PRODUCT MANUAL

SYNTOUCH NUMATAC®
TACTILE SENSOR

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TERMS AND CONDITIONS OF USE

Limited warranty, license and technical support

Using SynTouch sensors signifies the unconditional acceptance of the Limited Warranty and License found at syntouchinc.com/sensor-documents.

The fee to purchase SynTouch sensors does not include technical support from SynTouch or repairs to the sensors other than what is provided by the limited warranty. SynTouch will respond to requests for technical support or repairs in the manner and for the fee that SynTouch deems appropriate at its sole discretion. All requests for technical support or repairs must be submitted in writing to info@syntouchinc.com.

THE NUMATAC® TACTILE SENSOR (“NUMATAC”)

Hardware

The NumaTac consists of a rigid core surrounded by sealed open-cell foam like the human fingertip (Figure 1).

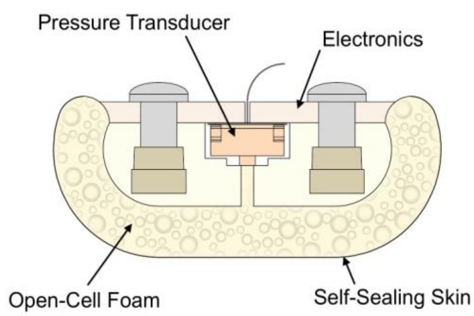

Figure 1 – The NumaTac.

The NumaTac is a robust, compliant tactile sensor for applications where contact detection is prioritized. Contrary to alternative high-resolution tactile arrays, the NumaTac is sensitive to impact over its entire surface and can be molded into complex 3-dimensional geometries. With customization, NumaTacs can be designed to cover robotic fingertips, hands, arms, or even an entire robot. In addition to high contact sensitivity permitting for dexterity and intelligent grasp control, the NumaTac’s compliance provides a cushion to protect the robot during a collision, sparing the robot, and anything or anyone it may bump into from serious damage.

The NumaTac sensor provides both compliance and contact sensitivity in a dynamic hardware configuration that is designed to be low-cost in mass production. Data collected from the enables the NumaTac to sense initial contact, with a high sensitivity for controlling collisions and enabling dexterous interactions.

Software

The NumaTac includes at no additional cost several software programs and programming libraries to help with the development of custom applications. These include graphical user interfaces to visualize and record data (Windows), software libraries for LabVIEW, and C-Libraries to support various hardware interfaces. Supported hardware includes the Cheetah SPI USB Host Adapter (LabVIEW: Windows, C-Libraries: Linux, Windows, OS X) and PEAK-System Technik’s PCAN-PCI Card (C-Libraries: Real Time Linux). Community developed and maintained, software libraries for Willow Garage's Robotic Operating System, ROS, as well as others are available, open source. Available for download at syntouchinc.com/software.

CARE AND HANDLING

Special care should be taken when using the NumaTac to ensure its long life and stable performance.

- Maximum Force: The maximum recommended force is 100N. Signals may be saturated below this force level.
- Skin abrasion: Abrading or puncturing the sealed foam of the NumaTac, as could happen if sliding across a rough surface or contacting very sharp objects, may cause leaks in the skin of the device, decreasing its sensitivity.
- Storage: Store the NumaTac in dry conditions. The NumaTac foam is sealed and water resistant, but the circuit board and electronics are not. Additionally, if water enters the sensor through small leaks in the foam the mechanical properties of the sensor could be altered. The NumaTac skin can be lightly cleaned with water if it is dried before use; however, care should be taken to keep the electronics dry. The sensor should never be used while wet.
- The mounting screws may be removed to affix the NumaTac to an adapter or surface. Always unplug the NumaTac cable from the sensor before removing the screws and replace them before reattaching the cable.
- Do not attempt to disassemble the NumaTac. No user-serviceable parts are inside, and disassembly will damage the sensor.

SENSOR ELECTRONICS

The integrated electronics of the NumaTac contains all sensory transducers, signal conditioning, and analog-to-digital conversion electronics to enable digital transmission of the sensor data (Figure 2).

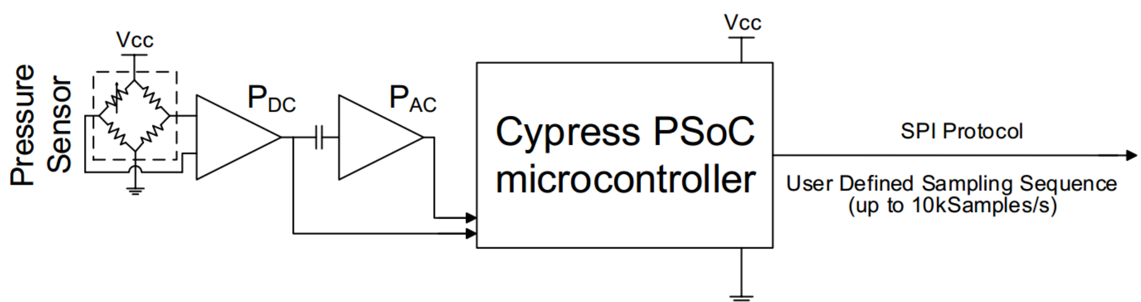

Figure 2 - Electrical schematic of the NumaTac

Sensor output

The NumaTac contains one sensor measuring static and dynamic fluid(air) pressure. Details of the acquisition and summary of performance of the sensor are provided below:

Sensory Modality	Symbol	Range	Resolution	Frequency Response
Air Pressure	P_{DC}	0 – 6.89 kPa	12.94 Pa	0 - 1750 Hz
Microvibration	P_{AC}	+/-0.27 kPa	0.13 Pa	10 - 1060 Hz

Table 1 – NumaTac Sensory Transducer Sampling Details

- Air pressure is measured with a piezo-resistive pressure transducer with a range of 0-6.89kPa (0-1psi) with reference to atmospheric pressure. The transducer output is biased in the positive direction to prevent negative saturation and amplified with a gain of 20 and a low-pass anti-aliasing filter at 1750Hz to produce the DC pressure signal (P_{DC}). A second stage includes a band-pass filter of 10-1060Hz and an additional gain of 100 to produce the high-resolution AC pressure vibration signal (P_{AC}). Both are sampled with 12-bit resolution for the range of 0-4.5V. Both AC and DC pressure can be estimated with the following equations (see Application Notes below):

$$fluid\ pressure = (P_{DC} - offset) \times 12.94\ {}^{Pa}/_{bit}$$

$$dynamic\ pressure = (P_{AC} - offset) \times 0.13\ {}^{Pa}/_{bit}$$

➢ **The pressure transducer used in the NumaTac is not thermally compensated and can drift slightly in response to changes in temperature. Due to the fabrication of the NumaTac, mechanical strains applied to the sensor body are coupled to the pressure transducer and may cause small fluctuations in sensor output.**

SENSOR PERFORMANCE CONSIDERATIONS

Permeability

The NumaTac sensor is designed to detect transient contact events, not to act as a steady-state indicator of force. The skin of the sensor is permeable to air, so when pressure is applied to the sensor, the air inside will leak out over a short period of time, returning the pressure signal to a normalized value. This prevents sensor drift that could occur over long periods of contact. The rate at which air leaks through the NumaTac skin during a contact event depends on the particular geometry of the sensor in question; typical values for the rate of decay range from $\boldsymbol{\tau}$ = 0.1 sec to $\boldsymbol{\tau}$ = 1 sec.

Maximum loading

➢ *The maximum force applied to the NumaTac should not exceed 100N.*

This assumes a 100N force applied uniformly to the sensing region of NumaTac while contacting a relatively large flat surface. Lower forces with sharper objects will result in higher local pressures that could result in skin puncture and should be avoided.

As a general rule, the NumaTac has a similar resistance to damage as the human finger. Large forces, heavy impacts, and sharp objects that would cause harm to a biological finger may also damage the skin or core of the NumaTac. Common sense should be used to avoid these situations.

Wear rate

The sensor's wear rate will depend upon usage and environmental conditions. In an effort to retain human-like compliance for grip, the hardness of the foam sensor was kept low and near human skin. SynTouch has worked with a leading foam fabricator to select materials optimized for sensitivity and wear resistance. In normal conditions, sensors have been tested to as many as 50,000 grasps without signal degradation. However, care should be taken to avoid sliding the NumaTac over abrasive materials that could wear through the foam skin, which is sealed with a fluroelastomer coating. Degrading the skin will cause the leak rate to increase and the sensitivity of the sensor to decrease.

Accounting for signal drift

Like human fingertips, the NumaTac is better at providing information about changes than absolute values. The recommended use of the sensor output is to use the raw data for various signal-processing algorithms. Moreover, absolute signal levels will drift slightly with changes in temperature and skin wear. In developing algorithms utilizing NumaTac data, make sure to incorporate a function to account for signal drift that will occur in their application and/or conditions of use. In general, these effects are not dramatic, but it is important to be aware of the potential occurrence of these changes. When the NumaTac is not in contact with external objects, it is recommended the sensor be tared to account for any offset.

ELECTRICAL CONNECTIONS

- *Do not supply the NumaTac 5V input with greater than 5.5V of voltage. This can cause damage to the electrical components, which could make the NumaTac unusable.*

NumaTac can be connected with a 6-pin connector (see below) that supplies 5V power and ground as well as the 4 SPI communication lines.

Connector

The NumaTac electronics board has been designed to mate with the following connector:

Manufacturer	**JST Sales America Inc**
Manufacturer Part Number	SHR-06V-S-B
Style	Rectangular Connectors - Housings
Connectors	Interconnects
Connector Type	Receptacle
Number of Positions	6
Pitch	0.039" (1.00mm)

Table 3 – 6-Pin Matting Connector Information

POWER REQUIREMENTS

The NumaTac requires a 5V power supply for SPI communication. For optimal sensitivity, the noise of these power supplies should be less than 20mV. As an alternative, if clean power is not available, the NumaTac can be supplied with an adapter board that only requires the four SPI lines, 5V power and ground. Power signals are conditioned with this board to provide appropriate output and are designed to work sufficiently with USB power supplies.

> ➢ *Do not supply the NumaTac 5V input with greater than 5.5V of voltage. This can cause damage to the electrical components, which could make the NumaTac unusable.*

SPI COMMUNICATION PROTOCOL

Overview

During regular data acquisition the master sends a 2-byte request for a particular sensor channel measurement and then pauses the clock while each sensor on the bus simultaneously acquires a 2-byte (12 bit) datum. The master then selects each sensor in sequence and drives the SPI clock so that each slave transmits its datum to the master when its chip select is activated.

SPI Configuration

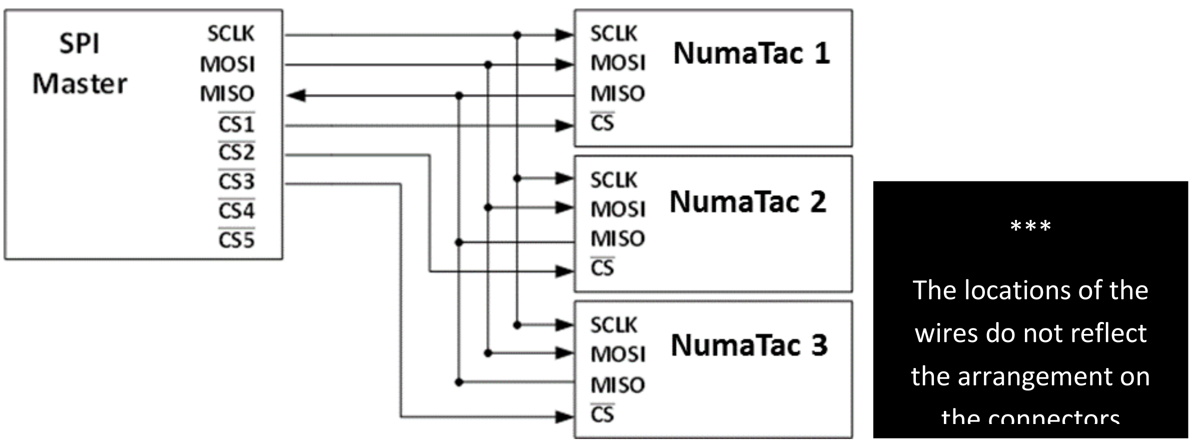

Figure 12 - SPI Connection Overview

SPI Communication Details

- Word Structure: 2-byte words (16 bits)
- Clock rate: 500kHz-10MHz
- Clock priority: idle low
- Clock phase: first edge
- MISO is changing at negative edge of SCLK; master should sample the signal from MISO line during positive edge and NOT sample the MISO line during negative edge of SCLK.
- Sensor samples MOSI line around positive edge; master should change the signal at negative edge and NOT change the signal at positive edge.
-

	MISO	MOSI
Signal update	-ve clock edge	-ve clock edge
Signal sample	+ve clock edge	+ve clock edge

Table 6 - Timing of SPI signal update and sample

Command Types

There are four types of basic commands between the host controller and individual NumaTac:

- Sampling command
- Resend command
- Parameter Set/Write command
- Parameter Read command

		First Byte								Second Byte							
	bit#	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
Sampling	0b	1	S	S	S	S	S	S	P	X	X	X	X	X	X	X	X
Resend	0b	0	1	0	1	0	0	0	0	X	X	X	X	X	X	X	X
Set/Write	0b	0	1	0	0	0	0	0	0	N	N	N	N	V	V	V	P
Read	0b	0	1	1	0	0	0	0	1	N	N	N	N	V	V	V	P
										Subset				Variables			

0b: indicating the command is sent as binary code

0/1 : command type

SSSSSS: sampling channels number (0~63)

Figure 13 – SPI Communication Protocol Command Types and Structure

➢ **While listening to the responses from the NumaTac the host should write 0x0001 to the MOSI lines to avoid errors.**

Sampling command

Description

The sampling command is a 2-byte command from the host. Only the first byte is processed and the second byte is ignored. Upon receiving the 2-byte command from the host, all NumaTacs with an active slave select during the command simultaneously and independently sample the requested channel specified by the 6-bit command SSSSSS (63 possible channels) and load the value into a 2-byte buffer.

➢ **NOTE: A minimum of 50µs delay is required between the sampling command and response from the NumaTacs. During this time the CS lines should be disabled.**

After the minimum delay of 50µs individual NumaTacs can be queried for this 2-byte buffer by enabling the CS and CLK line to each NumaTac for two bytes. This buffer must be read before sending a new sampling request. A sample of the recommended communication structure is outlined below:

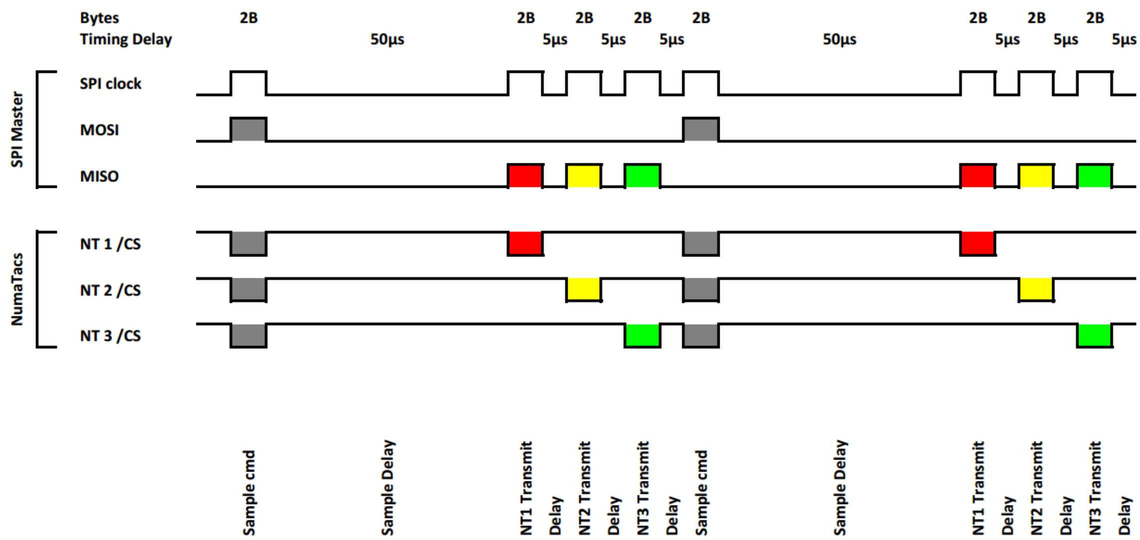

Figure 14 - Recommended Sampling Sequence for 3 NumaTacs

Detailed Sampling Commands

Description	Index	1st Byte Command	Return (bytes)	Note
Pac	**0**	0b10000000	2	
Pdc	**1**	0b10000011	2	

Table 7 – Sampling Commands

Response Format:

Signals from sensors are digitized as 12 bits of data; and split into two bytes (low byte and high byte) in the following format.

MSB LSB

Data<11:5>							Parity	Data<4:0>					0	0	Parity
bit 15	bit 14	bit 13	bit 12	bit 11	bit 10	bit 9	bit 8	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0

Figure 15 – Sampling Command Response Format

Error Handling

Sampling Errors	NumaTac Response	Description
Insufficient Sampling Delay (-)	0b10100101 00101101	There has been insufficient delay between the sampling command and response time (minimum delay is 50µs)
Channel Not Recognized (X)	0b10100101 01011000	The channel is not recognized by the NumaTac firmware or unavailable

Table 8 – Sampling Error Responses

Data Resend command

The data resend command is a 2-byte command from the host. Only the first byte is processed, and the second byte is ignored. Upon receipt of the data resend command, the or NumaTac responds with the previous 2 bytes of sampled data (this should be used in case of a parity error).

Chip select can be used to request a data resend from an individual NumaTac. If the data resend command is sent before the NumaTac has been sent a sampling command the NumaTac will ignore the resend request.

Set/Write and read command

The set/write and read commands are a 2-byte commands from the host (with additional bytes in the case of set/write. Upon receiving the command, the NumaTac responds with 2x bytes.

Group index		Subset name	Function
1	NNNN=0001	Information	NumaTac general parameters

Table 9 – Read/Write Function Subset Groups

Description	2nd byte Command	Return Bytes	rw	Details
NNNN = 0001				
General information subset	0b0001VVVP			
Flex version	0b00010000	4	r-	Format MMNN - ASCII (no parity)
Software version	0b00010011	4	r-	Format MMNN - ASCII (no parity)
Serial number	0b00010101	9	r-	Format ASCII (no parity)

Table 10 - Read/Write Function Details

Error Handling

Set/Write Errors	NumaTac Response	Description
Parameter is read-only (R)	0b10100101 01010010	Trying to write to a read-only parameter

Table 11 – Read/Write Error Codes