Testing Data Transfer over Plant Roots

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Abstract:

With today's internet, data packets can be sent globally over copper-alloy wiring, fibre-optic cable, wireless, microwave and other means. Many novel ideas for sending data have been tested, such as sending certain frequencies of sound waves through string (packing twine), making it possible to receive intelligible information on the receiving side. The roots of many plants have been shown to form large networks that can be used by these plants to transmit information (by chemical or other means) regarding predators and environmental conditions between each other.

The purpose of this project is to investigate the transmission of information through plant roots using modern data technologies. Data packets in the form of frequency derived symbols will be sent via plant roots, which form a natural network of living fibers. The data transmission is tested using two computers, each connected to one side of a tap root via the serial port. Hyperterminal is used as the client software on each computer, and the data is sent using z-modem protocol with crash recovery. This allows the transmission of the data in a half-duplex fashion, so that the data travels over only one wire.

Various root types were chosen to conduct this experiment because they have a "tap root" structure which presents a significant root core with a high water concentration. Early in the investigation, it was noted that data transmission was possible between two computers where the medium was a simple glass of salt water, so this type of plant was thought to present the best chance for significant study. Fibrous root types were initially considered, but data transmission with the experimental setup used yielded no discernible transmission in a rudimentary test. It may be that our probes were too crude or our technique not evolved enough to detect transmission in these small structures.

Data sent between the two computers was sent at different rates ranging from 300 bits per second up to 115,200 bits per second. 90% of the data sent at all data rates was received when sent across all root types. At a specific distance related to the diameter of the root itself, data transmission dropped off markedly and was inconsistent. Root durability was found to be difficult to test due to the penetration of the root sheath. Further investigation into the data transmission phenomena should include the use of smaller copper probes and the ability to emulate the root's natural environment to reduce dehydration.

Introduction:

Before and since the advent of the internet, many different ways of communication between two computers have been used, including fiber-optic, copper cable, microwave, wireless and others. Many other novel ideas for sending data over other media (such as brine-soaked string) have been tested with positive results. Plants and plant roots have been shown to be conducive to the transmission of electrical signals, but have largely been studied for self-generated electrical signaling.

In past experiments it has been found that certain plants send their own messages using special chemical signals, in order to warn other plants of predators or changing environmental conditions. This phenomenon occurs with strawberries, clover and reeds, as well as many other plants.

This experiment investigates the data transfer over plant roots where the data transmission is initiated by an outside source – in this case the serial port of a personal computer. The practical application of this may be to monitor the effects of environmental factors such as disease, parasites and weather patterns on farms, forests and greenhouses with probes that would send and receive data in various locations in a targeted environment of interest. Data could be transmitted via the plant root systems themselves and changes in their throughput could indicate the health of the environment. Wireless probes could be placed in one location and collect and transmit data collected via the roots of the surrounding area, improving the statistical analysis of environmental probes and ultimately causing fewer to be used.

The Experiment

Question:

Can information in the form of data packets be transmitted through plants, and specifically plant roots? If so, how feasible would this be in modern telecommunications? How much data (in bits) can be sent over the plants per millisecond? How far can the data travel through such a system without having to be resent? Could this technology be used in conjunction with monitoring of forests and nature, resulting in less time and money required for maintenance than current methods of data collection and analysis?

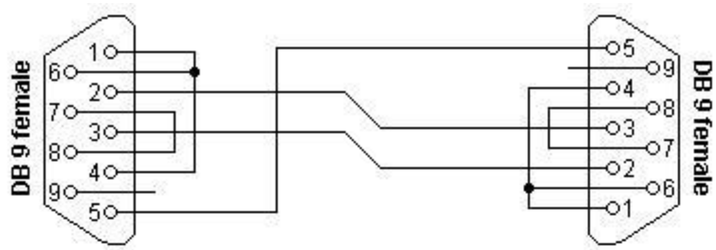
Hypotheses:

Data packets transmitted by an outside source – a serial port on a personal computer - can be transmitted over plants and or plant roots. As in other mediums, data transmission rates will decline with greater distance.

Materials:

-plant root (5 mm in diameter, dandelion – Taraxacum officinale)
-carrots (various diameters and lengths – Daucus carota)
-yellow turnips (rutabagas, various sizes - Brassica napobrassica)
-2 computers (COMP1-send and COMP2-receive)
-2 RS232 to RJ45 Adapters
-1 or 2 Serial (RS232) to USB Adapters, for the computers with no native serial ports (Note: Not required if both computers have serial ports)
-2 RJ45 Ethernet cables, with one end of the cable stripped for both (CABLE B & C)
-1 RJ45 Ethernet cables, with both ends intact (CABLE A)
-2 RJ45 Breakout Boxes
-Copper Wire (10 gauge, solid core)
-Text File 50KB or larger (referred to as test file), on COMP1

Diagram: RS232 Pinout on the PC connector. Note that only Pins 2 and 3 were used in this experiment.



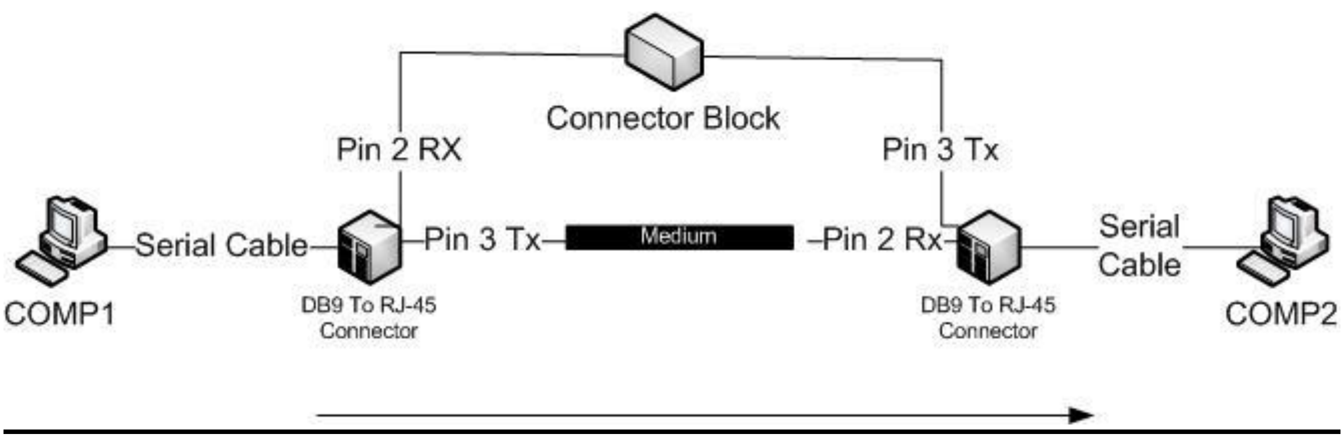
Connector 1	Connector 2	Function
2	3	Rx ← Tx
3	2	Tx → Rx
5	5	Signal ground
1 + 4 + 6	-	DTR → CD + DSR
-	1 + 4 + 6	DTR → CD + DSR
7 + 8	-	RTS → CTS
-	7 + 8	RTS → CTS

Procedure:

1. Insert each end of CABLE A (refer to materials) into a separate RJ45 breakout box.
2. Find green and green/white pins on CABLE B, on the stripped end. Strip green and green/white pins, and punch green pin down into one of the two breakout boxes, on pin 4.
3. Find green and green/white pins on CABLE C, on the stripped end. Strip green and green/white pins, and punch green/white pin down into the second breakout box, on pin 4.
4. Plug the RJ45 connectors of CABLE B into COMP1 and CABLE C into COMP2.
5. Set up the testing application (Hyperterminal) on both computers.
6. Take green pin of CABLE B, cut a 3 cm section of 10 gauge copper wire, and wrap green pin around it. Tape down tightly with electrical tape.
7. Repeat step 6 with the green/white pin of CABLE C.
8. Take 1 section of plant root (dandelions, carrots or turnips). Insert each copper wire piece (which are attached to CABLE B & C appropriately) into each end of the piece of plant root.
9. Send test file on Hyperterminal at 300 bit rate (other setting are: data bits 8, parity none, stop bits 1, and flow control none), with Zmodem protocol, with data recovery, from COMP1 to COMP2.

10. Record bps (bits per second) on COMP2 using the bps indicator on the receiving Hyperterminal software. Check the folder set to save the received text file on COMP2, compare file size to the same file on COMP1. Also open file and read through briefly to ensure data integrity.

Diagram: Test Bed for Root Experiment



File Sent From Here

File Received Here

Observations:

Note 1: Brine soaked string (10 cm length) was tested for line speed and found to be equivalent to copper wire.
Note 2: Small, fibrous root stems were initially tested but found to have no conductivity. Thus, a tap root structure (dandelion) was used. The result of the fourth experiment below was with dandelion root.

Experiment 1: Medium = copper wire	
Transmitted Rate (bps)	**Received Rate (bps)**
1200	**1170**
2400	**2320**
9600	**9560**

Experiment 2: Medium = 5% salt water		
Transmitted Rate (bps)	Received Rate (bps)	Time (seconds)
9600	9300	10
9600	9290	20
9600	9280	30
9600	9270	40
9600	9260	50
9600	9250	60
9600	9250	70
9600	9250	80
9600	9250	90
9600	9250	100

Experiment 3: Medium = Tap Water	
Transmitted Rate (bps)	Received Rate (bps)
9600	9260
	(constant over 5 minutes)

Experiment 4: Medium = Dandelion Root (5 mm diameter)		
Root Length (cm)	Transmitted Rate (bps)	Received Rate (bps)
15	9600	0 (failed)
10	9600	0 (failed)
5	9600	<100 (variable)
3	9600	9400
2	9600	9550
0 (no root baseline)	9600	9560

Experiment 5: Medium = Carrot (12 mm diameter)		
Root Length (cm)	Transmitted Rate (bps)	Received Rate (bps)
3	9600	9570
6	9600	9550
7.5	9600	(failed)

Experiment 6: Medium = Carrot (26 mm diameter)		
Root Length (cm)	Transmitted Rate (bps)	Received Rate (bps)
8	9600	9560
12	9600	9550
13	9600	(failed)

Experiment 7: Medium = Carrot (35 mm diameter)		
Root Length (cm)	Transmitted Rate (bps)	Received Rate (bps)
12	9600	9540
15	9600	9540
19	9600	9550
20	9600	(failed)

Experiment 8: Medium = Carrot (26 mm diameter)		
Root Length (cm)	Transmitted Rate (bps)	Received Rate (bps)
10	9600	9550
10	19200	19140
10	38400	38200
10	57600	57400
10	115200	115000

Experiment 9: Medium = Turnip			
Diameter (mm)	**Length (cm)**	**Max. Trans Rate (bps)**	**Rec. Rate (bps)**
70	**6**	**115200**	**114700**
130	**11**	**115200**	**114500**
180	**14**	**115200**	**115000**

Experiment 10: Medium = Carrots	
Diameter (mm)	**Maximum Data Transmission Distance (cm)**
4	**2**
5	**3**
10	**6**
12	**7**
21	**10**
26	**13**
28	**14**
33	**19**
36	**20**

Statistical Analysis

LEAST SQUARES CALCULATION FOR CARROT MAX TRANSMISSION LENGTH VS. DIAMETER

sample #	xi	yi	(xi-x)	(yi-y)	$(xi-x)^2$	(yi-y)2	(xi-x)(yi-y)
1	2	4	-7.31	-15.4	53.4361	237.16	112.574
2	3	5	-6.31	-14.4	39.8161	207.36	90.864
3	6	10	-3.31	-9.4	10.9561	88.36	31.114
4	7	12	-2.31	-7.4	5.3361	54.76	17.094
5	10	21	0.69	1.6	0.4761	2.56	1.104
6	13	26	3.69	6.6	13.6161	43.56	24.354
7	14	28	4.69	8.6	21.9961	73.96	40.334
8	19	33	9.69	13.6	93.8961	184.96	131.784
9	20	36	10.69	16.6	114.2761	275.56	177.454
SUM	**94**	**175**	10.21	0.4	353.8049	1168.24	626.676
Mean	**10.44444**	**19.44444**			39.31166	129.8044	
					variance	variance	

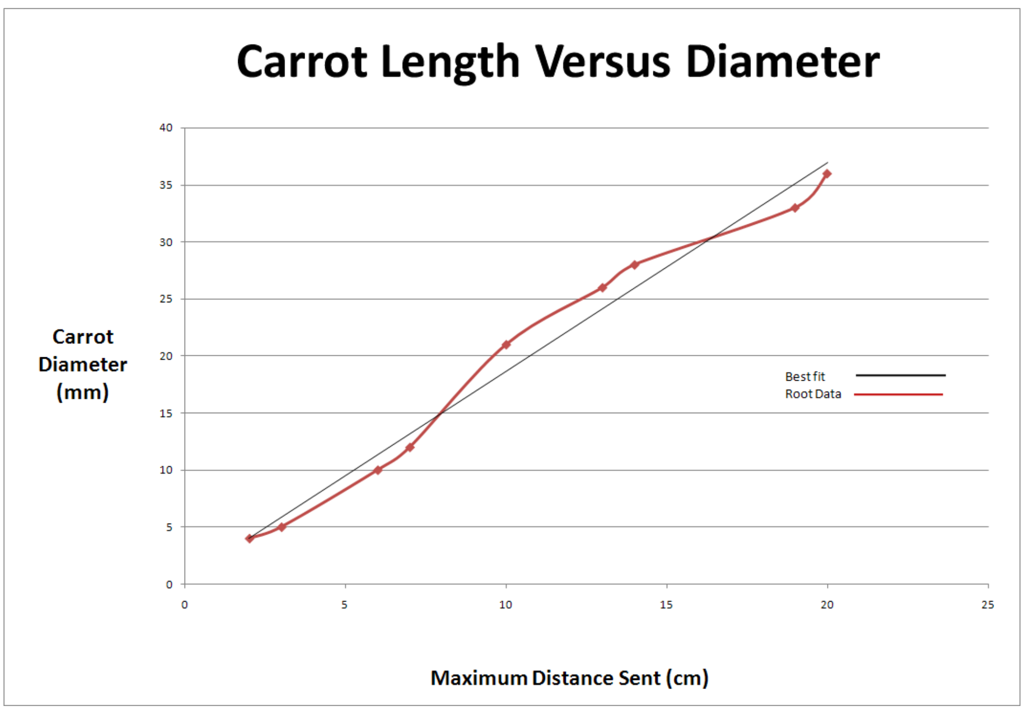
where x = the distance the data travelled (cm)
y= the diameter of the media (carrot) (mm)

x= independent (distance travelled)
y = dependant (carrot diameter)

variance x =	39.31166
std dev x =	6.269901
variance y=	129.8044
std dev y=	11.39318
b1=	1.771247
b0=	0.94475
R2=	0.950146

R2, the Coefficient of Determination is ~0.95. This indicates that 95% of the distance the data travelled (independent variable) was due to the diameter of the carrot (dependent variable).

Graph: Relationship Between Root Diameter and Distance Data Traveled Using a Carrot



Discussion

Initially, testing took place with copper wire to ascertain the test bed baseline transmission rate. Brine water and tap water were also tested initially to establish baselines. Before this preliminary testing, it was expected that a much slower rate would be achieved by the brine, tap water, and cotton string soaked in brine, however this was not true. The copper wire was only slightly faster than the other tested media.

Common belief tells us that metals are the only true “highly” conductive materials, but perhaps in this instance, conductivity was not the issue. The data itself is transmitted by electromagnetic waves at certain frequencies, not through electricity which involves the flow of electrons. The power of the signal is determined by the transmitting end and is referred to in decibels. The portion of the signal that is received correctly must be detected above background noise/frequencies and thus the ability to detect the signal is in direct proportion to the signal-to-noise ratio. In this experiment, possibly the main cause of signal dampening over the distance in the root is effected by the lack of liquid in the root due to drying once the probes were inserted. Even the carrots seemed to dry out over the time used to test them.

Before requiring adjustments to the original main procedure, fibrous plant root systems were crudely tested (multiple small roots going out in all directions), but data rates could not be established. The fibrous roots may have been too small or our transmission probes may have been too big. The root system type used is tap root, which uses a single large root, and proved the concept that data can be sent over plants. It is possible that fibrous roots systems with multiple side shoots that come into contact with the roots of other plants in multiple instances would equate to an overall high enough data rate to signify communications.

After testing different plant tap roots with the same test presented to the other media, it was found that actual bit rates of these plant roots were actually not much slower than that of copper wire. For instance, on a 9600 bit rate test, 9560bps was achieved by copper wire, and 9400bps was achieved by the plant root. While an expected slowdown in data rate over distance was expected, the roots transmitted data at a fairly high rate, then dropped off transmission altogether. The tested root types (dandelion, turnip and carrot) did not demonstrate a slowing of data rate gradually over distance. There appears to be a direct relationship between the diameter of the plant root itself and the distance that the data signal can be carried. In each case, transmission ended at a particular distance – the data rate did not gradually slow down over that distance.

The hypothesis that distance the data can travel is a function of the diameter of the media is somewhat supported by the fact that a distance limit was never reached with the large diameter turnips. In fact, very high data speeds of up to 115200 bits per second were observed with all of the turnips.

Using the least squares calculation with all the maximum distance data transmission actually showed a Coefficient of Determination of ~0.95 which indicates that 95% of the maximum distance travelled was due the the diameter of carrot (this calculation was only performed on the carrots).

In future, further experimentation should include several smaller, less intrusive probes used together over multiple “rootlets” which would protrude from the main root. This would allow the cumulative measurement of possible data transmission between plant root systems that are intertwined. This would be comparable to the bonding of data transmission signals over multiple modems or transmission paths.

Practical applications of the plant root experiment could include probe based systems that monitor agriculture such as fields of wheat, barley, rye, etc. These cereals have long root systems with lateral rootlets that could be capable of forming a subterranean data network could be monitored with solar-based probes located in strategic locations. As trees have larger root systems, we can assume that the distance data can travel would be greater and that more widely placed probes could be used to monitor the health of forests beyond standard satellite imagery.

Conclusion:

Plant roots were able to transmit data, although only over a short distance. A direct relationship was discovered between the diameter of the transmission media, the root diameter, and the length of the transmission path, the root length. Plant roots may not be a feasible alternative to copper wiring, but could still have some practical applications. More field testing will be required to determine whether plant roots will prove an effective way to transmit data in the process of monitoring forests, farms and orchards.

References

Davies, E. 2006. *Plant Electrophysiology – Theory and Methods: Electrical Signals in Plants: Facts and Hypotheses.* Berlin: Springer-Verlag.

Frost, C.J., Mescher, M.C., Carlson, J.E. & DeMoraes, C.M. (2008). Plant Defense Priming against Herbivores: Getting Ready for a Different Battle. *Plant Physiology* 146, 818-824.

Gomez, S., Latzel, V., Verhulst, Y. & Stuefer, J. Costs and benefits of induced resistance in a clonal plant network. *Oecologia, Volume 153, Number 4,* 921- 930.

Heil, M. & Bueno, J. 2007. Within-plant signaling by volatiles leads to induction and priming of an indirect plant defense in nature. *Proceedings of the National Academy of Sciences,* 104, 5467- 5472.

Malone, M. 1996. *Rapid, Long-distance Signal Transmission in Higher Plants*. San Diego: Academic Press.

National Instrument Tutorial. (2006, Sept. 6). Serial Communications Starting Point. *Developer Zone.* Retrieved February 27, 2010 from http://zone.ni.com/devzone/cda/tut/p/id/3450

Stallings, W. 2006. *Data and Computer Communications – 8^{th} Edition.* New York: Prentice-Hall.

Weaver, John E. 1926. *Root Development of Field Crops.* New York: McGraw-Hill.

Yarberry, W. 2003. *Computer Telephony Integration – 2^{nd} Edition.* New York: CRC Press.