if the machinery resources were utilized more efficiently in completing the field operations.

This paper describes the precision farming research work that have been undergoing at Universiti Putra Malaysia in designing, integrating, and configurating a complete data acquisition and differential global positioning system on a Massey Ferguson 3060 agricultural tractor for monitoring and mapping of terrain trafficability, tractor-implement performance, and tillage quality during field operations. The developed system among others would able to indicate to the tractor driver which area in the field that would exhibits low terrain traffiicability, whether he is operating the tractor and implement at the optimum conditions during any field operations, and whether the produced field conditions after the tilling operations are at the required seed bed quality.

TRACTOR WITH DATA ACQUISITION AND GLOBAL POSITIONING SYSTEM

The platform of this research is a Massey Ferguson 3060, agricultural tractor with a rated engine power of 64 kW@2200 rpm. The tractor is equipped with a 4.07 L, naturally aspirated, direct injection, 4 cylinders PERKINS engine and selectable 2

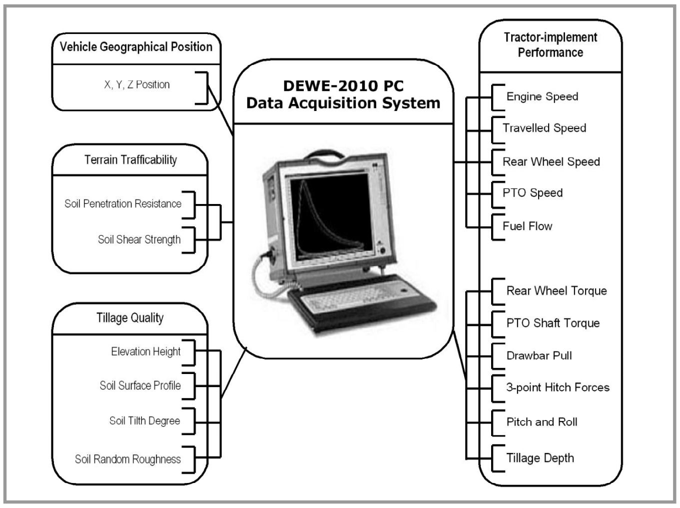

Figure 1: Block diagram of the complete data acquisition and global positioning system

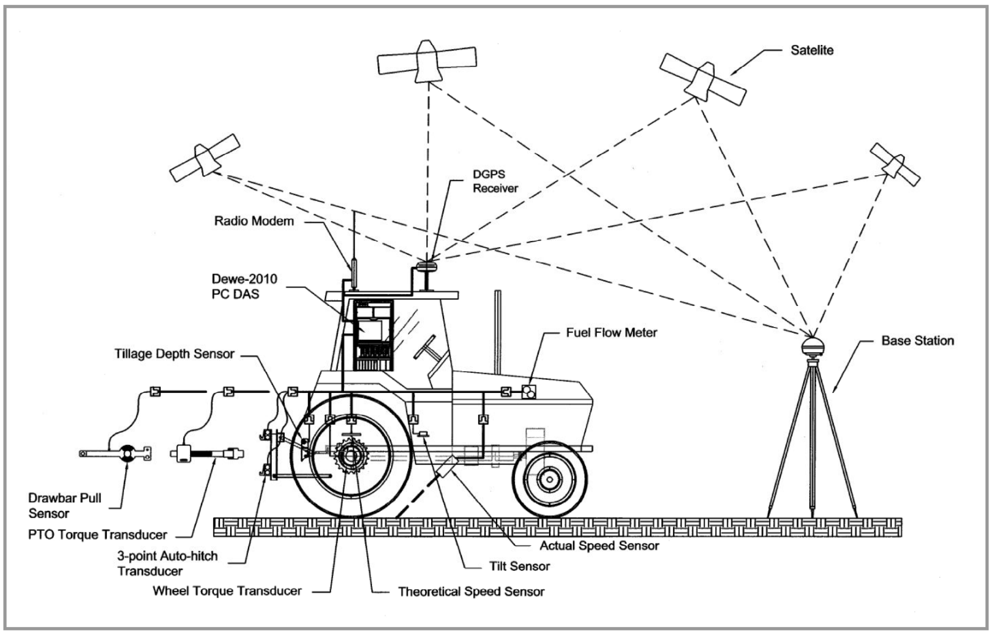

Figure 2: The complete data acquisition and DGP system for Massey Ferguson 3060 tractor

or 4 wheel drive options. The tractor size is considered to be the typical size for general use in most of the agricultural fields in Malaysia. The data acquisition and global positioning system on-board the tractor together with the automated soil penetrometer-shearometer unit, built-in transducers on the tractor, and automated soil surface profile digitiser were capable of providing information on terrain trafficability, tractor-implement performance, and tillage quality with respect to the tractor's geographical position during operation. Figure 1 shows the block diagram of the complete system with various measurements for the tractor. Figure 2 shows the complete data acquisition and global positioning system after being installed on the tractor.

The DEWE-2010 PC data acquisition system on board the tractor functions as a data collection, processing and storage center for all of enquired data from the available measurement transducers and DGPS receiver. The system is equipped with a Intel Celeron 700kHz processor, 128MB SDRAM, 15" touch screen TFT display, 20GB hard drive, a CD-ROM drive, a floppy drive and a 200kHz PCI A/D board. The available communication interfaces include a 10Base T Ethernet port, a USB port, 5 ports of 25 pin RS232 (1 port built-in onboard and 4 from an expansion serial board using a multi-plextor cable), a keyboard port, a VGA port for external display monitor. The system has an internal built-in UPS and runs either from an AC or a DC input source. The system A/D board is equips with 16 channel modules namely 4 units of DAQP-V Voltage Isolation Amplifier modules, 5 units of DAQP-FREQ Pulse Isolation Amplifier modules, and 7 units of DAQP-BRIDGE Strain Gage Amplifier modules. The DAISY Lab 5.6 software was used in the DEWE-2010 PC data acquisition system to control the data acquisition and provide facilities for logging, monitoring, processing, and storing of both the measured signals and collected GPS signal.

Two sets of DGPS receivers with individual radio units were used for local real time differential correction of the tractor's geological position while operating in the field. A local base station consisting of a Trimble Pathfinder Pro XRS DGPS receiver and a Pacific Crest PDL radio unit was established at a known surveyed point closed the field plot. Trimble AgGPS 132 DGPS receiver, Trimble TSC1 handheld data collector, and Pacific Crest PDL radio unit were placed inside the operator cabin of the Massey Ferguson 3060 tractor with the receiver and radio antennas being mounted on the cabin top using special magnetic vehicle fixtures. This instrumented tractor was used as a rover to collect unknown tractor position coordinate in the field during operation. The Trimble AgGPS 132 and Pathfinder Pro XRS DGPS receivers are built-in with 12-channel GPS engine with improved ionosphere models that could enable the interception of twelve satellite signals. This provides real time sub-meter differential position accuracy and offers differential speed accuracy of better than 0.1 mile per hour (0.16 kph) following NMEA (National Marine Electronics Association) Standard 0183 and TSIP (Trimble Standard Interface Protocol) requirements. The radio unit was linked to the DGPS receiver at 8 bits, odd parity and 9600 baud rates. The DGPS receiver on the rover was interfaced to the DEWE-2010 PC data acquisition system through a 25 pin, RS232 port [2].

A 3KVA Yanmar LA-series diesel generator set was employed to provide the external electrical source to run the automated soil penetrometer-shearometer unit and the automated soil surface profile digitiser. The generator set was placed in a special design sound barrier cabinet and mounted at the bottom right side location of the tractor. The 240 VAC output voltage of the generator set was delivered to the power supply outlet distribution cabinet that was placed at the back of the tractor operator seat. The cabinet houses three switching-mode multiple step-down AC to DC converter-regulator units to provide the respective 5V DC, 12 V DC and 24V DC supply outputs and a linear DC power unit to provide a 60V DC supply output.

Figure 3: Instrumented tractor with automated soil penetrometer-shearometer unit

AUTOMATED SOIL PENETROMETER-SHEAROMETER UNIT

A mounted type automated soil penetrometer-shearometer unit had been designed, developed, and calibrated to measure soil mechanical parameters for quantifying terrain trafficability of the field before the start on any field operations (Figure 3). The automated soil penetrometer and shearometer unit makes use of the commercial Eijkelkamp 06.15 penetrometer and a RMU I012 vane shearometer standard instruments. The penetrometer was capable of giving a measurement range of 0 to 10 MPa while the shearometer was able to a measurement range from 500 to 600 kgcm. These two instruments were housed in a special made frame having gear driving mechanisms and a three-point hitch attachment for rear mounting of its complete unit to the Massey Ferguson 3060 tractor. The motion controls for the penetrometer and shearometer were performed by the Omron CSIG-45-V1 Programmable Logic Controller unit and other external electronics and sensing devices. Powerpac Hybrids N31HRFJ-LNN-NS00 and N32HRFJ-LNN-NS00 stepper motors were used to drive the penetrometer and shearometer moving carriages in the vertical axis direction while Powerpac Hybrids E22NRFD-LNN-NS00 stepper motor was used to drive the rotating spindle of the shearometer. The complete unit was capable of measuring the soil penetration resistance and shear stress up to a maximum of 60 mm depth. DEWE-2010 PC data acquisition system was used to perform both the operational control of the penetrometer-shearometer and the logging of the soil penetration resistance and shear stress measurements at a fixed soil depth, and also tractor's position from the differential global positioning system.

The DEWE-2010 PC data acquisition on-board the instrumented tractor acts as a data recording, processing, and storage center for tractor's geo-position, soil penetration resistance and shear stress data. The concept of touch-screen virtual control panel was developed on DASYLab® platform to configure the data acquisition for the data acquisition and user controls through a touch-screen virtual control interface (Figure 4). Virtual buttons were created on the touch-screen control panel for the START, STOP, ON and OFF tasks and special read-out boxes are also created to display in real time the acquired data during the logging process. Before any field operations, the instrumented tractor and penetrometer-shearometer unit was brought to the field to perform the sampling operation. At the sampling location in the field and before the start of the measurement task, the main frame of the penetrometer-shearometer unit had to be lowered by the tractor's 3-point linkage until both penetrometer and shearometer shafts were at perpendicular position to the ground surface. The penetrometer-shearometer unit operates under a 3-axis movement directions namely, P axis for the vertical movement of penetrometer shaft, S axis for the vertical movement of shearometer shaft, and T axis for the clockwise rotation movement of shearometer shaft. Prior to the beginning of the measurement process, the two moving carriages were positioned at their respective P axis and S axis origins. The highest traversing end for the respective moving carriages was taken as their origins. The 3 position control cards of the PLC were programmed for the 3-axis movements to be in the required sequence. The P axis was programmed to move continuously at a linear speed of 30 mm/s to a travel depth of 150 m. During the process it was programmed to log the measured soil penetration resistance at every 25 mm travel

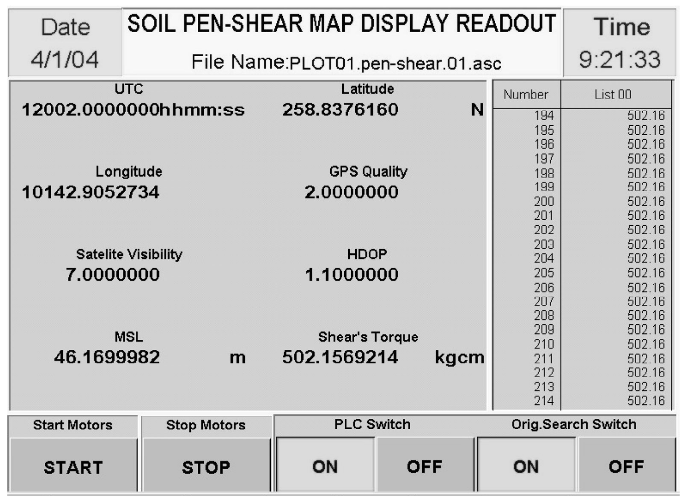

Figure 4: Touch-screen virtual control interface for automated soil penetrometer-shearometer unit

intervals into the DEWE-2010 PC data acquisition system. The S axis was programmed to move initially at a linear of 30 mm/s and stop at a known depth when the shearometer's vane was almost covered by the soil surface. This depth had to be earlier set in the DEWE-20101 PC data acquisition system and selected based on the size of vane used for the measurement. The T axis was programmed to trigger immediately after S axis stopped and was set to make one complete rotation at a speed of 1 rpm. During the process it was programmed to log the measured maximum soil shear stress value referred as the undisturbed soil shear strength into the DEWE-2010 PC data acquisition system.

The measured cone index by the penetrometer is calculated as follows:

$$P = F/A$$

where P is the cone index in MPa, F is the average penetration force in N , and A is the unit base area of the cone probe in m^2.

The measured soil shear strength by the digital vane test apparatus is calculated as follows:

$$\tau = \frac{6m}{\pi d^2 (d + 3h)}$$

where τ is soil shear strrength in kPa, m is twisting torque in kgcm, d is vane test apparatus blade diameter in cm, and h is vane test apparatus blade height in cm.

Figures 5 and 6 illustrate typical examples of soil cone index and soil shear strength maps that could be produced as the result of running the instrumented tractor and the mounted soil penetrometer-shearometer unit before any start of tilling operations in the field.

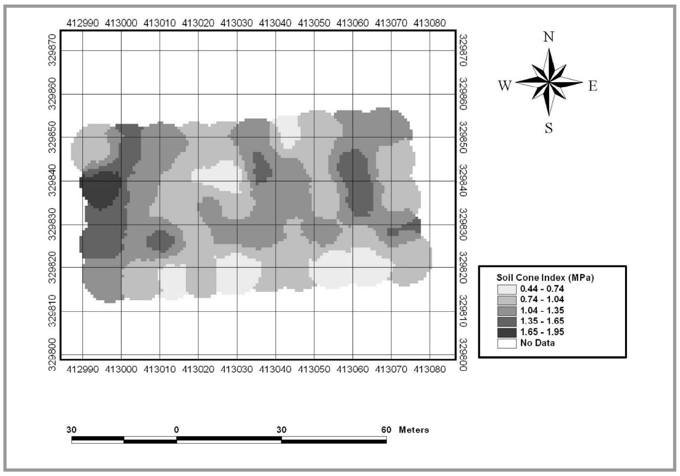

Figure 5: Soil cone index map

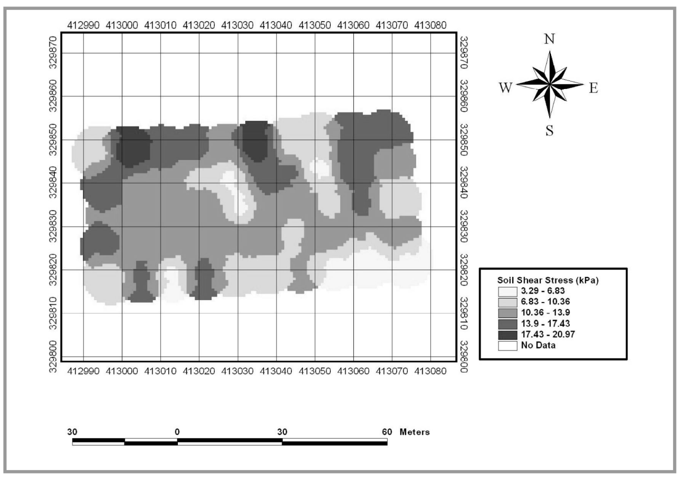

Figure 6: Soil shear strength map

TRACTOR-IMPLEMENT PERFORMANCE MONITORING SYSTEM

Apparently, the complete performance monitoring system on the instrumentation system that had been factory built-in the Massey Ferguson 3060 agricultural tractor could be able to measure, display and record tractor's engine speed, traveled speed, rear wheel speed, PTO speed, fuel flow, rear wheel torque, PTO shaft torque, pitch and roll angles, drawbar pull, tillage depth, and three-point hitch forces when the tractor-implement is operating in the field [3] (Figure 7).

The tractor traveled speed was measured by factory installed Doppler radar that was mounted rearward facing at 35 degree and located left side at midway of the tractor. It uses the Doppler effect from a 24 GHz microwave emission to generate a frequency signal that is proportional to ground speed. This radar unit could generate output signal at a frequency of 27.3 Hz per km/hr within ± 3% tolerances. Tractor rear wheel speed was measured by a factory installed conventional variable reluctance magnetic pickup that was located at the crown wheel of the rear axle differential unit of the tractor. This magnetic pickup unit could generate an output signal in the range from 12 to 14 Hz per km/hr, depending on the tire size fitted to the tractor. Tractor fuel flow rate was measured by a micro oval flow meter that was factory installed in the fuel line between the fuel filter and injection pump of the tractor. This fuel flow meter could measure the flow rate in the range from 0.025 to 40 L/hr within 1% accuracy.

The tractor rear wheels torques were measured by a pair of special made transducers that were mounted on each side of the rear wheel axles of the tractor. The design of the transducer was based on an extension shaft that was securely mounted between the rear wheel axle flange and tire rim. A RBE-4A Kyowa slip ring and a special made adapter were fitted to the end of extension shaft. Two sets of KFG-5-120-D16-11-L1M-2S Kyowa, 90˚ rosette, 120±0.8 Ohm, 2.1 gauge factor strain gauges were bonded at 45˚ shear planes on opposite sides of the extension shaft. Two L shaped steel conduits were mounted on each side of the tractor mudguards to carry the cables from the slip rings to the data acquisition system inside the tractor operator cab. Each torque transducer was designed for a torque range of 0 to 32 kNm with a sensitivity of 29.88mμV/V/kNm.

The tractor pitch and roll angles were measured by a CXTA02-AL dual axis tilt sensor that was located closed to the center gravity position of the tractor. This tilt sensor used a micro-machined acceleration sensing element with a DC response to measure inclination relative to gravity. This tilt sensor could measure the pitch and row angles in the range from - 20˚ to + 20˚ with a linearisation error of less than ±2%.

The tractor PTO torque was measured by a special made PTO shaft torque transducer that was located between tractor PTO and implement PTO input. The design of the transducer was based on the modification made on the standard commercial PTO tractor drive shaft. The free end of the female PTO drive shaft was provided with a raised collar, a screw bracket and a lock nut to position a 9E06-S1-3B NEC slip ring while the other end is welded to a universal joint. Two set of KFG-5-120-D16-11-L1M-2S Kyowa, 90˚ rosette, 120±0.8 Ohm, 2.1 gauge factor strain gauges were bonded at 5 degree shear planes on opposite sides of the circumferential outside surface of the female PTO drive shaft. The shaft transducer was designed for a torque range of 0 to 937 Nm with a sensitivity of 0.2852μV/V/Nm.

The tractor drawbar pull was measured by a special made drawbar pull transducer. The thick proof ring part was made close to the front pin of the drawbar pull transducer to reduce

Figure 7: Instrumented tractor with performance monitoring

the effects of lateral and longitudinal moments on the transducer measurements. A 7075-T6 aluminum alloy, having a low modules of elasticity, was employed in giving the transducer greater strain sensitivity. The drawbar transducer was mounted with four sets of KFG-5-120-C16-L1M-2R Kyowa, uniaxial, 120±0.8 Ohm, 2.1 gauge factor strain gauges at the nodes and 90˚ locations on the inner and outer circumference of the thick to the thick ring maximum strain nodes. The drawbar pull transducer was designed for a pull range of 0 to 50 kN with a sensitivity of 13.68µV/V/kN.

The tilling depth of the implement was measured by a 106˚ RS rotary position sensor which was fixed using two M4 set screws to a special made L-shape bracket that was attached to the rockshaft of the tractor. A special made bolt with protruding 'D' profile shaft on the other side was designed and inserted into the hollow rotor of the sensor to enable the both clockwise and counter-clockwise rotation. This rotary position sensor could measure the rotational angle in the range from 0 to + 106˚ with a linearization error of less than ± 2%.

The vertical and horizontal forces on the implement were measured by a special made 3-point auto hitch dynamometer. The design concept of the dynamometer was based on an instrumented inverted "U frame" assembly that was mounted between the tractor link and implement. The force sensing elements comprises of three steel extended orthogonal transducers that were located between the frame and hook brackets. Each extended octagonal transducer was mounted with KFG-5-120-C16-L1M-2R, Kyowa strain gauges at train angles nodes of 90˚ and 39.5˚. Each transducer was designed for a maximum horizontal and vertical force of 25 and 12.5kN, respectively. The complete dynamometer unit was designed for a draft range of 0 to 75kN.

The DEWE-2010 PC data acquisition system on-board the instrumented tractor was used to perform both the operational control of the tractor-implement performance monitoring system and the logging of all the tractor-performance measurements and tractor's position from the differential global positioning system. Virtual buttons were created on the touch-screen control panel for START, RECORD, PAUSE and STOP tasks and special read-out boxes are also created to display in real time the acquired data during the logging process (Figure 8). The data collection begins when the touch screen virtual button START is pressed and ends when the virtual button STOP is pressed. Once the program is executed, an input dialog box is prompt to acquire the user to input the field operation data such as plot name, operation name, and experiment number. The key enter is pressed to accept the input and start the data monitoring. The virtual button RESET is pressed before field operation to return the error initial value to zero. The virtual button RECORD is pressed to start to record the displayed data and virtual button PAUSE is pressed to pause the data recording and continue data monitoring. The virtual button RECORD is pressed again to continue recording or pressed the virtual button STOP to terminate the data collection. A new file is created every time the virtual button START is pressed and the file is closed and protected when the data collection is terminated. All data are recorded into the same file in ASCII format.

Figure 8: Touch-screen virtual control interface for instrumented tractor with performance monitoring

Figures 9 to 16 illustrate typical examples of implement's tillage depth, implement's draft, tractor's traveled speed, tractor's rear wheel slippage, tractor's fuel consumption rate, and tractor's tractive efficiency maps that could be produced as the result of running the instrumented tractor and a disk plow for the first tilling operation in the field.

AUTOMATED SOIL SURFACE PROFILE DIGITIZER

A towed type automated, 3-axis laser soil surface profile digitizer had been designed, developed, and calibrated to measure soil surface profile for quantifying the soil tilth degree of the field after a tilling operation [4] (Figure 15). The

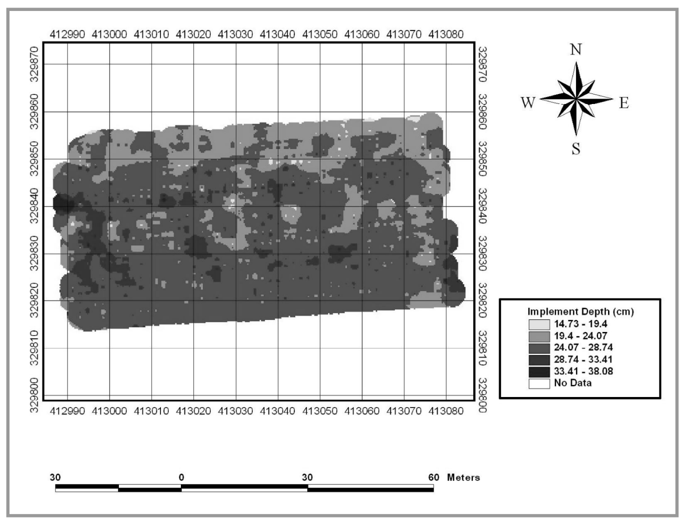

Figure 9: Implement's tillage depth map

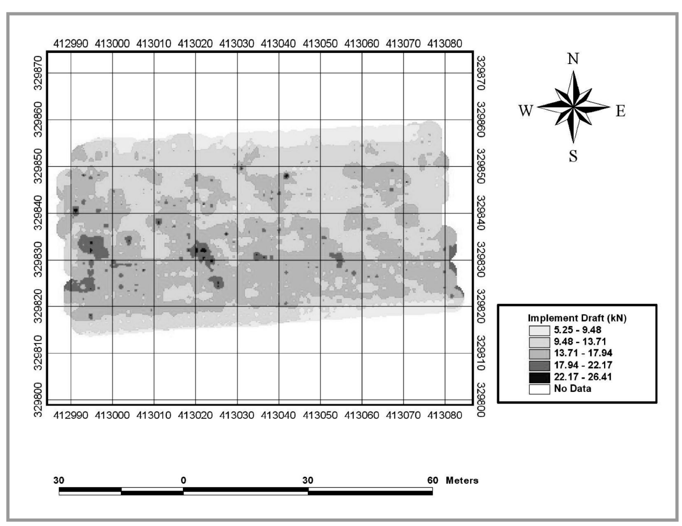

Figure 10: Implement's draft map

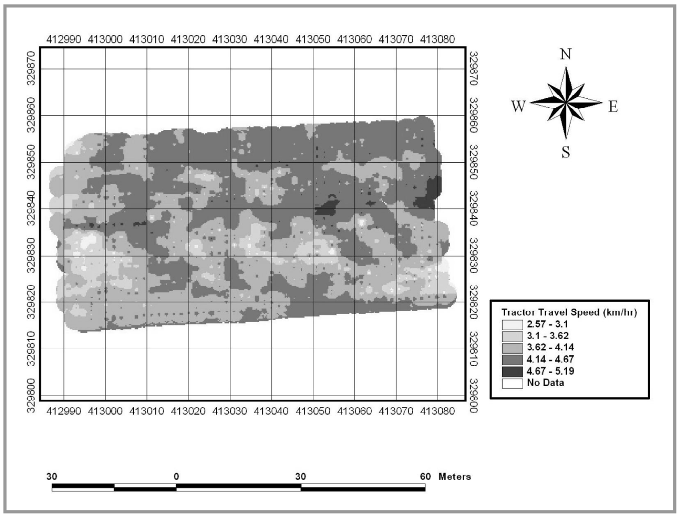

Figure 11: Tractor's traveled speed map

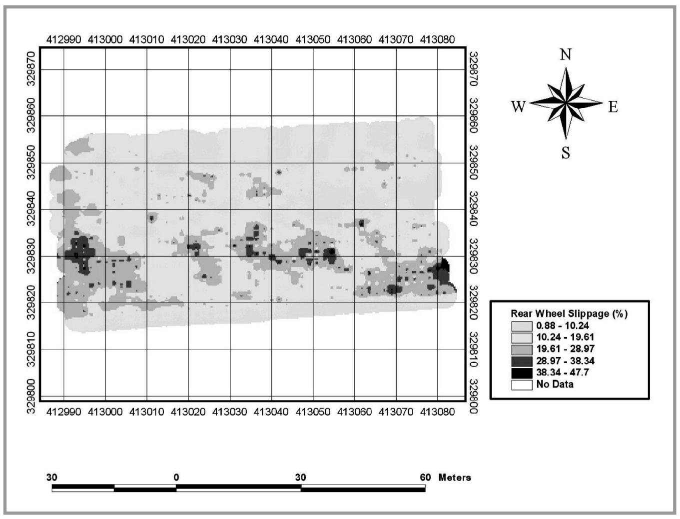

Figure 12: Tractor's rear wheel slippage map

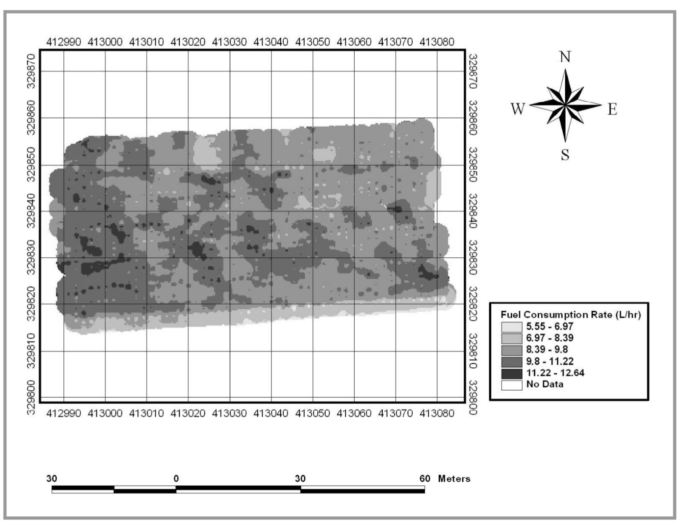

Figure 13: Tractor's fuel consumption rate map

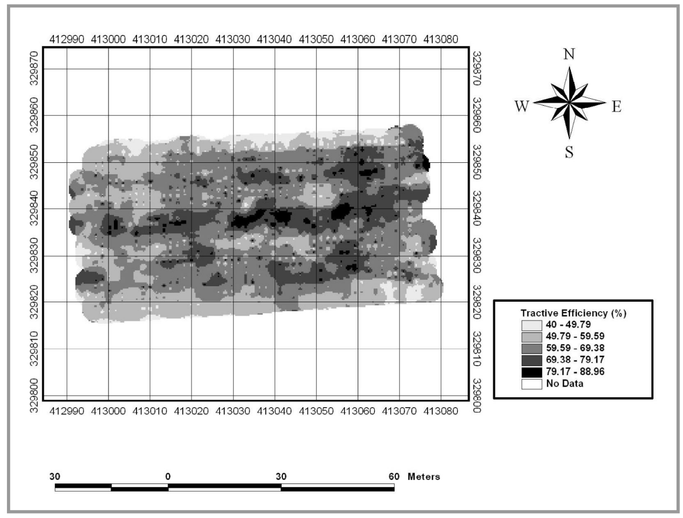

Figure 14: Tractor's tractive efficiency map

Figure 15: Instrumented tractor with automated soil surface profile digitizer

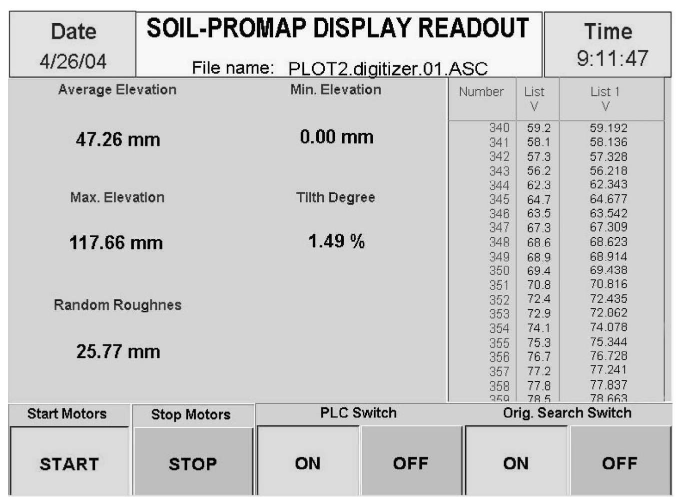

Figure 16: Touch-screen virtual control interface for automated soil surface profile digitizer

digitiser utilised an industrial Wenglor YT33MGC Opto-electronics laser displacement sensor with a build-in emitter, receiver, and signal conditioning circuitry. The elevations measurement principal utilised geometrical triangulation method, which was based on the angle of reflected beam to the sensor's receiver. The digitiser was capable of giving elevation measurement and digitising interval down to 0.2 mm and 1mm distances, respectively. The digitiser was designed to be used with a custom made trailer, which was use to transport, lift, and release the digitiser at the sampling location in the field. The structure and mechanism of the digitiser were designed to be rugged to ensure its workability in rough terrain conditions. The motion control for the digitizer was performed by the Omron CSIG-45-V1 Programmable Logic Controller unit and together with other external electronics and sensing devices. Three Pacific Scientific E21NRFT-LNN-N8-00 stepper motors were used to drive the laser displacement sensor in the 3-axis digitising directions. The system was able to digitise an area of 1.2m x 1.8m with provisions of varying the digitising interval to the required operation time and resolution.

The DEWE-2010 PC data acquisition system on-board the instrumented tractor was used to perform both the operational control of the digitiser and the logging of digital elevation data at a fixed grid interval and tractor's position from the differential global positioning system. Virtual buttons were created on the touch-screen control panel for ORIGIN SEARCH, START, and STOP tasks of the digitiser and special read-out boxes were also created to display in real-time the acquired data during the logging process (Figure 16). The instrumented tractor and soil surface profile digitiser was brought to the field to perform the sampling operation after a tilling operation. At the sampling location in the field and before the start of the digitising process, the four legs of the digitiser were adjusted accordingly for the digitiser to be parallel to the soil surface. The hydraulic system control lever was operated to release the digitiser from the trailer support. Prior to the beginning of the digitising process, the laser displacement sensor had to be positioned to its 3-axis origins. The Z-axis origin location was used as a benchmark's reference point for the elevation measurement. The data logging process began once the sensor started to traverse in the X-direction. When the sensor sensed an out of range data, it would trigger an alert signal to stop the X-axis stepper motor. Stepper motor Z automatically moved the sensor up or down in accordance to the types of alert it received; either too close to the target or too far from the target. After proper adjustments had been made, the X direction stepper motor resumed back operation and the data logging process would proceed with the reading being added or subtracted from the displacement of the sensor in Z-axis. After finishing the digitising process along X-axis, the sensor would index to another location in the Y-axis. By having the provision for Z-axis movement, the sensor was capable of giving an elevation measurement range up to 450 mm while retaining its 200mm resolution. The digitising interval and digitising area along X and Y-axis could be programmed in accordance to the user requirement through the DEWE- 2010 PC data acquisition system.

Figure 17 illustrate typical generated DEM of soil profiles at a sampling point in the field after tilling operation with disk plow, disk harrow after disk plow, and rotary tiller after disk plow that could be produced as the result of running the instrumented tractor and the soil surface profile digitiser immediately after completing the respective tilling operations. Random roughness index had been used here to quantify the tilling quality of the sampled area The random roughness index at that particular sampling point could be computed from the obtained DEM of the soil profile. Random roughness index of the soil surface profile is calculated as follows :

$$RR = \{[1 / n(n-2)]\ [[n\sum h^2 - (\sum h)^2] - [[n\sum xh - (\sum x)(\sum h)]^2 / [n\sum x^2 - (\sum x)^2]]]\}^{1/2}$$

where RR is the random roughness rndex, n is a number of elevation points, h is the elevation heights, and x is the digitizing intervals.

Consequently, random roughness map of the tilling area could be produced based from the random roughness indexes computed from obtained DEM of the soil profile at several sampling points within the area.

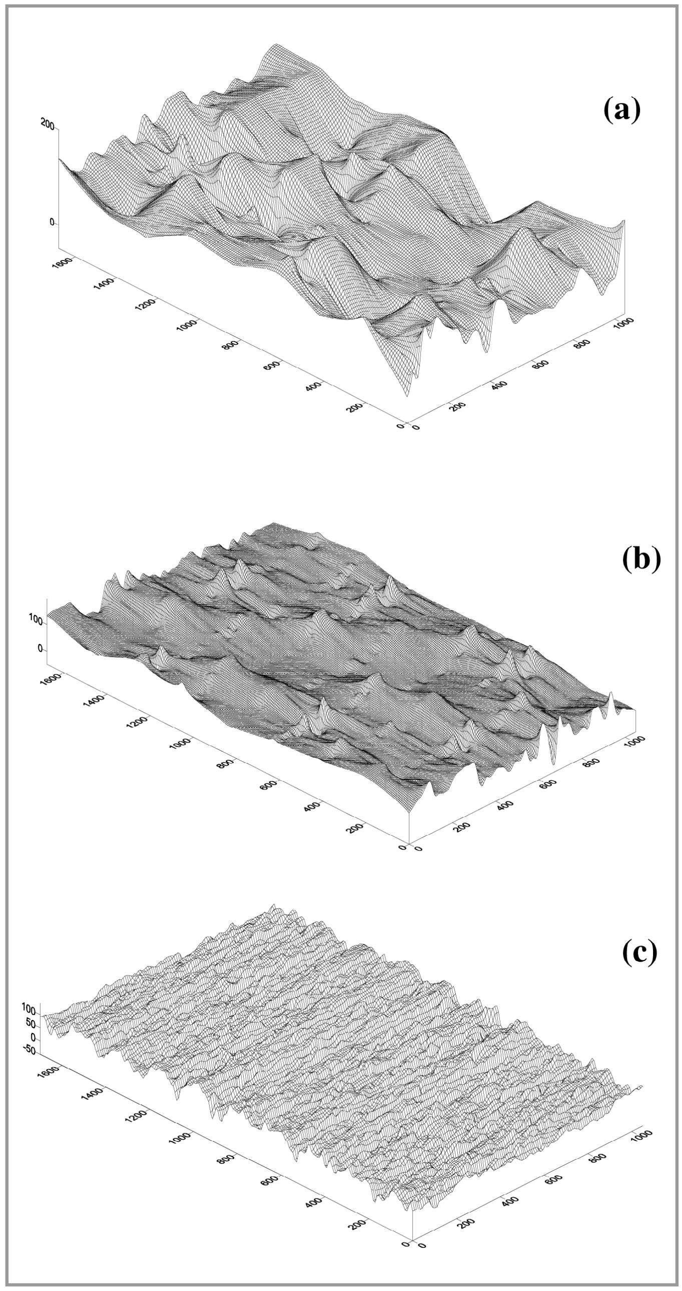

Figure 17: DEM model of soil surface profile by (a) disk plow, (b) disk harrow after disk plow, and (c) rotary tiller after moldboard plow

SUMMARY

A novel data acquisition and differential global positioning system had been integrated on–board a Massey Ferguson 3060 agricultural tractor for real-time mapping of terrain trafficability, tractor-implement performance, and tillage quality with geographical location. Field testings and data collection are currently in progress with the instrumented tractor and the soil penetrometer-shearometer unit, the instrumented tractor and a rotary tiller, and the instrumented tractor and the soil surface profile digitiser at a 4-hectare size are at the University's farm. The digitiser has the ability to digitize a soil surface for a maximum area of 1.05m X 1.8m in 1275 seconds when set at a digitizing interval of 10 mm. In the post processing of the collected field data, GIS software could be used to generate and overlay various data layers for presentation and interpretation. Available geostatistical techniques could be used to analyze the relationship of soil

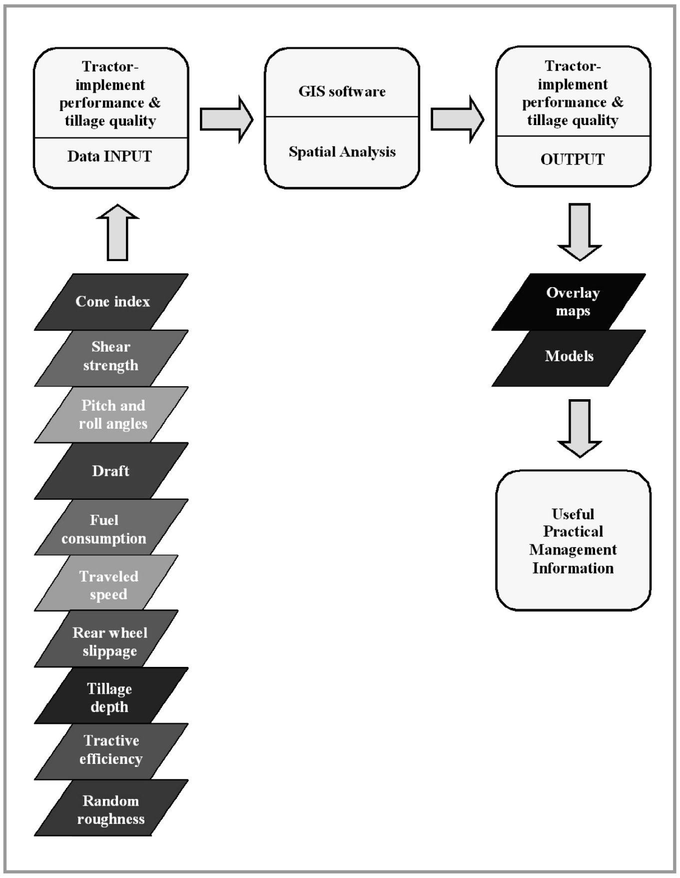

Figure 18: Management process in tillage operation

mechanical properties variability with the tractor-rotary tiller performance and the relationship of tractor-rotary tiller performance variability with the produced soil tilth degree after the tilling operation (Figure 18). Hopefully, this could give the tractor operator better understanding and controls on the tractor-rotary tiller for efficient field operations and proper site specific management of the field condition quality from any tilling operations for higher crop yield. Remedial actions with respect to the surrounding infrastructure of the area could be taken at the regions within the field area with poor machine trafficability and field performance before the beginning of the next planting season. Also, remedial actions with respect to operational set-up of the tractor-implement could be passed to the tractor driver to increase machine operational economics and improved the produced work quality prior to the related field operations following the next planting season.

ACKNOWLEDGEMENTS

This research project is classified under RM7 IRPA Project No. 01-02-04. The authors are very grateful to the Ministry of Science, Technology and the Environment Malaysia for granting the fund for this research project. ■

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