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Sensor system for a continuously and in real time measurement of soil mechanical and physical properties

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Abstract: The System of Sensors for a continuous and real time measurement of soil strength is a set of electronic circuit made around the Arduino Mega 2560. It consists of an alphanumeric display, a keypad, a conditioning circuit for strain gauges, a Bluetooth module, two 2.4Ghz RF Modules, two pressure sensors, four distance sensors, an electrical soil conductivity sensor, two rotation speed sensors, and GPS. It communicates with an Android system where the application managing all of calculation and decision-making operations is installed. The system embarks on a two-wheel drive tractor. The Android application for calculation and decision-making operations uses mathematical equations developed by researchers linking the cone index to the slip, and the drawbar pull. Information are stored on the Android system that can be a smartphone or a tablet, for later use.

Key words: Precision agriculture, Soil sensors, Arduino, Android, soil strength, wheel slip.

1. Introduction

The tractor is directly linked to the history of agricultural machinery. It is interesting because it focuses on the oldest and most decisive mechanization form designed for the progress of humanity. The tractor remains the symbol of modern agricultural mechanization. It is one of the most important technological phenomena. Unlike those of the 50s, technological developments in recent years are not technical changes, but technological evolutions. The tractor technology is at the forefront of technologies, tillage tools have undergone the same process.

Most of farming works require the use of a tractor. It supports all the work of the technical route aimed at preparing the seedbed. It is the largest consumer of energy especially during the plowing operation. Reducing energy consumption requires real-time knowledge of soil mechanical and physical characteristics in order to act instantly on agricultural operations of the tractor.

Tillage, aiming to loosening the soil, preparing the seedbed and controlling weeds, reduces the soil strength and increases its porosity. It also modifies its moisture; and generally it changes soil mechanical and physical properties. Soil compaction can severely limit root growth and water infiltration, decreasing, therefore, the crop quantitatively and qualitatively. The soil strength can help identify areas where soil physical characteristics have a negative impact on the crop. However, according to (Ayers and Perumpral, 1982; Morrison and Bartek, 1987; Hummel and Newman, 2004) the soil strength is a function of soil moisture, porosity and type of soil, as well as of compaction and penetration velocity of the cone.

The conventional and standard instrument for measuring the soil strength is the cone penetrometer. Measuring the soil strength by a cone penetrometer is named cone index (CI) and is punctual. Cone index is used as a main indicator for soil compaction and crop root development. Nevertheless, several measurements must be performed requiring a lot of hard and tiring work.

Due to the obvious influence of the penetration velocity on the measurement of the cone index (CI). (Sun and al, 2007) have designed an attractive method to determine the penetration power of a penetrometer by exploiting the electrical current variation of a DC motor using a Hall sensor and maintaining constant the velocity of the cone penetration. Others like (Zenga and al, 2008) have developed a twin sensor horizontal penetrometer for simultaneous measurement of soil water content and soil strength. Further researchers have developed other methods but they still remain one-off and do not allow continuous measurement.

For one-off measurements, even when automated, cone penetrometer measurements are, according to (Campbell and O'Sullivan, 1991), time consuming and highly variable from one point to another. This method of measurement does not allow to be embarked on tractors to perform continuously and in real time measurements. It does not develop tillage control systems according to the state of the soil so as to make decisions in situ and in real time.

Further works have been led in this field so as to find measurement methods or systems, having adequate soil sensors to measure the soil strength continuously and in real time. Some of these works, (Gilandeh, 2009) Designed and built a measuring system with multiple instrumented shanks to measure mechanical impedance of soil at different depths over the entire top 40 cm of the soil profile while moving through the soil. This system allows shanks for the simultaneous measurement of soil strength at four depths, while moving through the field. (Hemmata, and al, 2014) Have developed an acoustic multiple-tip horizontal penetrometer, with three 30° prismatic tips attached horizontally to S-shape load cells and worked at depths of 10, 20 and 30 cm. The tips working at 10 and 30 cm depths were also fitted with microphones.

Developing a sensor system for a continuously and in real time measurement of soil mechanical and physical properties. seems very interesting, because it provides us with a an effective tool offering low-cost and quick information in order to plan, within a context of the precision agriculture, a good management of the current and future state of the ground, a pattern of crop root development, and a gain in energy during the deferent stages of the tillage.

Nevertheless, the enormous difficulty in obtaining in situ the characteristics of agricultural soil quickly and with low-cost remains one of the greatest limitations of the precision agriculture. Many researchers and manufacturers have tried to develop sensors for in situ and in real time measurements of the mechanical and physical properties of an agricultural soil. These sensors are based on electricity, electromagnetics, optics, radiometry, mechanics, acoustics and pneumatics. While only electrical, electromagnetic and optical sensors are widely used so far. Several studies have been conducted in this field; one of them consists of automatizing tillage operations depending on the state of the soil in view to reducing energy costs or for a future idea to the destination of the soil.

The objective of this research was to develop an evolving system that enables to measure the mechanical and physical properties of the soil continuously and in real-time. This system can be a an effective tool offering low-cost and quick information in view to planning, within the context of the precision agriculture, a good management of the current and future state of the soil, a pattern of crop root development, and a gain in energy during the deferent stages of the tillage. This system is based on several studies led on the soil and tillage, uses several latest technologies namely microcontrollers, sensors, electronics and the C programming language and it is embarked on a tractor. This is because a sound and a sustainable agriculture without electronics is, according to (Jahns, and Speckmann, 1999), inconceivable today as electronic systems are used to reduce farm inputs, protect the environment, secure farm income and produce high quality crops.

2. Materials and Methods

2.1. Development of system

The system is embarked on a tractor, it is based on real-time measurements of the slip, the dynamic radius of the drive wheels, drawbar pull, soil moisture, and on the equations developed by several researchers and approved. It also links soil strength with slip, wheel load, drawbar pull, soil moisture, porosity, and texture.

Soil texture that can indicate the trends of soil on its physical qualities is constant at human scale. It is taken as a constant in the system for a given soil. The measurable variables in real time are soil moisture, dynamic radius of the tractor drive wheels, drawbar pull, and the theoretical and actual speed of the tractor.

For the measurement of parameters specified as variable, we had to implement an electronic system composed of several modules as needed. This system includes a microcontroller main board, the Arduino mega 2560, on which is connected several modules necessary for the proper functioning of the entire system. The system includes also annex boards on which is connected the measurement and communication modules enabling communication with the main board.

2.1.1. The main board

The mainboard (Figure 1) is the Arduino Mega 2560 Rev. 03 based on the powerful ATmega2560 microcontroller. This board has 54 digital pins input / output (of which 14 can be used as PWM outputs), 16 analog inputs (which can also be used in digital I / O pins), 4 UARTs (hardware serial ports), a 16Mhz crystal oscillator, a USB connection, a power jack connector, an ICSP header, and a reset button. It contains everything needed to support the microcontroller.

The Arduino Mega 2560 can be powered either via the USB connection (which provides up to 500mA 5V) or using an external supply of 7 to 12 volts. It can provide a 3.3V output voltage. The ATmega 2560 has 256KB FLASH memory to store the program, 8KB of which is used by the bootloader. The ATmega 2560 has also 8 KB of SRAM, and 4 KB EEPROM.

The mainboard contains firmware that manages the various modules of measurement, the user dialogue as well as the communication with the Annex boards and the Android system. Modules connected to the mainboard are, an HC-05 Bluetooth module to communicate with the Android system, an RF module NRF25L01 to communicate with annex boards, a 20X4 LCD display showing information to users, a 4x4 matrix keypad to interact directly with the system, a real time clock RTC 1307 and HX711 an amplifier for strain gauge, as well as a soil moisture sensor to measure the soil dielectric permittivity which is a function of the water content and, with which the system can calculate the soil water content. The main board is supplied with power by the tractor battery after regulation of the voltage to 7V.

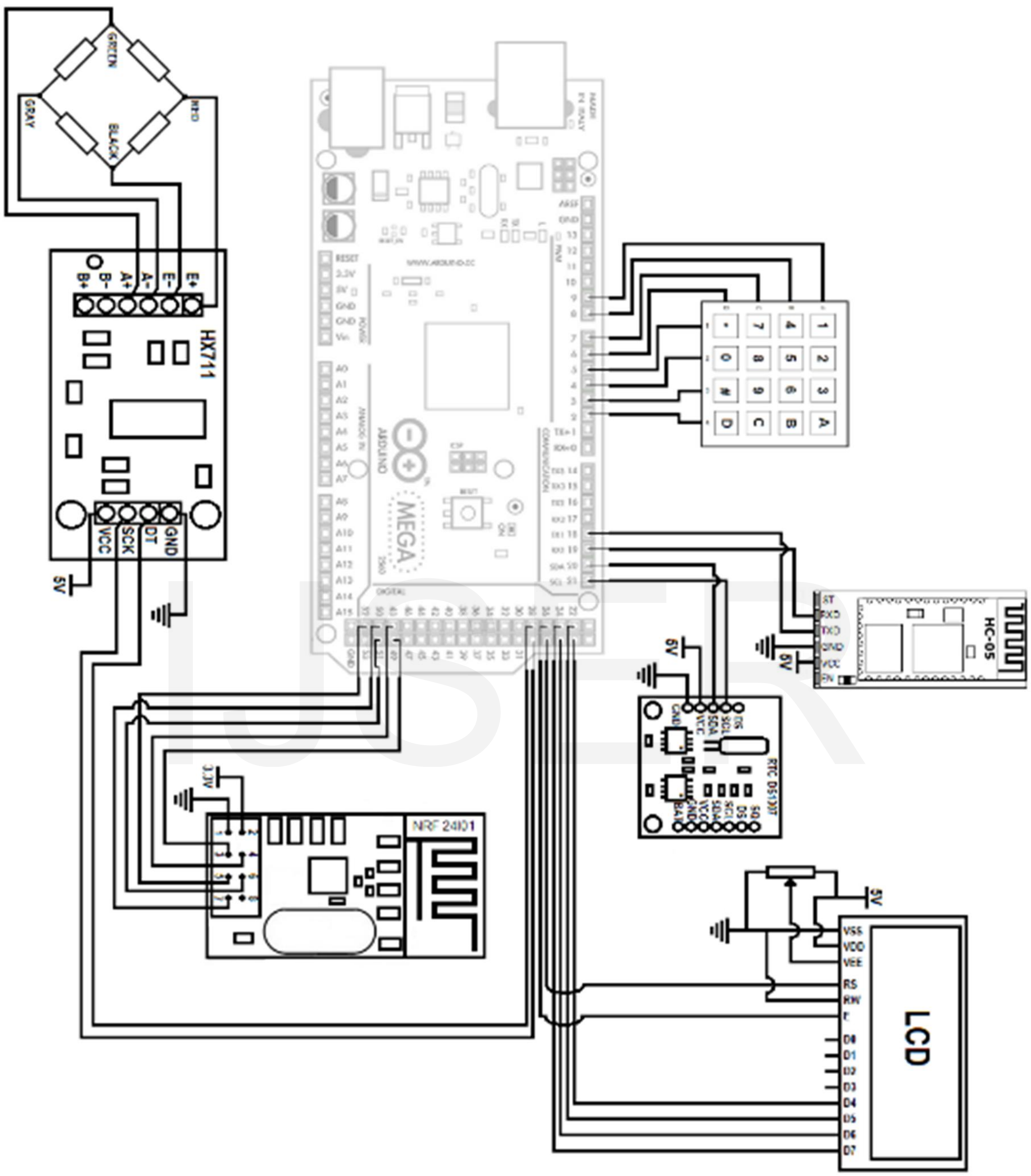

Figure 01: main card Circuit

2.1.2. The annex board

The annex board (Figure 2) is the Arduino micro based on the ATmega32U4 microcontroller. It has 20 digital input/output pins (7 of which can be used as PWM outputs and 12 as analog inputs), a 16 MHz crystal oscillator, a micro USB connection, an ICSP header, and a reset button. The Arduino micro is powered via the USB connection. It can provide a 3.3V output voltage.

Modules connected to the annex board are; an RF module NRF25L01 to communicate with the main board, a gyroscope module gy521 to calculate the wheel revolution number, a pressure sensor MPX 5500 to measure the pressure inside the tire and finally a two ultrasonic sensors to measure both rolling and static radius. The annex board is placed inside the wheel. The annex board contains firmware that manages the various modules for measurement, and the communication with the main board. The annex board is supplied with power by 9V battery directly after regulation of the voltage to 5V.

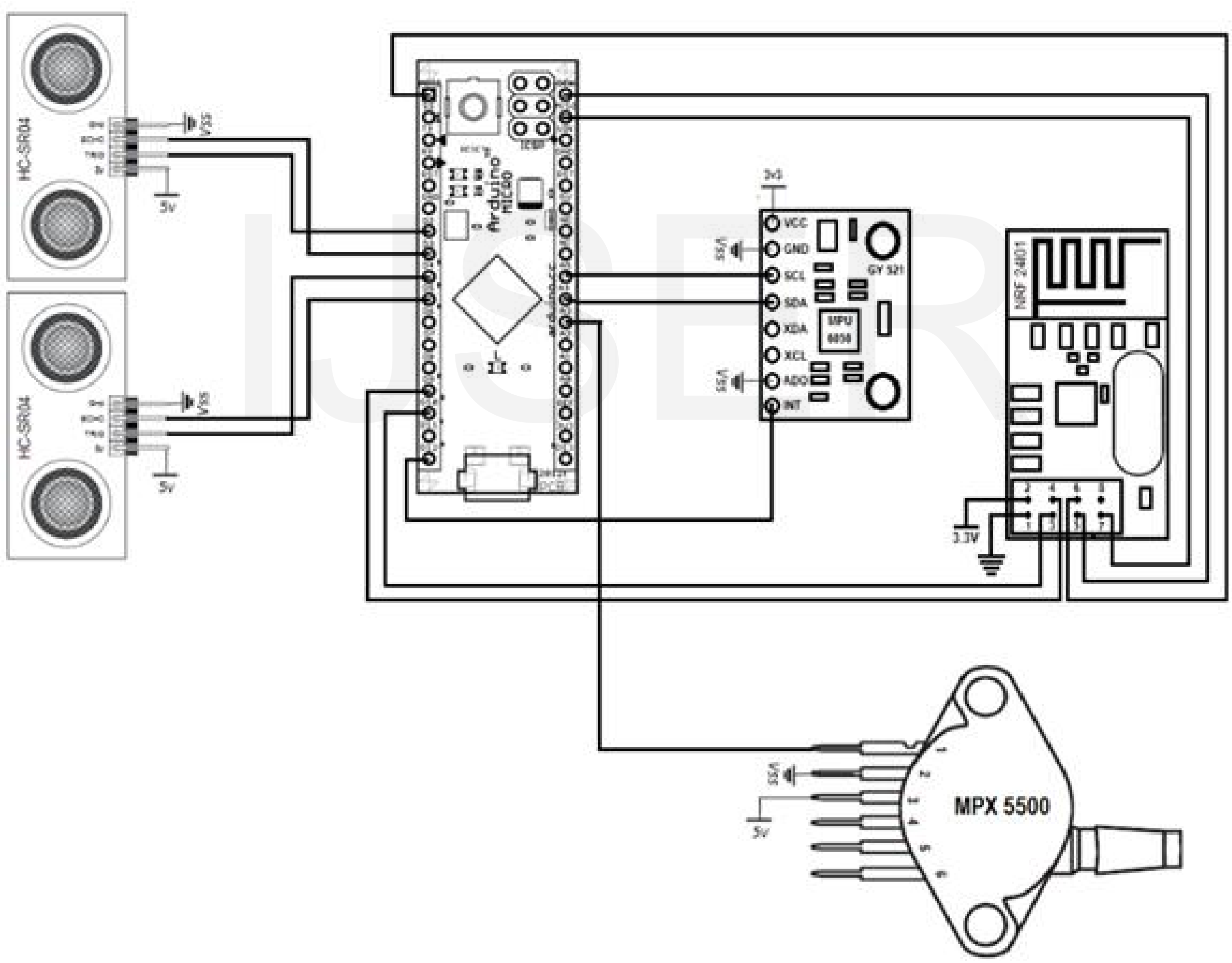

Figure 2: annex board Circuit Figure

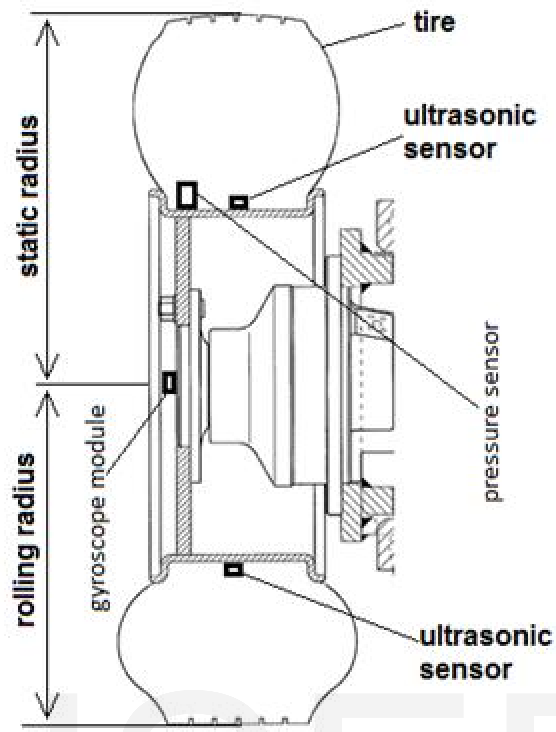

Figure 3: Location of sensor inside tire

2.2. Models used by a system

In this section, we explain how the system uses equations to determine soil strength by the android application. Brixius (1987) developed a more generalized expression for tractive characteristics of bias-ply pneumatic tyres. His approach is based on a mobility number called B_n which is given by:

$$B_n = \frac{CIbd}{W}\left(\frac{1+5\frac{\delta}{h}}{1+3\frac{b}{d}}\right) \qquad (01)$$

$$\frac{T}{rW} = 0.88(1 - e^{-0.1B_n})(1 - e^{-7.5S}) + 0.04 \qquad (02)$$

$$\frac{H}{W} = \frac{T}{rW} - \frac{MR}{W} \qquad (03)$$

$$\frac{MR}{W} = \frac{1.0}{B_n} + 0.04 + \frac{0.5S}{\sqrt{B_n}} \qquad (04)$$

W = vertical wheel load
MR = motion resistance

T = wheel torque
H = Net traction or drawbar pull

The equations (02) (03) (04) give:

$$\frac{H}{W} = 0.88(1 - e^{-0.1B_n})(1 - e^{-7.5S}) - \left(\frac{1.0}{B_n} + \frac{0.5S}{\sqrt{B_n}}\right) \qquad (05)$$

Let us take: $A = (1 - e^{-7.5S})$ and $C = 0.5S$

The equation (05) becomes

$$\frac{H}{W} = 0.88A - \frac{0.88A}{e^{0.1B_n}} - \frac{1.0}{B_n} - \frac{C}{\sqrt{B_n}} \qquad (06)$$

Equation (01) and equation (06) are used to predict variation of soil strength in real time and in continuous measurements. First, the system calculates B_n by resolving equation (06) and in the second time, the system calculates CI from the equation (07) with GPS coordinates.

$$\frac{B_n W}{bd\left(\frac{1+5\frac{\delta}{h}}{1+3\frac{b}{d}}\right)} = CI \qquad (07)$$

To find B_n we must have H net traction or drawbar pull, vertical wheel load W, rolling radius r and slip S.

To measure slip, various researchers used different techniques like Doppler radar effect, electronic circuits using photo-transducer, etc. for accurate measurement of slip. These designs were complicated and costly (Raheman and Jha, 2006).

To calculate S, the system uses: $S = 1 - \frac{V}{\omega r}$ (08)

The system calculates the wheel angular velocity $\omega = 2\pi N$ by measuring N in rpm, wheel rolling radius r in (m) and uses the GPS method to calculate actual velocity V in (m/s). To measure the rotational speed of the drive wheels, the system uses the angular position of the gyro. When the gyro goes through the same angular position, it is one, half or quarter a turn, measured for a time t, the system calculates the number of revolutions per minute.

$\omega = 2\pi N$ So $V_t = \omega r$

Section width b in (m), overall unloaded diameter d in (m) and section height h in (m) are constants according to tire and are introduced manually into a system by a keypad. The loaded tire deflection δ is calculated by the system, static radius minus rolling radius. H net traction or drawbar pull is measured directly by the HX711 an amplifier for strain gauge connected to the main board. The vertical wheel load, W or Dynamic Weight (Reactive Force) on driving wheel is calculated by the following equation. We assume angle of the uphill grade relative to horizontal equal to zero, H parallel to ground.

$$W = \frac{W_t(L-X)+Hh}{L} \qquad (09)$$

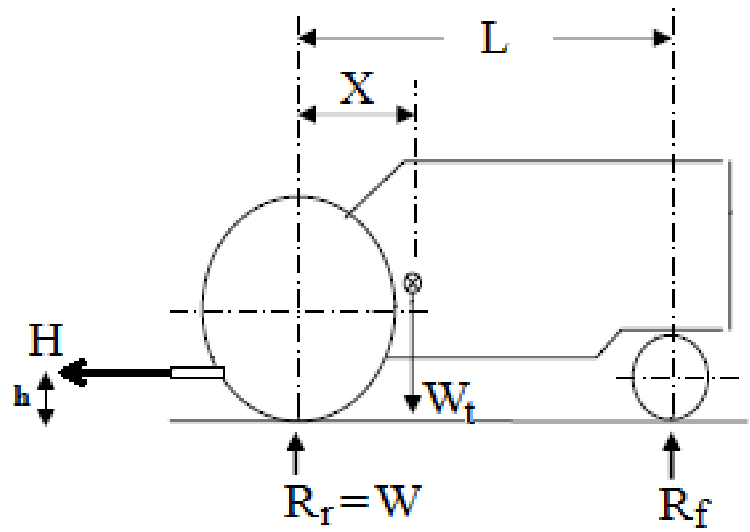

Figure 4: tractor forces

The constants are W_t tractor weight, L wheelbase of the tractor, X distance from the tractor's gravity center to its rear axle, and h height of the application point of drawbar pull H above the ground.

2.3. Android App structure

Android application was written in Android Studio IDE 2.1. The Android app (Figure 5) collects the measurement data from the mainboard Arduino Mega 2560 through the Bluetooth module, it calculates CI, and other ratios introduced in the program. It memorizes calculation results in a file readable by Excel and plots the data changes for CI (soil resistance), H (drawbar pull) and S (slip) along the parcel according to the GPS coordinates. The constants (Wt, L, X, h, d, b) are introduced one times in the program by way of keyboard.

2.4. firmware structure of Mainboard

The realization of the firmware was made using the open source Arduino IDE 1.6.11. The firmware (Figure 6) in the mainboard collects data measurements (r rolling radius, α angular position, p pressure of rear wheel) from annex boards (Arduino Micro) through the RF module. It performs measurements of the drawbar pull H and stores them in memory, displays the current values of the measures and executes the request of Android application.

2.5. firmware structure of Annex board

The realization of the firmware was made using the open source Arduino IDE 1.6.11. The firmware in each annex boards (Figure 7) performs measurements of the rolling radius r, the angular position α and the inner pressure of the rear wheel p. The measurements are stored in memory, and send to the mainboard through the RF module.

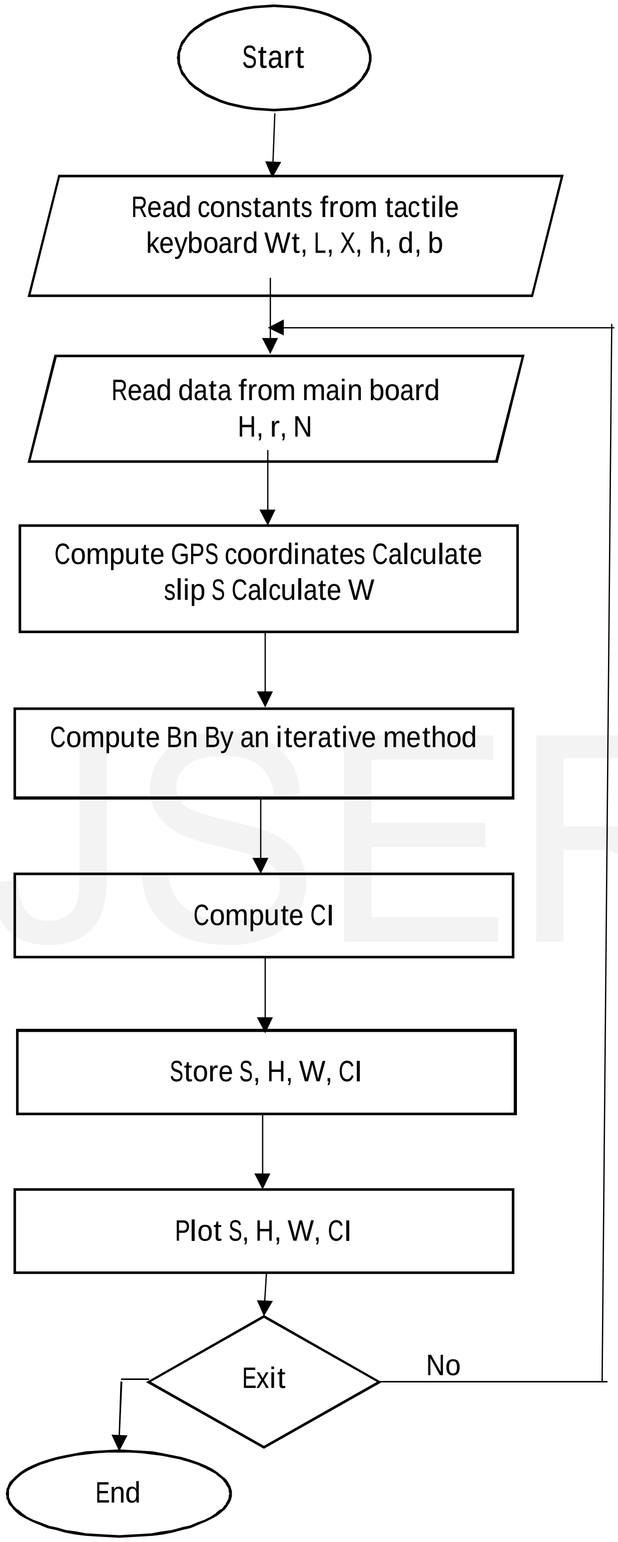

Figure 5: Android App structure flow chart

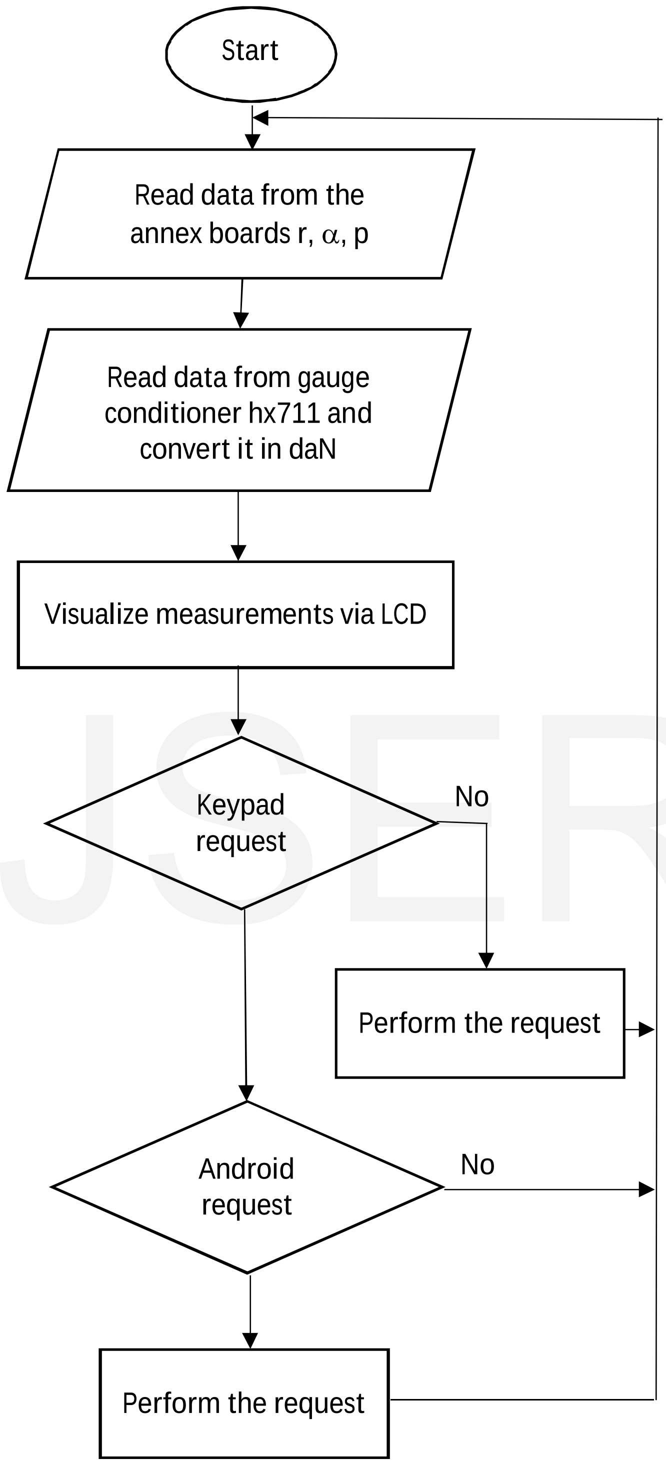

Figure 6: mainboard firmware flow chart

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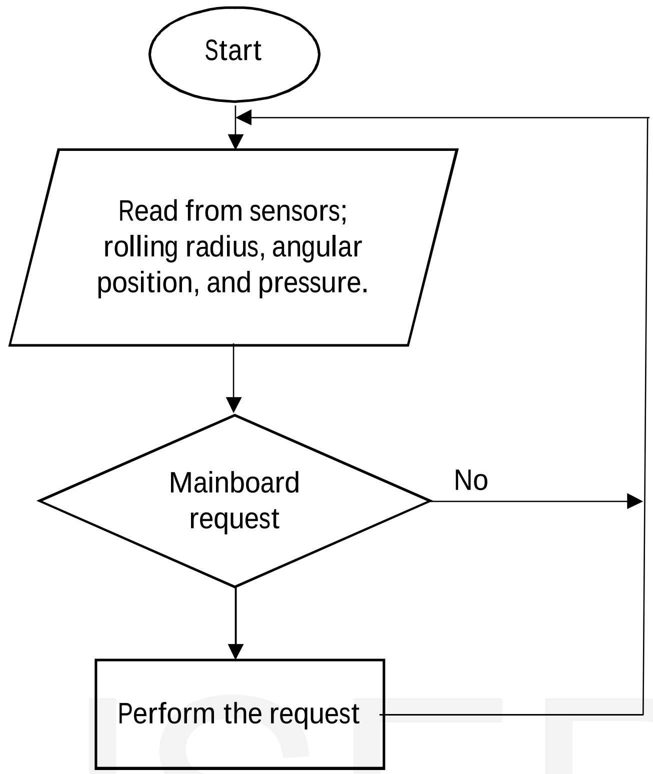

Figure 7: annex board firmware flow chart

3. Testing, Results and Discussion

This system was designed and constructed in order to evaluate a soil strength continuously and in real time, it use a mechanical transducer and electronic sensors. A mechanical transducer was used to read the drawbar pull, but electronic sensors was used to determine a slip.

Proteus ISIS Professional software was used in the design and the test of the mainboard and the annex boards. The firmware for the control of the two cards was made with Arduino IDE. Android app was made with Android studio. The system with all its cards, firmware and android app were realized and tested in the Electrical engineering laboratory of (Département du Génie Rural, Ecole Nationale Supérieure Agronomique, alger. algerie).

Field experiments were conducted in three parcels that differ in soil strength, at the experimental station of (Institut Technologique des Grandes cultures d'Oued Smar alger).

The three parcels had respectively their cone index measured with a penetrometer, 1.01 MPa, 1.12 MPa, 1.23 MPa, and density of 0.98, 0.93, 1.06, and moister of 23.07%, 24.36%, and 14.71%.

The experiments were conducted by running the tractor at constant speed of 6 km/h.
The results were largely satisfied and opens for new studies.

4. Conclusion

Sensor system for a continuously and in real time measurement of soil mechanical and physical properties is specifically designed to be a scalable hardware and software. In hardware, there is a possibility to add or change sensors with better sensors when the sensor dialog method with the Arduino board is the I2C or one wire. In addition, we can change the prediction equations and calculations in Android application Software.

The system combines the results of measurements and calculations, and according to soil texture, soil moisture predicts soil strength based on the Brixius equations. The information are stored on the Android system that can be a smartphone or a tablet, for later use. The results are also used to predict energy consumption.

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