Introduction:
Data analysis on the Ranger Robot was being hindered by high noise levels on digital data which had been processed through analog to digital converters. The data originated from analog sensors, specifically output torque sensors on the ankles. The output data showed noise levels of around 40%, which required it to be extensively filtered in Matlab before it could be analyzed. Thus, no "real time" data analysis would be possible with such noisy data.

Purpose:
The goal of this testing was to determine the source of noise on the output of the ADCs. This was accomplished by testing ADCs on the Ranger Robot as well as on the Ko Brain board under a variety of conditions. Using the Ko Brain board, tests were performed on an ADC internal to the board's microcontroller, the Freescale Semiconductor 56F8347, as well as one on an IC package external to the microcontroller, but still on the board, the Analog Devices AD7490. Using the satellite board on the Ranger, tests were performed on an ADC internal to the board's microcontroller, the Freescale Semiconductor 56F803.

The ADCs were tested to determine noise levels and noise sources for each. All of the ADCs tested have 12 bits of resolution, yielding 4096 possible output levels.

Experimental apparatus:
Ko Brain board
Ranger Robot
Oscilloscope
Variable Voltage DC Power Supply
Wire wrap wire
Soldering iron
1.5 V battery
Battery holder
10 kΩ, 100 kΩ resistors
22 nF capacitor
Multimeter
Jumper wires with clip connectors
Laptop with CodeWarrior and Data Collection (RoboDaq) software
Programming and Data Transfer Cables

Procedure:
The testing was performed on three separate occasions; 2 sets of tests were performed on the Ko Brain and 1 set of tests was performed on the Ranger.

Ko Brain 2/23/08:
1. Programmed microcontroller to collect data from gyroscopes and accelerometers.
2. Connected board data outputs to laptop to gather data and powered board with power supply.

3. Rotated and moved the board to check that the gyroscopes and accelerometers were yielding expected results. This also allowed determination of the maximum data amplitude plotted in the software so that the correspondence between amplitude and counts (or levels) would be known for both the internal and external converters.
4. Recorded amplitude of noise floor for each data output.

Ko Brain 2/29/08:

1. Connected board data outputs to laptop to gather data and powered board with power supply.
2. Recorded amplitude of noise floor for the following cases. Used wire wrap wire to keep wires short to reduce electromagnetic interference. Soldered connections to battery holder, resistor, and capacitor to ensure good contact.
    a. Connected input pins to analog ground.
    b. Connected input pins to 1.5 V battery in holder.
    c. Connected input pins to 1.5 V battery in holder in series with 10 kΩ resistor to simulate an input resistance.
    d. Connected input pins to 1.5 V battery in holder in series with 10 kΩ resistor. Connected 22 nF capacitor in parallel with battery to remove any high frequency noise that could be coming from the battery.
    e. Connected input pins to 1.5 V battery in holder. Connected 22 nF capacitor in parallel with battery to remove any high frequency noise that could be coming from the battery.
    f. Connected input pins to 1.5 V battery in holder in series with 100 kΩ resistor to simulate an input resistance.

Ranger 2/25/08:

1. Connected board data outputs to laptop to gather data and powered up Ranger.
2. Connected 1.5 V battery to ~2 m analog input ribbon cable using battery holder and recorded amplitude of noise floor.
3. Grounded analog data input on board and measured noise.
4. Grounded buffer amplifier input (which feeds the ADC in the microcontroller) and measured noise.

Data:

Noise levels were recorded for both the internal and external ADCs in the amplitude units provided in the data acquisition program. This equates to digital levels or counts by the following relationships: counts of external = amplitude / 16; counts of internal = amplitude / 8. The percentage noise was calculated by dividing the number of noise counts by the total number of counts, which in this case is 4096 because the ADCs have 12 bits of resolution.

Ko Brain ADC Testing

Testing with Grounded and Constant Voltage Inputs, Input Resistance & Capacitance
2/29/2008

Input Source	Noise Level	Internal	External	Difference (Int - Ext)
Ground	*Amplitude*	32	50	
	Counts	4	3.125	0.875
	Percentage	0.10%	0.08%	0.02%
1.5 V battery	*Amplitude*	40	65	
	Counts	5	4.0625	0.9375
	Percentage	0.12%	0.10%	0.02%
1.5 V, 10 kΩ	*Amplitude*	300	32	
	Counts	37.5	2	35.5
	Percentage	0.92%	0.05%	0.87%
1.5 V, 10 kΩ, 22 nF	*Amplitude*	N/A	47	
	Counts	N/A	2.9375	
	Percentage	N/A	0.07%	
1.5 V, 22 nF	*Amplitude*	N/A	53	
	Counts	N/A	3.3125	
	Percentage	N/A	0.08%	
1.5 V, 100 kΩ	*Amplitude*	475	32	
	Counts	59.375	2	57.375
	Percentage	1.45%	0.05%	1.40%

Input Source	Signal Level	Internal	External
1.5 V battery	*Min. Amplitude*		-12,416
	Max. Amplitude		-12,368
	Min. Counts		-776
	Max. Counts		-773
1.5 V, 10 kΩ	*Min. Amplitude*		-12,416
	Max. Amplitude		-12,384
	Min. Counts		-776
	Max. Counts		-774
1.5 V, 10 kΩ, 22 nF	*Min. Amplitude*		-12,417
	Max. Amplitude		-12,368
	Min. Counts		-776
	Max. Counts		-773
1.5 V, 22 nF	*Min. Amplitude*		-12,432
	Max. Amplitude		-12,385
	Min. Counts		-777
	Max. Counts		-774
1.5 V, 100 kΩ	*Min. Amplitude*	15,375	-12,432
	Max. Amplitude	15,850	-12,400
	Min. Counts	1,922	-777
	Max. Counts	1,981	-775

Note: Counts of external = amplitude / 16; Counts of internal = amplitude / 8

Ranger ADC Testing

Testing with Grounded and Constant Voltage Inputs at Different Sources
2/25/2008

Input Source	*Noise Level*	*External*
Ground	*Amplitude*	8
(at board)	*Counts*	1
	Percentage	0.02%
Ground	*Amplitude*	80
(buffer input)	*Counts*	10
	Percentage	0.24%
1.5 V battery	*Amplitude*	400
(~2m ribbon cable)	*Counts*	50
	Percentage	1.22%

Conclusions:

Several valuable conclusions can be drawn from this testing. Concerning practical data gathering, using unshielded, parallel analog input wires in the form of a ribbon cable caused more than 1% noise on the output. A solution to this is to use a shielded cable, such as a coaxial cable, for all data collection.

Electromagnetic interference is an important factor in ADC circuits. From the Ko Brain testing, it was determined that nearby circuits, such as the switching power supply circuit, could create electromagnetic interference which would be coupled onto the ADC circuit, creating noise on the output. Circuits must be designed to minimize interference, especially from power supplies and high current circuits such as the motor controllers.

The comparison testing between the internal and external ADCs on the Ko Brain board showed that in most cases, the external converter had lower noise levels than the internal converter. With an input resistance, the external ADC showed noise levels about 20 times less than the internal ADC. Thus, to gain more precision, an external converter is a better choice. Additionally, external IC packages are readily available with up to 18 bits of resolution, whereas most microcontrollers' internal ADCs only have 12 bits of resolution.

Discussion:

For analog to digital converter circuit design in the future, a high resolution, external ADC package is preferred. Board layout must be optimized to shield the ADC circuit from EMI, especially that coming from elsewhere on the board. Additionally, care must be taken to prevent ground loops which would create a voltage differential between the ground levels at different points on the board. Thus, separate and well-designed analog and digital grounds are essential. Another consideration is that the voltage range of the analog input signal must match the voltage range of the ADC. A converter with programmable voltage gain may prove useful to maximize the number of levels utilized for a given analog input.