Soil Sampling Sensor System on a Mobile Robot

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ABSTRACT

Determining if a segment of property is suitable for use as an aircraft is a vitally important task that is currently performed by humans. However, this task can also put our people in harms way from land mines, sniper and artillery attacks. The objective of this research is to build a soil survey manipulator that can be carried by a lightweight, portable, autonomous vehicle, sensors and controls to navigate in assault zone. The manipulators permit both surface and sub surface measurements. An original soil sampling tube was constructed with linear actuator as manipulator and standard penetrometer as sampling sensor. The controls provide local control of the robot as well as the soil sampling mechanism. GPS has been selected to perform robot global navigation. The robot was constructed and tested on the test field. The results verified the concepts of using soil sampling robot to survey runway is feasible.

1. INTRODUCTION

Determining if a segment of property is suitable for use as an aircraft runway or military drop zone is a vitally important task that is currently performed by humans. However, as shown in the FOB Rhino hostilities[1], this task can also put our people in harms way from land mines, sniper and artillery attacks.

"While the Rangers secured the perimeter and searched the compounds buildings, specialists from the Air Force, reportedly from the 23rd Special Tactics Squadron of the Special Operations Command based at Hurlburt Field, near Ft. Walton Beach, Fla., walked the runway in the dark. Alert for mines, they tested the runway with a soil penetrometer, a long rod with a cone-shaped end and a sliding weight. It registers soil resistance when the weight is dropped, allowing bearing characteristics to be evaluated."[1]

According to Reference [2], the three most important pieces of information are used to determine the feasibility of constructing an airfield at a particular location are the field condition, the natural soil strength and the soil behavior. One critical factors the air field engineers need to find is natural soil strength in terms of California Bearing Ratio(CBR).

The definition of the CBR is: The ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material.

C.B.R. = Test load/Standard load × 100

The test may be performed on undisturbed specimens and on remolded specimens, which may be compacted either statically or dynamically.

Figure 1. Hand held penetrometer

For measuring subsurface characteristics, three methods are usually used. The first is an auger that is used to drill a hole to a given depth. The second is a soil sampler. A soil sample can be removed from a drilled hole at some depth for laboratory analysis using an open cone device. The third is to use a cone tipped rod that is forced into the soil. The amount of vertical force(soil strength) required to push the penetrometer at a given depth(position) is recorded and used to characterize the soil. The amount of horizontal force may also be measured to characterize the frictional resistance of the soil. Among the three, the cone penetrometer approach is the simplest method in operation.

The cone penetrometer is a probe-type instrument. It is used to determine the strength of the soil and other material. This is accomplished by pushing a rod with attached cone (ASAE standard cone) into the ground. The resistance of the cone, as it is pushed into the ground, is measured, and recorded in the memory of the computer as cone index values. The depth of the cone below soil surface is also measured and recorded in the local computer. The penetrometer data can be conveniently transferred to a remote computer for further analysis. In our case, the soil sampling mechanism would be transported to a certain place and execute the designated tasks autonomously. Such a device should not be too big or too heavy. One practical solution is to integrate the soil sampling function of Cone Penetrometer into a small mobile robot that can read soil strength and then use the soil strength reading, or vertical force reading to estimate a CBR value according to their correlations[2].

2. SYSTEM ARCHITECTURE

The architecture of the position and soil strength feedback systems is shown in Figure 2.
Two sensors are needed. One to measure the cone penetrometer penetration depth. This is measured with a position encoder mounted on the axle of the actuator. The other is to measure the vertical penetration force. This is achieved by a force measurement unite that is added between the linear actuator and penetrometer. Vertical penetration force is used in the CBR determination. The vertical force may be measured with a load cell.

The amount of force needed for a push device has been suggested by Dr. Mark Bowers[3] to be 8000 pounds per square foot. This is equivalent to 55.6 pounds per square inch. For a 0.2 square inch base, the force would be 11.1 pounds. A linear actuator with more than 100 pounds of force capability and several inches of penetration has been selected. This should permit quite, measurements that can be used to produce force versus distance curves that can be related to the California Bearing Ratio (CBR) as shown in the Figure below.

Core of the soil sampling mechanism has three major components: a linear actuator, a load cell and the cone penetrometer. See Figure 3.

. The Linear Actuator we configured is built by Ultramotion, Inc[4]. The configured actuator in the survey robot has a maximum actuator length of 8 inches and the maximum pushing strength is 400 lb.

The linear actuator is a high resolution instrument powered by Animatics 1720 SmartMotor. Detailed features are listed at their website[5]. Some features caught attentions including:

1. Powerful: The maximum force of the actuator is 400 lb.
2. Accurate: The actuator encoder has a highly accurate resolution of about 61000 counts/inch, or 0.000016393 inch/count.
3. Programmable: The Smart Motor has a RS232 serial port that can be used to communicate with the external computer using ASCII only. Also the Smart Motor has its own protocols that can be programmed with external computer.

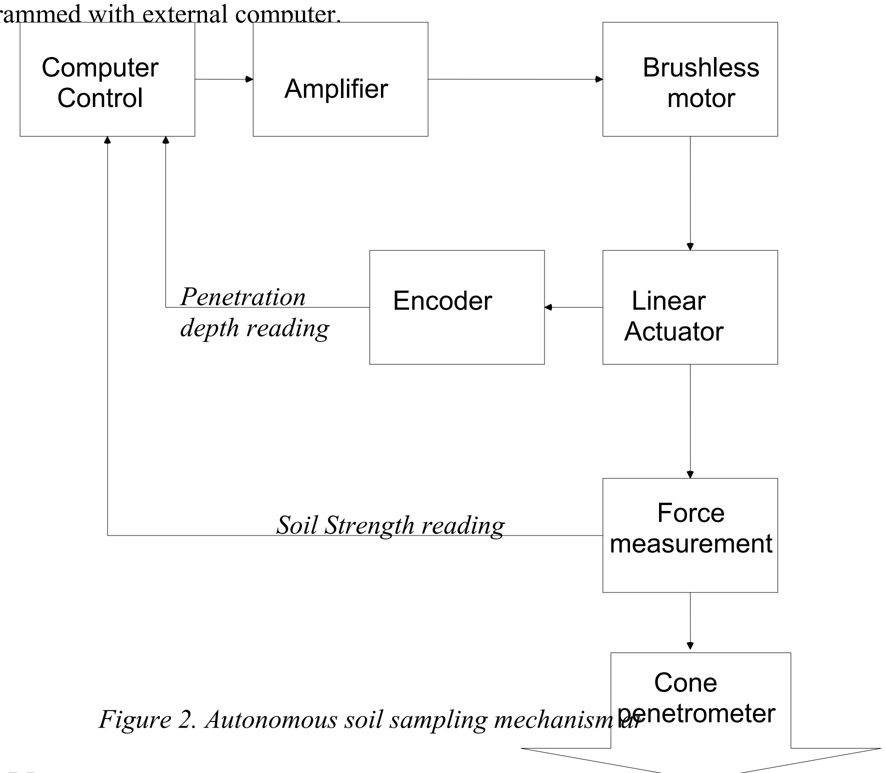

Figure 2. Autonomous soil sampling mechanism ar

. Load Cell / DRI

A pre-calibrated load cells and torque transducers that, when used with Digital Remote Indicator, safely allow the accurate measurement of forces.

One end of the load cell is mounted on the linear actuator and the other end on the cone penetrometer. When the cone penetrometer pushes against the ground, the resistance of the soil would be transferred onto the load cell. And then the load cell generates a force signal according to its deformation with the force. The magnitude of the signal will be caught by the Digital Remote Indicator(DRI) attached to the load cell. The DRI will then digitize the force signal and can be transferred to the external computer.

. The DRI incorporates a high sampling rate of up to 1,000 hz for precise peak force and torque measurements. The output frequency of the DRI to the external computer is 8Hz. DRI lends itself to thousands of applications and permits hands-free testing. The remote load cells are available in capacities up to 500 pounds. There is also a port on the DRI that can be used to interact with the external computer. That's where the central control computer gets force data.

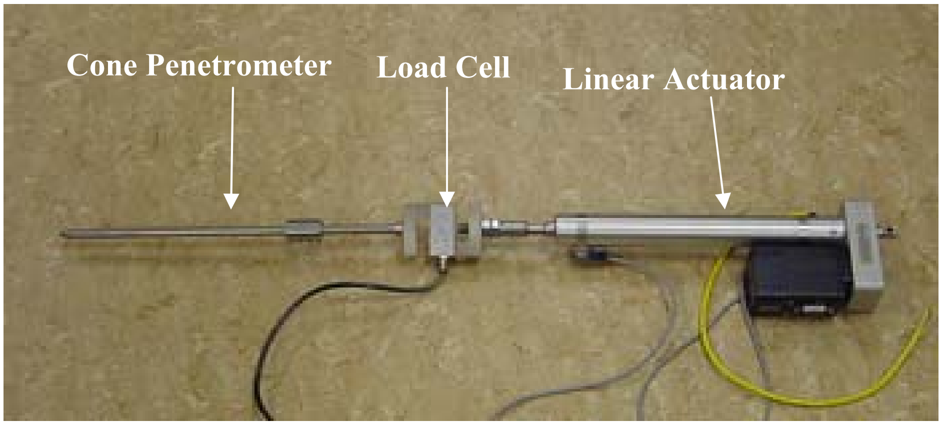

Figure 3. Core of Soil Sampling mechanism

Cone Penetrometer

To match it with the load ability of the soil survey robot, A standard 0.5-inch (1.27 cm) outside diameter cone was selected for the soil strength measurements. The penetrometer is connected with the load cell, and the load cell with the actuator. The actuator, when functions, would push the penetrometer into the ground at a certain speed, thus we can read the soil penetration force vs. penetration depth at a given moment.

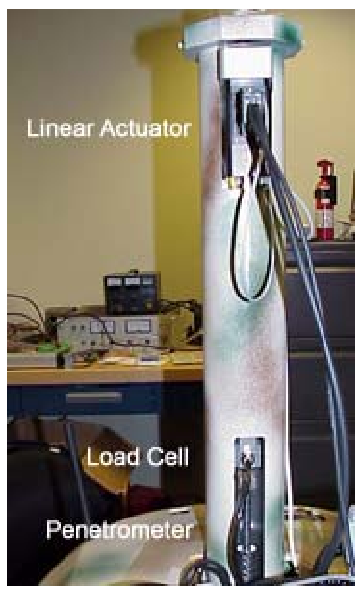

Figure 4. Soil Sampling Tube

Soil Sampling Tube

The soil sampling core is contained into an aluminum tube, which is mounted onto the bottom of the robot. The tube functions as sample core protector and force withstander. When the linear actuator pushed the penetrometer against the ground, the force actuator withstands will be transferred to the robot aluminum bottom. The penetrometer is connected with the load cell, and the load cell with the actuator. The actuator, when functions, pushes the penetrometer into the ground at a certain speed, thus we can read the soil penetration force vs. penetration depth.

. Integration with the mobile robot

The overall function of the robot is to carry the soil sampling device to a targeted waypoint. Stop and let the soil sampling device sample the soil, and then send back sample data to the remote base. The computer communicates with the soil sampling tube via two RS232 ports. There are two motion units in the robot: The robot is guided by the GPS receivers with a bounded error of approximately 10 feet. On the robot navigation side, both wheels rotate a that navigate the robot from one spot to the next; on the soil sampling unit side, the linear actuator pushes the penetrometer down for soil sampling and lift up after that.

3. SOIL SAMPLING STRATEGY

The direct result desired to get is the relationship between the soil strength at a certain depth level or the depth level at certain strength. The linear actuator can run in two modes:

a.) Velocity Mode

In Velocity Mode, the linear actuator pushes the penetrometer down at certain Speed to a designated position and stop there. At each depth level, the central control computer will read the soil strength from the Load Cell/DRI.

b.) Torque Mode

In Torque Mode, the linear actuator pushes the penetrometer down at certain torque until balanced by the resistance strength from the ground. At each torque level, the central control computer can read the penetrating depth according to the linear actuator encoder feedback.

Both modes would generate two dimension sample readings between penetrating depth and the soil strength.

4. FEATURES

The constructed survey robot can reliably complete all functional tasks as verified by repeated field tests. Some eminent advantages of the designed survey robot including

- Reliable and Accurate --- The soil sampling sensor system provide a highly reliable and accurate behavior that can perform penetration action and read the soil strength. The resolution can be as accurate as 0.00001639 inch/count.

- Adaptive Navigation --- The GPS navigation gives the robot adaptive navigation ability, i.e., starting from any point on earth, with any initial orientation, the robot can carry the soil sampling mechanism to the targeted point. Even if the robot motion system is not very accurate, its motion errors will be compensated by continuous adjustments from GPS guidance.
- Practical --- It is based on easy understanding technologies, simple to operate. The soil sampling sensor system is re-programmable also. Theoretically, any waypoint on the surface of the earth could be reached, given longitude and latitude. The soil sampling provided a quick test method for characterizing subgrade soils. Its readings can be matched to CBR value via correlations developed.

Figure 5. Soil Sampling robot in a typical field test

5. TEST AND RESULTS

Based on the above, the field test of survey robot is carefully scheduled. A patch of land about an acre was chose to test the soil survey robot functionality. A typical test consists of 5 to 6 waypoints to be explored. The distance between two adjacent waypoints is between 20 to 100 feet as indicated above. The waypoints are marked with red flags or white paper. Take consideration of the GPS accuracy, the robot is considered hit the waypoint once it stopped within 5 to 10 feet circle around the waypoint flag.

At a certain point, the immediate results from the soil sampling mechanism is a set of two dimensional data

(penetration depth, soil strength)

The data is based on a ½ inch diameter standard hardened stainless steel stick as penetrometer base, with a 30-degree, right circular cone as described before. A typical 15 sample reading is listed below:

Data Sampled at time: Thu Oct 17, 2003 05:09:17 AM

Record#	**Depth(inch)**	**Force(lb)**
1	-0.8536575	7.6
2	-1.01626	13.2
3	-1.1788625	17.6
4	-1.3414625	21.2
5	-1.504065	32.4
6	-1.6666675	46.4
7	-1.8292675	61.6
8	-1.99187	78.8
9	-2.1544725	97.2
10	-2.3170325	112.8

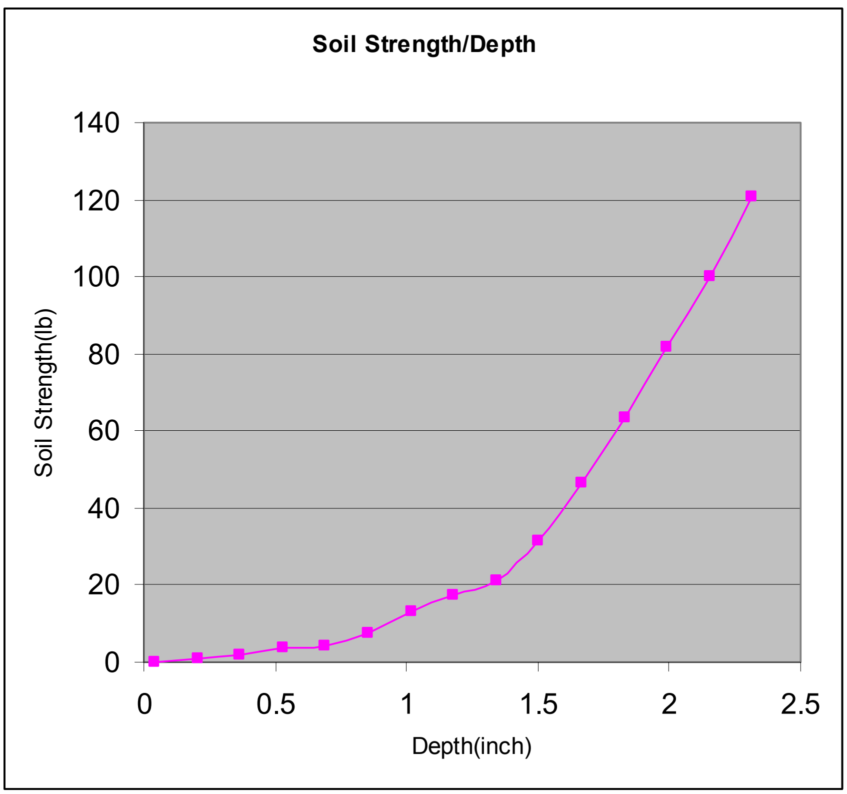

Figure 6. At a certain point, two dimensional graph of penetration depth vs. soil strength

6. CONCLUSIONS

The proposed sensor system for soil sampling was constructed and fully verified the concept of sample soil properties with autonomous mobile robot is feasible. Extensive experiments have been conducted. The soil sampling system was demonstrated to the air force officers at Hurlburt Airforce Base in November 2002. The robot finished designated tasks on site with a better than expected accuracy. This is the first time an autonomous soil sampling sensor system was successfully integrated with a GPS guided mobile robot. The performance of this robot verified the concept that robot can take place of personnel for the soil sampling operation in unstructured environments, which will substantially reduce risks and save energy and thus protect our military engineers during their task executions.

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