PapillArray Tactile Sensor (Beta v1.3)

Specifications

Document #: PTS_B1.3_SPEC_JAN21

January, 2020

Foreword

Information contained in this document is the property of Contactile Pty Ltd. and shall not be reproduced in whole or in part without prior written approval of Contactile Pty Ltd. The information herein is subject to change without notice and should not be construed as a commitment on Contactile Pty Ltd. This manual is periodically revised to reflect and incorporate changes made to the PapillArray Tactile Sensor Development Kit.

Contactile Pty Ltd assumes no responsibility for any errors or omissions in this document. Users' critical evaluation is welcome to assist in the preparation of future documentation.

In consideration that Contactile Pty Ltd (Contactile) products are intended for use with robotic and/or automated machines, Contactile does not recommend the use of its products for applications wherein failure or malfunction of a Contactile component or system threatens life or makes injury probable. Anyone who uses or incorporates Contactile components within any potentially life threatening system must obtain Contactile’s prior consent based upon assurance to Contactile that a malfunction of Contactile’s component does not pose direct or indirect threat of injury or death, and (even if such consent is given) shall indemnify Contactile from any claim, loss, liability, and related expenses arising from any injury or death resulting from use of Contactile components.

Compliance

The devices are sold as is.
The devices are specifically designed solely for the purposes of research and development only made available on a business-to-business basis.
The devices are not for resale.

Table of Contents

1 Introduction 4
2 Safety 5
2.1 General 5
2.2 Explanation of warnings 5
2.3 Precautions 5
3 Physical specifications 6
3.1 Sensing pillars 6
3.2 Casing 6
3.3 Environmental conditions 6
3.4 Transduction mechanism overview 6
3.5 Mechanical drawings 7
4 Sensing characteristics 8
4.1 Displacement sensing 8
4.2 Force sensing 8
4.3 Temperature effects on accuracy 8
5 Electrical specifications 9
5.1 Anti-alias filtering 9
5.2 Sampling rate 9
6 Installation 10
6.1 Mounting the sensor 10
6.2 Interfacing 10
6.3 Power 10
7 Software and algorithms 11
7.1 Visualisation software 11
7.2 C++ Library 11
8 Maintenance 12
8.1 General 12
8.2 Silicone 12
8.3 Cabling and Connectors 12
8.4 Periodic calibration 12
9 Terms and conditions of sale 13

1 Introduction

The PapillArray Tactile Sensor Development Kit (Beta v1.3) is a system of (up to) two PapillArray Tactile Sensor arrays and a Communications Hub. Each PapillArray Tactile Sensor array can measure 3D displacement, 3D force, and vibration on each sensing element, as well as global 3D force, global 3D torque, the onset of slip, and friction. The Communications Hub supplies power for (up to) two sensors and coordinates the simultaneous data acquisition from up to two PapillArray Tactile Sensors; i.e., coordinates sampling of the 9 pillars if one sensor is connected to the Communications Hub, 18 pillars if two sensors are connected to the Communications Hub. The Development Kit is shipped with a calibration file for each sensor, as well as visualisation software and a C++ Library for developing software control algorithms using the sensor signals.

The main components of the PapillArray Tactile Sensor Development Kit (Beta v1.3) are shown in Figure 1.1, connected to a laptop running the visualisation software.

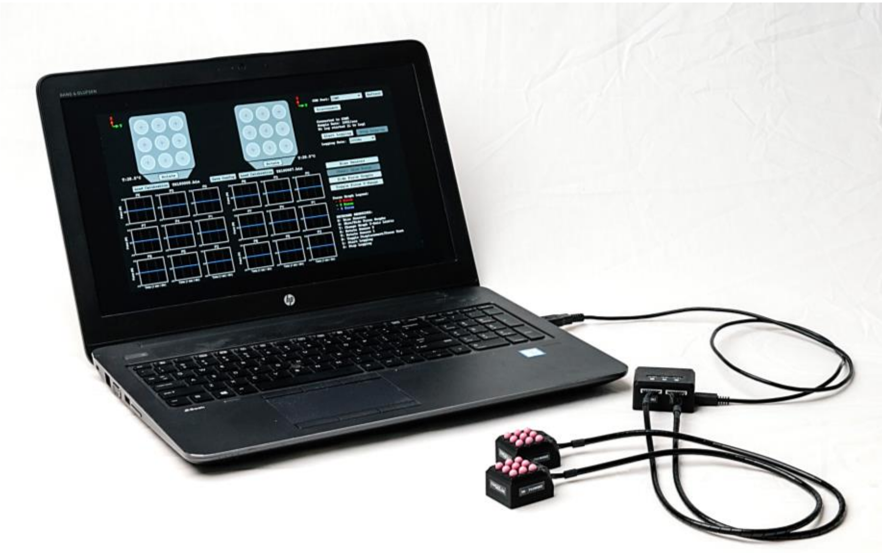

Figure 1.1 – The PapillArray Tactile Sensor Development Kit (Beta v1.3). Laptop not included.

This document contains the specifications for the PapillArray Tactile Sensor (Beta v1.3). Figure 1.2 shows the PapillArray Tactile Sensor (Beta v1.3).

Figure 1.2 – The PapillArray Tactile Sensor (Beta v1.3).

2 Safety

2.1 General

The customer should verify that the maximum loads and moments expected during operation fall within the sensing range of the sensor as outside this range, sensor reading accuracy is not guaranteed (refer to Document #PTS_B1.3_SPEC_JAN21). Particular attention should be paid to dynamic loads caused by robot acceleration and deceleration if the sensors are mounted on robotic equipment. These forces can be many multiples of the value of static forces in high acceleration or deceleration situations.

2.2 Explanation of warnings

The warnings included here are specific to the product(s) covered by this manual. It is expected that the user heed all warnings from the manufacturers of other components used in the installation.

Danger indicates that a situation could result in potentially serious injury or damage to equipment.

Caution indicates that a situation could result in damage to the product and/or the other system components.

2.3 Precautions

DANGER: Do not attempt to disassemble the sensor. This could damage the sensor and will invalidate the calibration.

DANGER: Do not attempt to drill, tap, machine, or otherwise modify the sensor casing. This could damage the sensor and will void any warranty.

DANGER: Do not use the sensor on abrasive surfaces or surfaces with sharp points/edges. This could damage the silicone surface of the sensor.

DANGER: Do not simultaneously connect the Communications Hub to multiple PCs through the MAIN and MNTR micro-USB ports. This will damage the Communications Hub and sensor electronics.

CAUTION: Sensors may exhibit a small offset in readings when exposed to intense light sources.

CAUTION: Exceptionally strong and changing electromagnetic fields, such as those produced by magnetic resonance imaging (MRI) machines, constitute a possible source of interference with the operation of the sensor and Communications Hub.

CAUTION: Temperature variations can cause drift in sensor readings. Some temperature compensation is included in Development Kit version of the PapillArray. However, bias removal in software prior to operation is necessary, and it is recommended that biasing is performed each time the sensor is known to be unloaded.

3 Physical specifications

3.1 Sensing pillars

The physical characteristics of the sensing pillars are shown in Table **3.1**.

Table 3.1 – Physical characteristics of sensing pillars.

Pillar height	3.9 – 4.5 mm. Centre pillar tallest, corner pillars shortest
Pillar diameter	6 mm
Pillar spacing	8.5 mm on square grid
Material	Silicone
Shore hardness	A40

Note: Pillar size, shape, spacing, and hardness can be customised - height and hardness most easily.

3.2 Casing

CAUTION: The sensor casing material is ABS plastic. Do not clean with solvents such as acetone as this may damage the casing. Isopropanol is a suitable cleaning agent; however care must be taken to avoid liquid ingress.

The physical characteristics of the casing of the PapillArray Tactile Sensor are summarised in Table **3.2**.

Table 3.2 – Physical characteristics of plastic casing.

Dimensions (W x L x H mm)	31.8 × 38.5 × 22.2
Material	ABS plastic
Mounting	4x M3 threaded holes on bottom side

3.3 Environmental conditions

The PapillArray Tactile Sensor (Beta v1.3) is designed to be used in standard laboratory or light-manufacturing conditions and does not yet have ingress protection to withstand dusty environments, or fresh- or salt-water immersion to any depth. The PapillArray Tactile Sensor (Beta v1.3) may be used in environments with up to 95% relative humidity, non-condensing.

3.4 Transduction mechanism overview

Each of the nine silicone pillars in the 3x3 array uses an optical transduction mechanism to measure the 3D displacement of the tip of the outer hemispherical tip of the pillar; from this displacement measurement, 3D force on the pillar is estimated via a factory calibration which is performed before shipping and applied in software in real-time.

Details on the performance of this sensing approach for a larger pillar design can be found here:

[1] *Khamis, Xia, Redmond, Sensor and Actuators A: Physical, 2019.*
https://www.sciencedirect.com/science/article/pii/S0924424718319794

3.5 Mechanical drawings

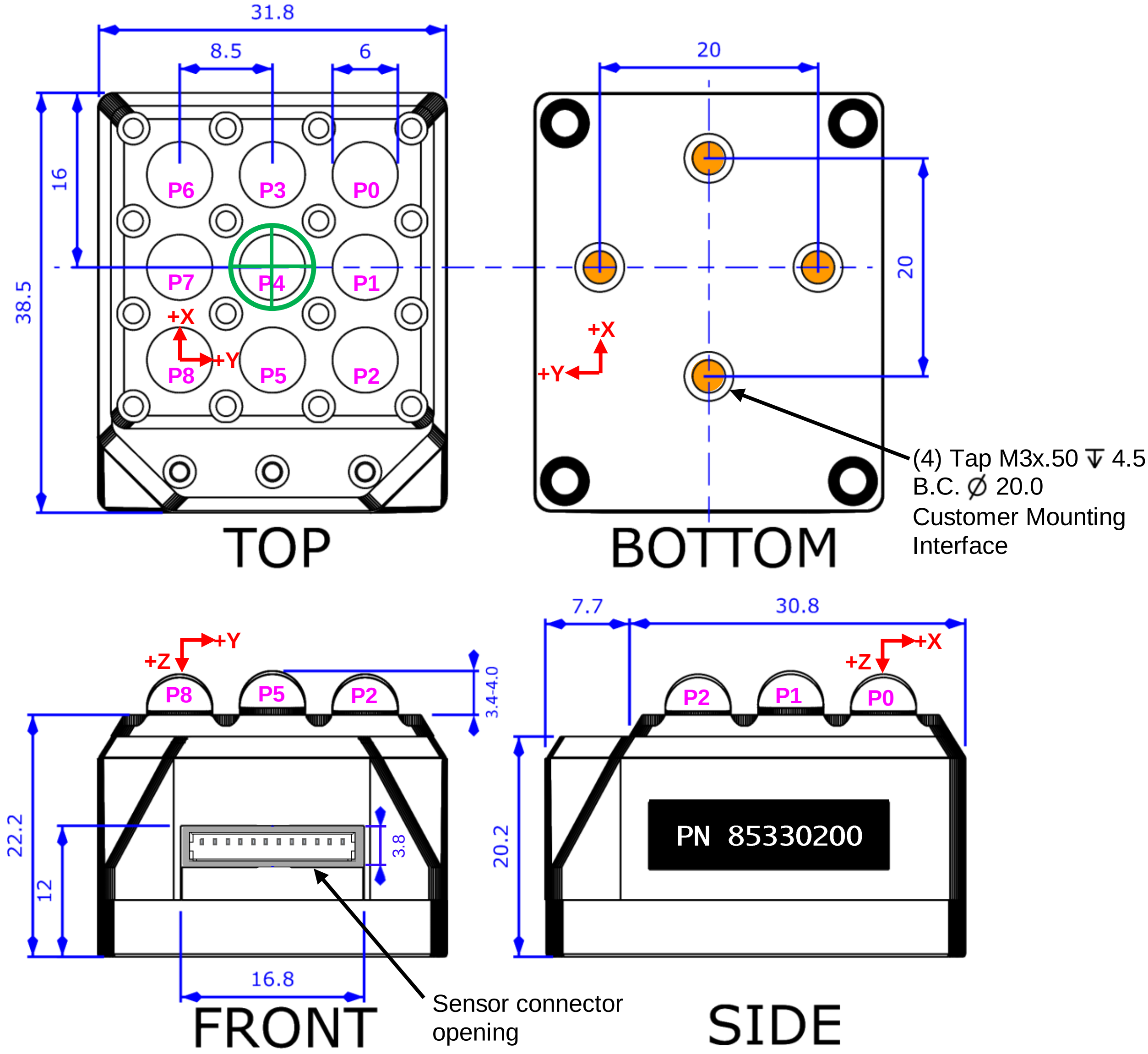

Figure 3.1 – Mechanical drawing of PapillArray Tactile Sensor (Beta v1.3). All dimensions are in mm. X-, Y- and Z-axis orientations are labelled with red arrows (→). Origin of measurement frame of reference is labelled with a green target (⊕). Pillar numbers are labelled in magenta (**P0** – **P8**). Customer mounting interface is shown as orange circles (●).

4 Sensing characteristics

4.1 Displacement sensing

Pillars can be deformed to the point of mechanical failure without damaging any of the sensing electronics, but the indicated sensor reading is only valid within the ranges listed in Table 4.1.

Table 4.1 – Displacement sensing range for valid reading and associated measurement resolution (standard deviation of sensing error).

Single sensing element		
	X, Y	**Z**
Sensing range (mm)	±1	+1.5
Resolution (mm)	< ±0.03	< ±0.01
Resolution (as % of sensing range)	< ±1.8%	< ±1.0%

Note: Sensing range can be traded for sensing resolution in customised designs.

4.2 Force sensing

Force readings are subsequently estimated from 3D pillar displacements. The force and torque sensing ranges and measurement resolutions are listed in Table 4.2.

Table 4.2 – Force and torque sensing ranges for valid reading, and associated measurement resolution (standard deviation of sensing error).

Single sensing element				
	Fx, Fy		**Fz**	
Sensing range (N)	±1		5	
Resolution (N)	< ±0.02		< ±0.02	
Resolution (as % of sensing range)	< ±1.5%		< ±0.6%	
Global (entire 3x3 array)				
	Fx, Fy (N)	**Tx, Ty (Nm)**	**Fz (N)**	**Tz (Nm)**
Sensing range	±9	~ ±0.125	40	~ ±0.063
Resolution	±0.007	~ ±0.001	0.007	~ ±0.0005

Note: Sensing range can be traded for sensing resolution in customised designs.

4.3 Temperature effects on accuracy

Temperature variations can cause drift in sensor readings; this is due to variation in LED output and due to thermal expansion/contraction of the pillar silicone. Some temperature compensation is included in this version of the PapillArray. However, bias removal in software prior to operation is necessary and it is recommended that biasing is performed each time the sensor is known to be unloaded. Bias removal is a standard procedure for many commercial force/torque sensors.

5 Electrical specifications

5.1 Anti-alias filtering

A hardware anti-alias low-pass filter with a cut-off frequency of 338.8 Hz for 1000 Hz sampling frequency is applied to each of the four photodiode signals coming from each sensing pillar. The frequency response of the anti-alias filter is shown in Figure 5.1.

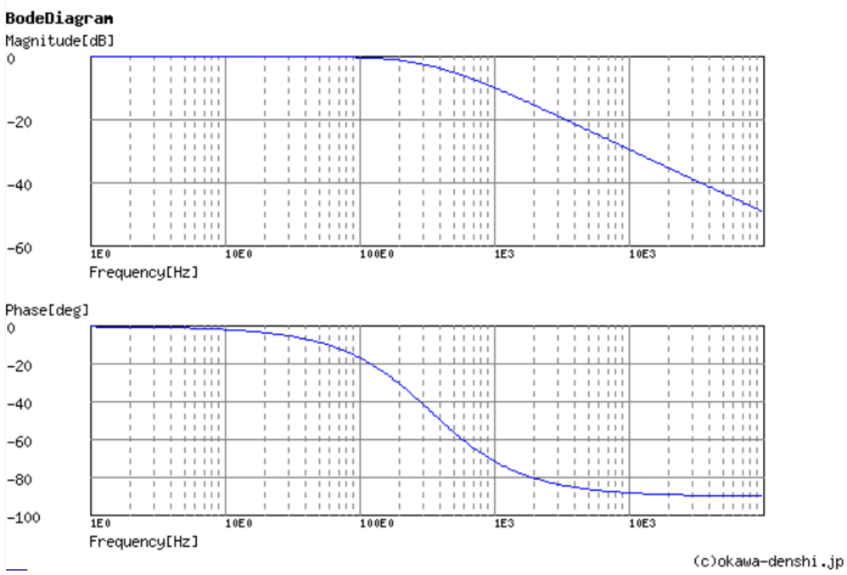

Figure 5.1 – Input filter frequency response (-3dB @ 235Hz)

5.2 Sampling rate

Each pillar can be sampled at 1000 Hz at full 16-bit resolution. This is coordinated by the Communications Hub. For more specifications of the Communications Hub, see Document #PTSCH_B1.3_SPEC_JAN21.

6 Installation

6.1 Mounting the sensor

DANGER: Do not attempt to drill, tap, machine, or otherwise modify the sensor casing. This could damage the sensor or invalidate the calibration.

DANGER: Do not exceed the mounting interface depth. This could damage the sensor.

DANGER: Do not over-tighten the screws when mounting the sensor. This could cause the mounting bolt to become dislodged from the casing and damage the sensor.

The sensor can be mounted using the bolt pattern provided on the bottom of the sensor. See section *3.5 Mechanical drawings*.

6.2 Interfacing

A separate Communications Hub device coordinates the simultaneous data acquisition from up to two PapillArray Tactile Sensors (Beta v1.3); i.e., coordinates sampling of 18 pillars across two independent sensors.

Data transmission between the Communications Hub device and the host computer (i.e., laptop, PC) is via a serial connection emulated on the USB connection, visible as a COM port on the host computer.

Raw photodiode readings are read on the host computer through a closed application programming interface (API) provided. The calibrated values are also calculated through this API (see Section *7 Software and algorithms*).

For more specifications of the Communications Hub, refer to Document #PTSCH_B1.3_SPEC_JAN21. For more information about installation and operation of the Development Kit, refer to Document #PTSDK_B1.3_MAN_JAN21.

6.3 Power

Power for the Communications Hub and up to two PapillArray Tactile Sensors (Beta v1.3) is supplied over the same single micro-USB to USB cable used to communicate with the Communications Hub. A standard USB 2.0 5 V / 500 mA port is sufficient. USB 3.0, 3.1, or 3.2 are also compatible.

For more specifications of the Communications Hub, refer to Document #PTSCH_B1.3_SPEC_JAN21. For more information about installation and operation of the Development Kit, refer to Document #PTSDK_B1.3_MAN_JAN21.

7 Software and algorithms

7.1 Visualisation software

A Java-based graphical user interface (GUI) is provided for basic post-installation testing and general demonstration of sensor operation.

This GUI can be found on the Contactile USB flash drive which was shipped with the Development Kit. The executable file is located in the folder ‘Visualisation Software’ in the root directory.

For further information, refer to the document PTSVIS_B1.3_MAN_20MAR20.

7.2 C++ Library

A C++ Library is provided which converts the raw photodiode readings into calibrated 3D displacement and 3D force signals for each of the sensing pillars, and global 3D force and 3D torque for the entire sensor array, for up to two sensors. The library also contains algorithms which can detect incipient slip (in the absence of torque) and subsequently estimate the coefficient of static friction.

The C++ Library can be found on the Contactile USB flash drive which was shipped with the Development Kit. The files are located in the folder ‘C++ Library’ in the root directory.

For further information, refer to the document PTSC++_B1.3_MAN_20MAR20.

8 Maintenance

8.1 General

For most applications, there are no parts that need to be replaced during normal operation.

Sensors must be kept free of excessive dust, debris, and moisture. Debris and dust should be kept from accumulating on or in the sensor(s).

8.2 Silicone

Periodic inspection of the condition of the silicone of the sensor is recommended.

During normal use, the silicone surface finish may become dull - this is normal.

If the silicone appears worn or there are signs of damage, the silicone may need to be replaced and the sensor recalibrated. Contact Contactile for options on replacing the silicone and recalibration.

8.3 Cabling and Connectors

In industrial-like applications that continuously or frequently move the system's cabling, you should periodically check the cable jacket for signs of wear.

Damage to the outer jacketing of the sensor cable could enable moisture or water to enter an otherwise sealed sensor. Ensure the cable jacketing is in good condition to prevent sensor damage.

The sensor cables are not designed to be frequently connected and disconnected. To avoid damage to the sensor cables and sensor ports, avoid frequently connecting and disconnecting the sensor(s) from the Communications Hub.

The sensor cables and connectors are not designed to be user serviceable. Contact Contactile for options on repairing or replacing cables and connectors.

8.4 Periodic calibration

Periodic calibration of the sensor and its electronics is required to maintain accuracy and resolution. We recommend annual recalibrations, especially for applications that frequently cycle the loads applied to the sensor. Contact Contactile for options on recalibration.

9 Terms and conditions of sale

Liability

1. To the full extent permitted by law, Contactile is not liable for any damages incurred, including any consequential damages, as a result of the provision of products, services, data, reports, or information provided herein or as part of the provided services. This includes without limitation any loss of production, damage to person or property, loss in investment, caused either directly or indirectly by Contactile. The Purchaser agrees to indemnify Contactile and its agents, and keep Contactile indemnified against all such claims, including but not limited to all financial losses, loss of income, charges, expenses, law suits, liabilities, fees, or costs.
2. Where Contactile acts as an agent on behalf of the Purchaser with other contractors, manufacturer's or suppliers, Contactile accepts no responsibility for the performance of said third-parties, and the Purchaser indemnifies Contactile from any obligation or liability relating to their performance.
3. The Purchaser acknowledges that despite best efforts by developers, no product is free of defects (or bugs). As such, Contactile does not imply that its work product, or the work product from its suppliers, will be defect free. Contactile shall not be liable for any damages relating to said defects.
4. All liability limitations that form part of this agreement survives the completion or termination of this agreement in perpetuity.

Intellectual Property

5. Intellectual property created during the course of this agreement shall remain the property of Contactile until all outstanding fees have been paid by the Purchaser after project completion. The Purchaser is liable for all costs associated with the maintenance and transfer of intellectual property from Contactile to The Purchaser. The Purchaser also agrees to attribute recognition of authorship to Contactile as reasonably requested by Contactile, including but not limited to design registrations and patents. Once all outstanding fees have been paid after project completion, ownership of all intellectual property created as part of this Agreement will be transferred from Contactile to The Purchaser.
6. Contactile and its agents may use existing intellectual property to facilitate lower project costs, such as open-source and publicly-available source code, or source code already developed by Contactile or its agents. In return, the Purchaser will grant Contactile a perpetual and royalty-free license to use the intellectual property generated as part of this agreement for use in projects that are not commercially competitive to The Purchaser's products or services.
7. Contactile will take reasonable care to check that all intellectual property used in the execution of products or services to the Purchaser is available for perpetual royalty-free use by the Purchaser, however Contactile will not be liable for any damages if intellectual property encumbrances are later discovered.
8. Some information provided to The Purchaser may be confidential to Contactile or a third party. Contactile will notify and/or mark such information as confidential. The Purchaser will treat this information as confidential, and will not disclose it to third-parties without prior agreement from Contactile.
9. For designs developed by Contactile known to the public, the Purchaser grants Contactile rights to reference products that include these designs, using company and product name, as well as images, for Contactile's use in its marketing portfolio.

Jurisdiction

10. This agreement is governed by the laws of New South Wales Australia. The Purchaser waives any rights it may have to select an alternative governing jurisdiction.
11. If any part of this agreement is not-enforceable by New South Wales law, only the un-enforceable part or parts of this agreement will become invalid, and the remainder of the agreement will remain in full-effect to the maximum extent permissible by law.