Tractor Performance Instrumentation System

by

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ABSTRACT

A Microcomputer - based data acquisition system was designed and developed at Michigan State University, USA to conduct field data studies. The system designed for the research carried out used an Apple IIe microcomputer for collecting data on-board the tractor. An AI13 Analog to Digital (A/D) convertor was chosen to interface each analog signal to the microcomputer. A commercially available Dj TPM II was employed to display information such as an engine speed, ground speed, percent drive wheel slip, distance travelled and area covered per hour. The frequency output from the radar unit was channeled through a frequency to voltage (F/V) convertor, so that AI13 Analog to Digital (A/D) convertor could read it. The fuel consumption was measured using an EMCO pdp-1 fuel flow meter attached to the engine fuel line. The draft of the tillage and other drag equipments was determined using strain gages attached to the drawbar of the tractor. The system was developed to collect the draft and fuel requirements for various farm equipments on different kind of soils.

Apparently, Universiti Pertanian Malaysia has purchased the available system on-board the tractor (Autotronic) which are capable of measuring engine speed, distance travelled, forward speed, fuel consumption, field capacity, wheel slip, horizontal force at drawbar point, and draft forces at the 3-point hitch. A 3-point hitch dynamometer was designed and developed to obtain information on tractive characteristics and implement draft characteristics that are typical for Malaysian conditions.

INTRODUCTION

Energy limitations have directed agricultural engineering researchers to study and improve the efficiency of field machines through the conduct of field data studies. To adequately evaluate crop production and to be able to choose alternative crop production or tillage systems, information needs to be collected. Among the information is the implement draft and fuel requirements on different soils of major crop production systems. Soil types, soil conditions, operation depths, operation speeds and type and size of implements will determine the draft and fuel required and the traction ability of the tractor in the field. Implement draft requirement is an important consideration in selecting implements, tillage systems and a tractor size that is compatible with the operation. In addition to the required tractor size, implement draft will also be used to determine the fuel consumed for an operation.

Microcomputers were increasingly utilized in the acquisition and processing of implement - tractor performance data. Thomson and Shinners (1987) reported using a portable instrument system to measure draft and speed of tillage implements. Measurements were taken and stored using a data logger, then transferred via magnetic cassette tape to a microcomputer for further processing. Lin et al. (1980), Carnegie et al. (1983), Clark and Adsit (1985), Bowers (1986), and Grogan et al. (1987), were examples of researchers who developed microcomputer - based data acquisition systems for measuring in - field tractor performance.

The system designed for the research carried out at Michigan State University, USA used an Apple IIe[1] microcomputer for collecting data on-board the tractor and an IBM microcomputer for data processing. The Apple IIe data acquisition system was developed by earlier researchers (Tembo, 1986; Guo, 1987 Mah, 1990 and Wan Ishak, 1991) at Michigan State University. The Apple IIe was chosen for its compactness and durability in adverse physical conditions as observed by Carnagie et. al. (1983) and reported by Tembo (1986).

This paper will discussed on the instrumentation developed by the author at Michigan State University, USA. The knowledge and experience by the author was then applied to the system on-board the tractor (Autotronic) which was available at Universiti Pertanian Malaysia, Malaysia. A 3-point hitch dynamometer was designed and developed and was used together with Autotronic to obtain draft and fuel information.

INSTRUMENTATION

Research carried out at Michigan State University, USA utilized a Ford 7610, 68.84 kw (86.95 hp) tractor. The tractor-on-board data acquisition system was developed for the infield data collection. The data acquisition system consists of Dickey John Tractor Performance Monitor II (DjTPM II) to measure the engine speed, ground speed and tractor front and rear wheels rotation speeds; an EMCO pdp-1 fuel flow transducer to measure the fuel consumption; and strain gauges to measure the draft of implements. The data obtained from the transducers were then recorded directly by the data acquisition system.

Speed Measurements

The Dickey-John Tractor Performance Monitor II (DjTPMII) consisted of a Doppler radar unit, an engine rpm sensor, a magnetic pickup sensor used for determining drive wheel speed, an implement status switch, and a computerized console which displayed information from the sensors.

Radar ground speed measurement was obtained by using the frequency signal generated from the DjTPMII radar unit. The radar unit and mounting bracket were installed so that the face of the unit projected onto an unobstructed view of the ground when facing rearwards. The nominal angle setting of the radar unit which determined the accuracy speed measurement, was set and checked with a calibrated face plate and plumb bob. The frequency output from the radar unit was channelled through a Frequency to Voltage (F/V) converter, so that AI13 Analog to Digital (A/D) converter could read it. The F/V converter applied was an M1080 10 KHz converter.

Engine speed was obtained using the frequency signal generated by the DjTPMII engine rpm sensor. The engine rpm sensor fit between the existing mechanical drive sender and the tachometer cable leading to the operator's console. The sensor contained a separate keyed drive pin that was inserted into the tachometer drive sender. As the sender rotated, the sensor generated a frequency proportional to engine speed. The frequency signal from the sensor was routed through an M1080, 10KHz F/V converter, so it could be read by the AI13 A/D converter.

To measure the front and rear wheel rotational speeds, magnetic pickups supplied by Wabash Inc., Huntington, Indiana were used. In tachometry applications, such as this, magnetic pickups produced an output frequency from an actuating sprocket in direct proportion to the rotational speed. The frequency produced was then converted directly to wheel rpm by means of a frequency-to-voltage converter (M1080). The signal produced in this mode was given by;

$$\text{Frequency (Hz)} = \text{Number of sprocket teeth} * \text{wheel rpm}/60$$

The front wheel rotational speed sensor in the 2WD mode of the tractor used for the tests served as the ground speed measuring sensor. The front wheel rotational speed sensor consisted of a 60 tooth sprocket mounted on the inner hub of the front wheel and a cylindrical pole piece magnetic pickup was mounted perpendicular to the sprocket teeth.

The rear wheel rotational speed measurement was used primarily for determining the drive wheel slip, in the 2WD mode. The rear wheel rotational speed sensor consisted of an 80 tooth sprocket mounted on the inner hub of the rear wheel and a

Wabash Inc. cylindrical pole piece magnetic pickup mounted in the same manner as the front wheel speed sensor.

Fuel Flow Measurement

The fuel consumption was measured using an EMCO pdp-1 fuel flow meter attached to the engine fuel line. It was necessary to insert a three-way valve in the return line to bring the injector surplus fuel back into the line downstream from the flow meter. The magnetic flow counter of the flow meter generated an electric current pulses whose frequency was directly proportional to flow rate. The output of the flow meter was amplified before input to a Frequency-to-Voltage (M1080 F/V) converter. The amount of fuel and time consumed was recorded directly to the data acquisition system.

Drawbar Draft Measurement

The draft of the tillage and planting equipment was determined using strain gages attached to the drawbar of the tractor. Signals from the strain gages were tranferred to the signal conditioner. To enable the AI13 A/D converter to read the output signal from the strain gages, a strain gage signal conditional model M1060 was employed. The M1060 consists of a high quality difference amplifier with a variable stage gain, adjustable transducer excitation voltage (range : 3 to 12 volts) and provision to lower the excitation voltage to a value less than 3 volts. By applying the M1060 strain gage signal conditioner, the low level millivolt strain gage signal was amplified to the standard voltages (-5 to +5 volts), detectable by the AI13 A/D converter.

Calibration of Transducers

Calibration of the strain gages for draft measurement was done using a Universal Testing Machine with a maximum load of 4627 kg (10200 lb). The calibration of the other transducers were carried using a frequency function generator. Regression equations for each transducer were obtained.

The method used to arrive at the calibration equations was through estimating the maximum load expected for each of the transducers. The maximum expected loads (i.e., engine rpm, fuel consumption, ground speed, rear wheel speed and front wheel speed) were converted into frequencies. A frequency function generator was used to generate the maximum frequencies for their respective transducers which were later fed into the signal conditioner to obtain analogous voltages.

The calibration of the fuel flow meter was done using a custom made frequency simulator that was designed to expand the narrow signal obtained from the sensor to one that the conditioner could display. The frequency simulator had four preset frequency levels of 100,250,500, and 1000 Hz., which were used to determine the calibration equation for the fuel consumption. The respective equations and the coefficients of determination for each channel are listed in Table 1.

The Data Acquisition Hardware

The data acquisition system was capable of operating at high speeds, collecting up to 16 channels of data sequentially and storing the data into RANDOM-ACCESS-MEMORY (RAM) space in the microcomputer. The system consisted of an AI13 Analog to Digital (A/D) converter (Interactive Structures Inc.) and a 65C02 microprocessor based microcomputer (Apple IIe, Apple Computer Co.). The analogue to digital conversion was the heart of the data acquisition system. It was the interface between the analog and digital domains. Analog signals were sampled, quantized and encoded into digital format. An M1000 Series (Data Capture Technology) signal conditioner provided the required conditioning of all signals from the transducers to the A/D converter. Figure 1 shows how the transducers were connected to the data acquisition system.

The data acquisition system is powered by 12VDC-120VAC, 60 Hz, 500 watt sinusoidal voltage converter. Input power to the converter is supplied by a 12 VDC battery with free floating ground. The signal from each sensor is passed through a signal conditioner and through an analog-to-digital converter. The data were stored as ASCII code in the Random Access Memory (RAM) of a microcomputer which was later transferred to a floppy disk. A second computer was used to convert the data from ASCII code to numerical values for analysis.

Model Equations

The equations for the draft and fuel consumption used in the model were obtained from ASAE D230.4 (ASAE, 1990) and Machinery Management (FMO, 1987). The implement draft was estimated based on the operation speed, operation depth and implement width. The operation speed and depth used were obtained from the experiment. The fuel required by each implement operation was estimated based on the implement equivalent power take-off power (EPTOP) and the tractor available power take-off power (APTOP). The implement EPTOP was calculated using the drawbar power and tractive efficiency. The implement drawbar power was calculated using the implement draft and operation speed. The tractive efficiency was estimated from the wheel slippage and soil cone index obtained from the field experiments. The tractor used in the experiment produced APTOP of 64.1 kW.

Field Experiments

The field experiments were carried out on farms at Michigan State University (MSU) and in Clinton County, Michigan. The implements used for the field experiments were a moldboard plow, chisel plow, tandem disk harrow, field cultivators, row crop planters, and grain drills. Experiments were carried out on different soils at different speeds and depths of operation. Data were also obtained and recorded on previously tilled areas.

Special care was taken to provide a stable source of electrical power during operation. The data collected were stored temporarily in RAM memory during each experimental run of the tractor. The data were stored as an ASCII file in order to provide ease in transferability to other computers for analysis. About 500 to 1000 data sets at 20 Hz frequency sampling were obtained for each experimental run. Each data set contained one data point for each of the six measured parameters. These data sets were used to calculate the engine rpm, ground speed, rear wheel revolution, front wheel revolution, wheel slip, implement draft, implement power requirement and fuel consumption. The data recorded using the on-board acquisition system were then retrieved and transferred to an IBM Computer. The fuel consumption, draft and drawbar power required by the implement are compared with the values computed by the computer model. Table 2 shows an example of the experimental and model draft and fuel requirements for chisel plow on Capac Loam Soil.

RESEARCH IN MALAYSIA

A similar research was currently carried out at Universiti Pertanian Malaysia, in Malaysia. The ultimate objective of the research work was to develop on information data base on the draft and energy requirements of various field operations that are involved in the Agricultural Production in Malaysia. A 3-point hitch dynamometer was designed and developed by Azmi et.al (1994) to obtain information on tractive characteristics and implement draft characteristics that are typical for Malaysian conditions. Work was also currently underway to develop a data acquisition system for a tractor with the capability of measuring and recording performance data of the tractor-implement operating in the field. Apparently, the available system on-board the tractor are capable of measuring engine speed, pto speed, distance travelled, forward speed, fuel consumption, field capability, wheel slip, horizontal force at drawbar point and draft foresat the 3-point hitch.

Data Acquisition System

The employed data acquisition system was the product of Data Electronics (Australia) Pty. Ltd. The whole system consists of a Datataker 605 unit, a Channel

Expansion Module, a Memory Card Reader-Programmer and a Compact Contura 3/25c Notebook.

The Datataker 605 unit is a microprocessor based data logger that can be either internally powered by a 6 volt cell or externally powered from any 8-28 Volt AC/DC source. It has 64 Kbytes of internal battery backed RAM that is capable of storing in excess of 16,000 readings at a sampling rate of 25 samples per second, and at the same time supports optional plug in credit card sized 1 Mbyte memory card for additional data storage up to 330,000 readings. Each bridge circuitary on the beam transducer are independently wired to the individual channels of the Datataker 605 unit. The constant current bridge configuration was employed for strain-gages on the centilever beam transducers for the reason of obtaining better measurement accuracy. The bridge sensivity with such a configuration is known to be independent of the cable length. Apparently six of the 10 available channels on the Datataker 605 unit are being utilized for the transducer's circuitary. Additional two channels are wired individually to two toggle switches. The first toggle-type switch is used to trigger the Datataker 605 unit for taking initial readings while the second switch is for the actual data collections and recordings.

The compact Contura 3/25c notebook with in-house Decipher Plus software is used as the host computer. The Datataker 605 unit can be either run directly from the host computer or by the program commands that has been earlier pre-recorded into the memory card. As for the later,the command program will be automatically executed whenever the memory card is inserted to the Datataker 605 unit. The Memory Card Reader-Programmer is used with the host computer to log the program commands into the memory card. The communications between the host computer with Memory Card Reader-Programmer and the Datataker 605 unit were made via the RS232 COMMS serial interface.

System Command Program

Field operation of the 3-point hitch dynamometer was conducted with the Datataker 605 running under the prerecorded program command in the memory card. As for the purpose, a command program was written for the Datataker 605 to scan, sample and receive the signals from the available circuitary channels of the beam transducers, and logged all measured signals into the memory card. Upon the completion of the field operation test, all the stored data in the memory card would be downloaded to the storage medium of the host computer with the use of the memory card Reader-Programmer at the laboratory. The stored data were in standard ASCII character strings and could be imported into any available text editors, word processors, srpeadsheets and graphical packages.

The command program structure began with the conditional tests on the status of the two available external toggle switches marked as SWITCH-1 and SWITCH-2. These switches were individually wired to the digital input signal of the Datataker 605 unit. Triggering SWITCH-1 would indirectly execute the subcommand program for taking the initial force readings. This subcommand program was written to scan and record input signals at channel 1 to 6 of the datataker 605 unit at 1 second sampling interval, 30 seconds averaging and recording interval, and for the total duration of 15 minutes. Average readings from each channel were computed to give the initial vaue for the vertical and horizontal force measurements. Activating SWITCH-2 would indirectly execute the sub-command for the actual force measurements. Consequently, this sub-command program was written to scan and record the six input channels at 1 second sampling interval, 1 minute averaging and recording interval, and for the duration of time SWITCH-2 was left activated. The collected data would be stored inaccordance to the specified format and units with the earlier intial values taken care off.

Field Experiments

Field demonstration test was conducted to observe the performance of the 3-point linkage dynamometer and its data acquisition system in measuring and recording the implement forces during actual operation. A 2-654 disk plow was mounted to the tractor together with the 3-point linkage dynamometer. Two specially made steel DAS boxes were made to house the Datataker 605 unit together with the Channel Expanson Module and the COMPAC Contura 3/25c Notebook. These two boxes were then securely bolted to a rigid made frame rack located beside the operator seat in the tractor cab. The available auxilary 12 DC volt point source inside the cab was employed to run the set-up data aquisition system.

The demonstration test was conducted at the close-by University Research Farm Universiti Pertanian Malaysia. The test was conducted at three different gear combinations with specified travelled speeds of 3.70, 5.37 and 7.41 kph, respectively. The acquired field plot for the test was once rotovated a day earlier. Such preparation was necessary to get the type of terrain conditions that favours for the running of this test. The soil type in the locality area is aluvium series with sandy-clay classification. The prepared plot is almost flat having a runway of 100 meter distance. Table 3 shows an example of the measured horizontal and vertical component forces of implement.

On that day of the test, the already pre-recorded command program in the memory card was entered into the data acquisition system on-board the tractor at the laboratory. Once this was entered, the system was set on halt and set ready to begin the data initiation or collection task upon trigerring and activating the respective switches on the DAS box. The sampling and recording of the initial reading were taken prior to the beginning of the test run when the tractor is stationary with its disk plow being slightly raised off the ground at the field plot. The tractor was then set for the plowing operation at its rated engine speed in the selected test gear combinations.

CONCLUSIONS

Information database on the energy requirements of various field operations that are involved in crop production is very important for the machine design and farm managers. Computer data acquisition system has been the most significant tools in the developments of agriculture. Researchers at Michigan State University, USA have successfully developed the Tractor-on-board data acquisition system, able to measure the draft and fuel requirements. The draft and fuel consumptions were used to determine the size and number of tractors and implements to be used for a particular farm size. Researchers at Universiti Pertanian Malaysia, Malaysia are developing an information data base on various field operating using the available Tractor-on-board System (Autotronic). The data acquisition system on-board the tractor for the dynamometer was able to received and record the signal inputs from the transducers. The system has demonstrated to perform excellently under the present tractor noise and vibration levels at the field.

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Table 1 Regression Equation for the Transducers

Channel	Gain Code	Transducer	Equations	R^2
6	0	Engine Rpm	Hz = v*0.08914+1.6936	0.9998
7	0	Ground Speed	Hz = mv*0.0978+2.2774	0.9992
8	0	Rear Wheel Rpm	Hz = mv*0.0835+2.7575	0.9988
9	0	Front Wheel Rpm	Hz = mv*0.0902+1.1103	0.9986
10	0	Draft	N = v*24000.664-12.857	0.9991
11	0	Fuel Consumption	Hz = mv*0.2036+0.8803	0.9999

Table 2 Experimental and Model Draft and Fuel Requirements for Chisel Plow on Capac Loam Soil

Speed, km/h	Depth, cm	Expt. Draft, KN	Expt. Fuel, L/h	Model Draft, KN	Model Fuel, L/h
3.68	25.00	22.06	13.32	15.97	14.28
5.26	25.00	16.37	10.92	13.88	13.27
5.39	25.00	20.56	16.31	17.47	14.81
4.69	25.00	22.26	17.86	16.86	15.04
5.01	20.00	16.92	11.03	13.71	13.24
5.34	20.00	17.47	11.86	13.94	14.00
6.82	20.00	18.38	16.23	14.98	13.78
8.44	13.00	11.39	12.84	10.47	10.92
8.20	10.00	8.44	8.43	7.97	9.58

Table 3 Measured horizontal and vertical component forces of implement.

Beam	Measurement, kN	Tractor travel speed, kph					
		3.70 kph		5.37 kph		7.41 kph	
		Mean	STD	Mean	STD	Mean	STD
Left	Horizontal	18.75	5.61	24.95	6.99	22.00	8.78
	Vertical	22.20	2.70	27.26	2.77	26.38	1.47
Right	Horizontal	6.62	1.15	7.09	0.58	8.09	0.41
	Vertical	23.45	4.15	25.73	2.23	27.59	1.61
Top	Horizontal	-9.17	5.26	-12.37	6.70	-10.27	8.78
	Vertical	6.00	3.39	10.75	2.58	6.00	7.12
Resultant horizontal force, kN		15.80	1.72	19.67	1.16	19.81	1.96
Resultant vertical force, kN		51.65	3.37	63.74	2.67	59.96	4.98

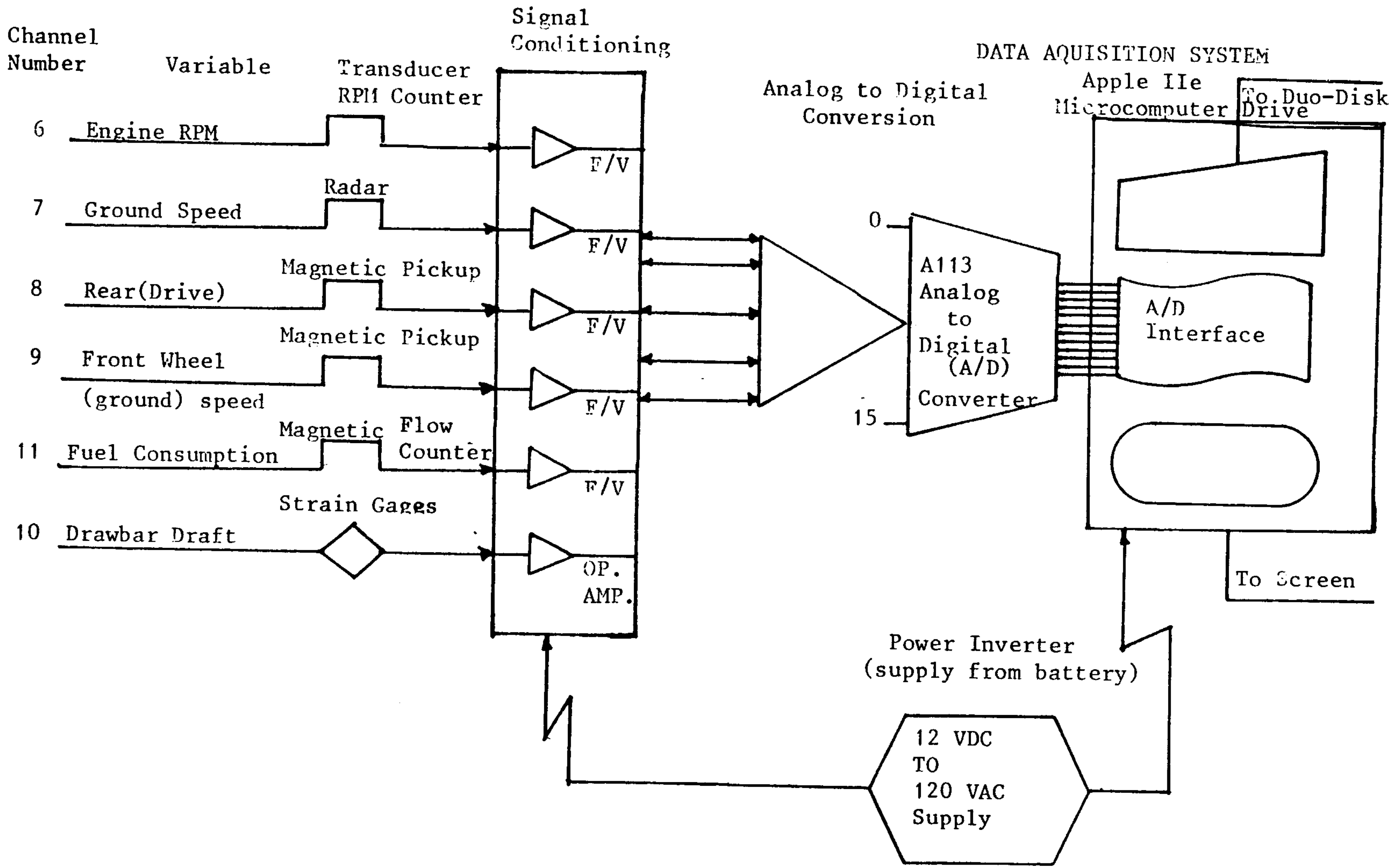

Figure 1: Block Diagram of the Data Acquisition System Hardware