TF03 UART/CAN

Long-distance Single-point LiDAR

User Manual

www.benewake.com

Benewake (Beijing) Co., Ltd.

Described Product

Long-range single-point LiDAR: TF03 UART / CAN

Manufacturer

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Legal information

Original document

This document is an original document of Benewake (Beijing).

TABLE OF CONTENTS

1 INTRODUCTION

The User Manual provide important information on how to use TF03. It contains the basic information about TF03 and describes how to set up and configure the interfaces.

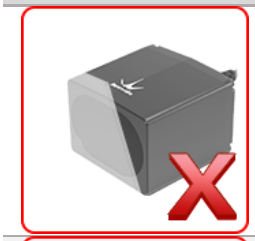
The User Manual contains detailed information about the interfaces including syntax and available functionality. It focuses on TF03 specific topics and does not describe the basic technology behind each interface.

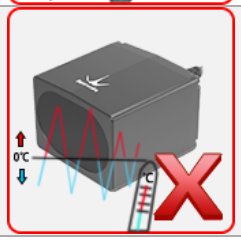
The details of the result output formatting and the contents and syntax of the command channels are shared by several interfaces. They are described in an appendix valid for all relevant interfaces.

1.1 Failure scenarios

As a precision optical distance sensor, TF03's performance is greatly affected by environment. Certain scenarios will even damage TF03. Each of these failure scenarios have been tested in real field tests.

Table 1 Failure scenarios of TF03

Scenario	Description	Scenario	Description
	Do not cover the laser window.		Avoid moving objects in the detection field.
	Avoid the presence of heavy smoke, fog and rain in the detection field.		Avoid condensation.
	Avoid direct exposure to high pressure cleaning.		Avoid exposure to strong light source with same wavelength.
	Do not exposure to corrosive liquids.		Avoid extreme vibrations.

	Do not use in extremely low temperature environments.		Do not use in extremely high temperature environments.
	Avoid exposure to sudden and extreme temperature changes.		Avoid direct exposure to another LiDAR with same wavelength.

1.2 Symbols and document conventions

Warnings and important information in this document are labeled with symbols. The warnings are introduced by signal words that indicate the extent of the danger. These warnings must be observed at all times and care must be taken to avoid accidents, personal injury, and material damage.

The following symbols and conventions are used in this document:

WARNING

Indicates a situation presenting possible danger, which may lead to death or serious injuries if not prevented.

CAUTION

Indicates a situation presenting possible danger, which may lead to moderate or minor injuries if not prevented.

NOTICE

Indicates a situation presenting possible danger, which may lead to property damage if not prevented.

NOTE

Indicates useful tips and recommendations.

2 PRODUCT DESCRIPTION

2.1 Appearance Overview

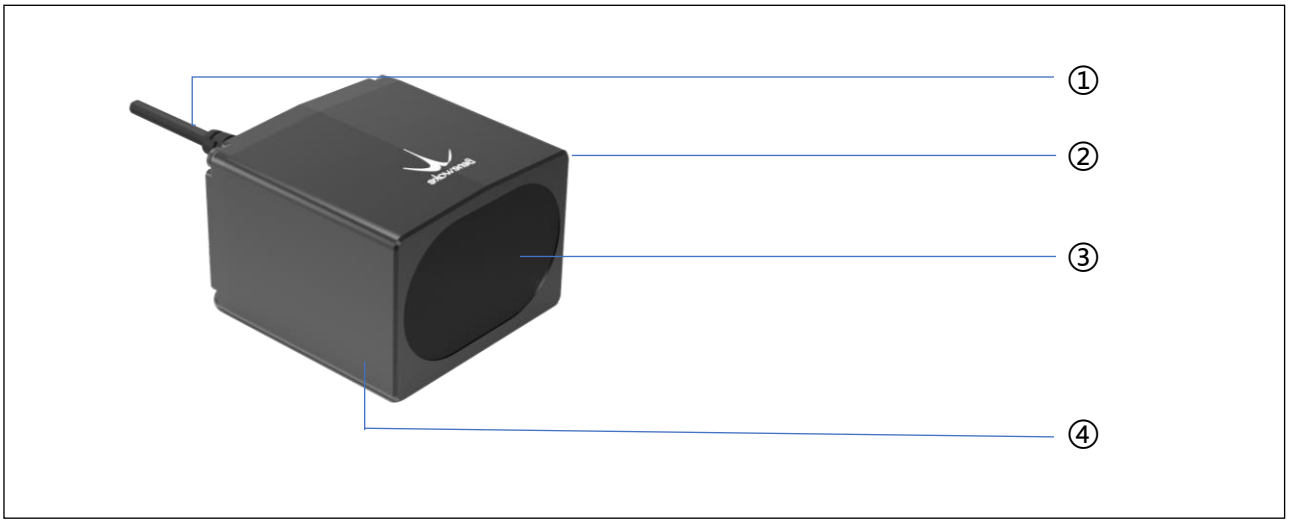


Figure 1 Module view of TF03

① Cable with male connector, Molex SD-51021-007, 7pin

② Laser window (Receiving)

③ Laser window (Emitting)

④ 3mm diameter hole (4mm deep) for mounting (4x)

2.2 Dimensional drawing

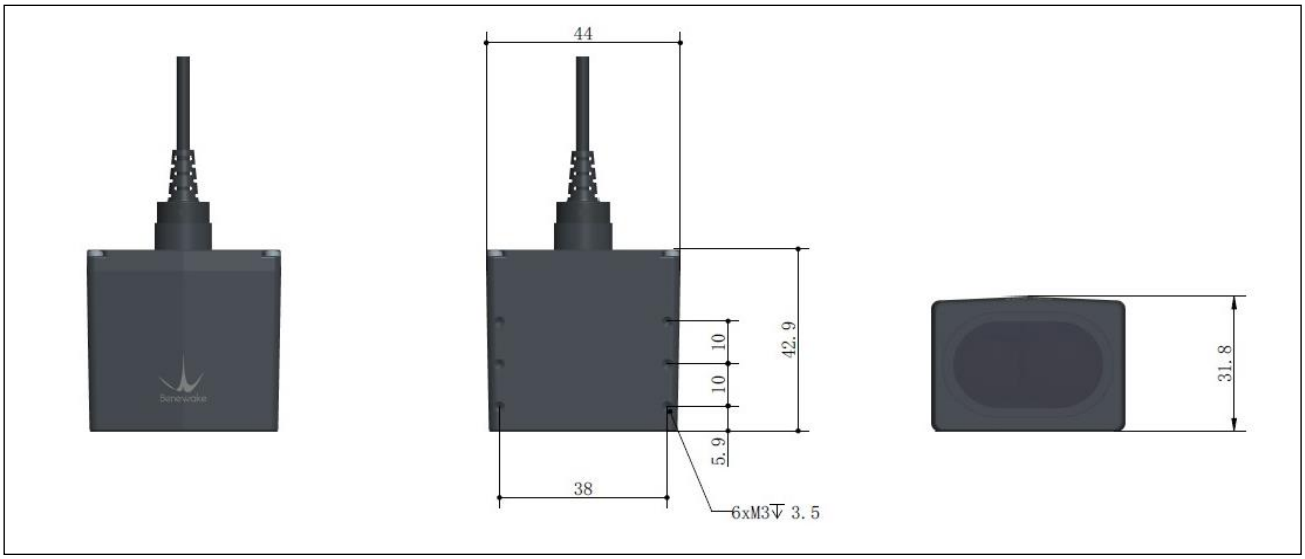


Figure 2 Dimensional drawing of TF03 (Left 1: top; Left 2: bottom; Left 3: front; Unit: mm)

2.3 Measuring principle

TF03 is a typical Pulse Time of Flight (PToF) sensor. TF03 emits a narrow pulse laser, which is collimated by the transmitting lens, which enters the receiving system after being reflected by the measured target and is focused on the APD detector by the receiving lens. The time between the transmitted signal and the received signal is calculated through the circuit amplification and filtering, and the distance between TF03 and the measured target can be calculated through the speed of light.

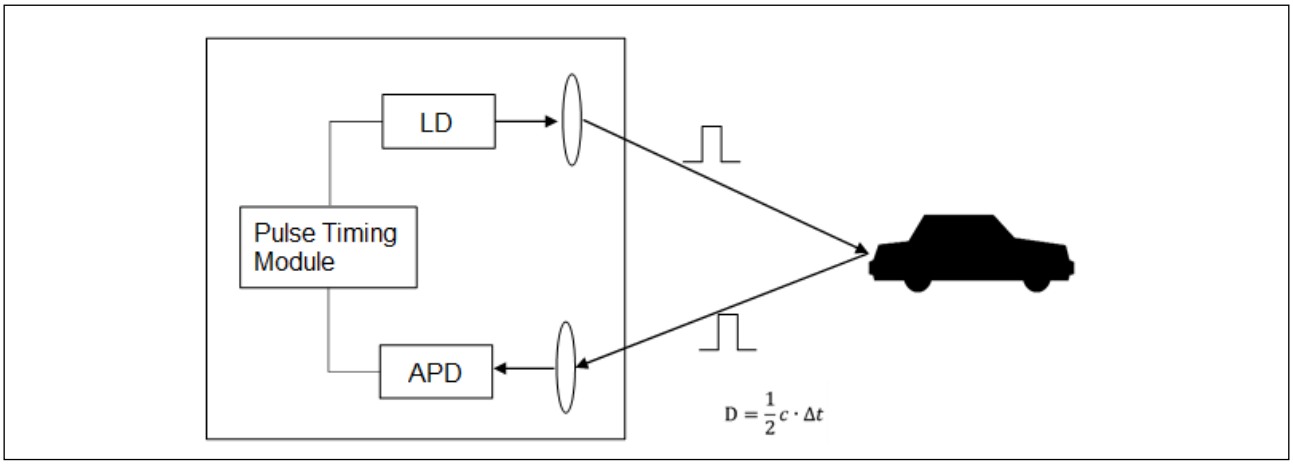


Figure 3 Pulsed time of flight (PToF)

2.4 Technical specification

NOTICE

TF03 has two versions, TF03-100 and TF03-180. The only difference between the two versions is the maximum detecting range, which is 100m and 180m respectively.

Table 2 Technical specifications of TF03

Parameters		Minimum	Typical	Maximum
Performance	Range (@90% reflectivity, 0klux)	0.1m		100m / 180m
	Range (@10% reflectivity, 0klux)	0.1m		40m / 70m
	Range (@90% reflectivity, 100klux)	0.1m		80m / 130m
	Range (@10% reflectivity, 100klux)	0.1m		30m / 50m
	Accuracy	±10cm (within 10m), 1% (10m and further)		
	Distance resolution		1cm	
	Frame rate	1Hz	100Hz	1000Hz
	Repeatability		1σ: <3cm	

Optical parameters	Light source		LD	
	Central wavelength		905nm	
	Photobiological safety		Class1(EN60825)	
	FoV		0.5°	
Environment	Ambient light immunity		100kLux	
	Operation temperature	-25℃		60℃
	Enclosure rating		IP67	
Connections	Supply voltage	5V DC		24V DC
	Average current	≤150mA @ 5V, ≤80mA @ 12V, ≤50mA @ 24V		
	Power consumption		≤1W	
	Overvoltage protection			300V
	Polarity protection			200V
	Communication interface level		LVTTL (3.3V)	
	Communication interface		UART/CAN	
Others	Dimension		44mm*43mm*32mm(L*W*H)	
	Housing		Aluminum alloy	
	Optical window		Infrared transmitting glass (HWB760)	
	Storage temperature	-40℃		85℃
	Weight	86g	89g	92g
	Cable length		70cm	

NOTICE

The basic technical specifications, like accuracy and repeatability, are measured with white background board (90% reflectivity) at 0klux condition.

NOTICE

Only the frame rate satisfying the following formula is supported.

$$Frame\ rate = a \times 10^b, a \in \{1,2,3,4,5,6,7,8,9\}, b \in \{0,1,2,3\}$$

If a value does not satisfy this formula is set, TF03 will set its frame rate to 100Hz. The normal frame rate is under 1kHz, but the maximum frame rate can reach as much as 7kHz. Please contact us if you need higher frame rate.

2.5 FoV

The field-of-view, FoV, is the angle covered by the LiDAR sensor. The horizontal FoV of TF03 is *0.5*° and the vertical FoV of TF03 is *0.15*°.

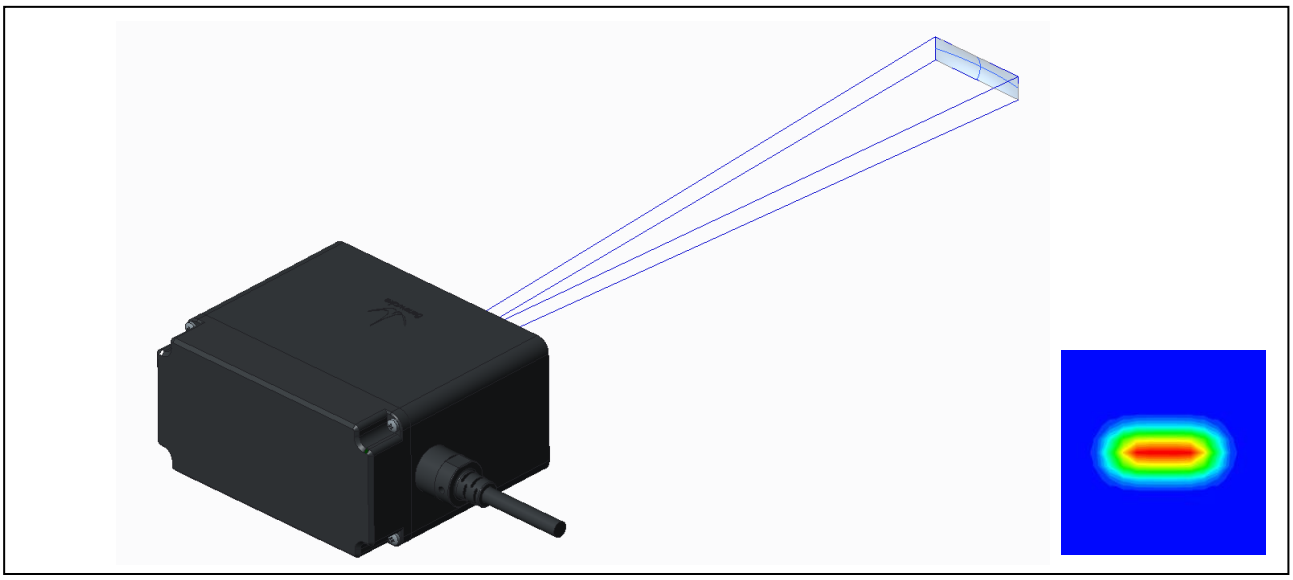


Figure 1 FoV of TF03. Horizontal divergence 0.5°, vertical divergence 0.15°.

NOTICE

0.5° and *0.15*° are theoretic values. Because the manufacturing error and the installing error exist, there is divergence between each TF03's actual FoV and its theoretic values.

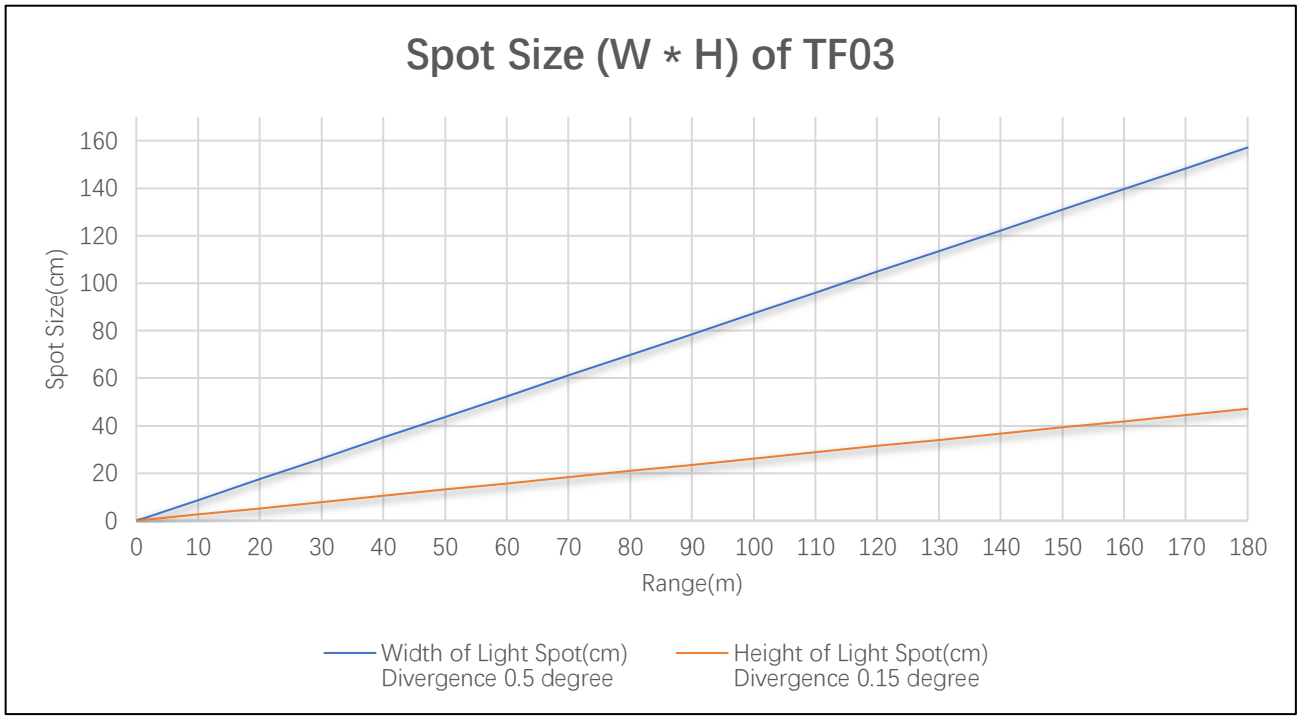


Figure 4 Spot size of TF03 at different range

3 ELECTRICAL INSTALLATION

3.1 Pin and wire color assignment

TF03's cable has six 26 AWG wires. The connector is Molex SD-51021-007 1.25 W/B-7Pin.

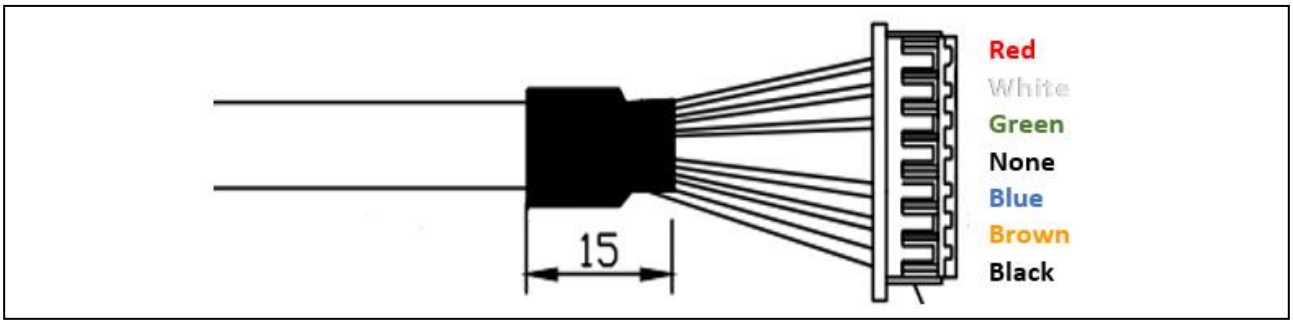


Figure 5 Male connector, Molex SD-51021-007 1.25 W/B-7Pin

Table 3 Pin assignment on 7-pin male connector

Pin	Color	Signal	Function
1	Red	DC 5~24V	Supply voltage
2	White	CAN_L	CAN-BUS Low
3	Green	CAN_H	CAN-BUS High
4	N/A	N/A	N/A
5	Blue	UART RxD	UART receive
6	Brown	UART TxD	UART Transmit
7	Black	GND	Ground

3.2 Wire cross-sections

CAUTION

If you use flexible connecting cables with stranded wire, then you must not use ferrules when connecting the wires to the terminals on TF03.

Wire all connections with copper cables!

➢ Use the following wire cross-sections:

- supply voltage at least 0.13 mm² (approx. 26 AWG), if local power supply in the immediate vicinity.
- supply voltage at least 0.21 mm² (approx. 24 AWG) at maximum length of 2m (6.562 ft), if the connection is made to an existing 24 V DC supply.
- switching outputs minimum 0.13 mm² (approx. 26 AWG), maximum cable length 2m

(6.562 ft) with 0.21 mm² (approx. 24AWG).

- data interface minimum 0.13mm² (approx. 26AWG).

➢ Lay all cables such that there is no risk of tripping and all cables are protected against damage.

On the usage of a typical power supply with a nominal voltage of 24V DC ±5%, the following maximum cable lengths are allowed for the supply of the operating voltage:

Table 4 Maximum cable lengths for the supply voltage

Wire cross-section	Cable length
0.13 mm² (approx. 26AWG)	4 m (13.1 ft)
0.32 mm² (approx. 22AWG)	10 m (32.81 ft)

3.3 General conditions for data interface

The table below shows the recommended maximum length of cable as a function of the data transmission rate selected.

Table 5 Maximum cable lengths for the data interfaces

Interface type	Transmission rate	Maximum cable length
CAN bus	1MBit/s	10 m (32.81ft)
UART	115 200 Bd	1.5 m (4.92ft)

NOTICE

With appropriate cable termination, termination in accordance with related specification.

- Use screened cable(twisted-pair) with at least 26 AWG.

3.4 Wiring the UART Interface

A screened cable is required for the wiring of the UART interface.

✧ Pay attention to max. cable length as per section 3.3 “General conditions for the data interface”.

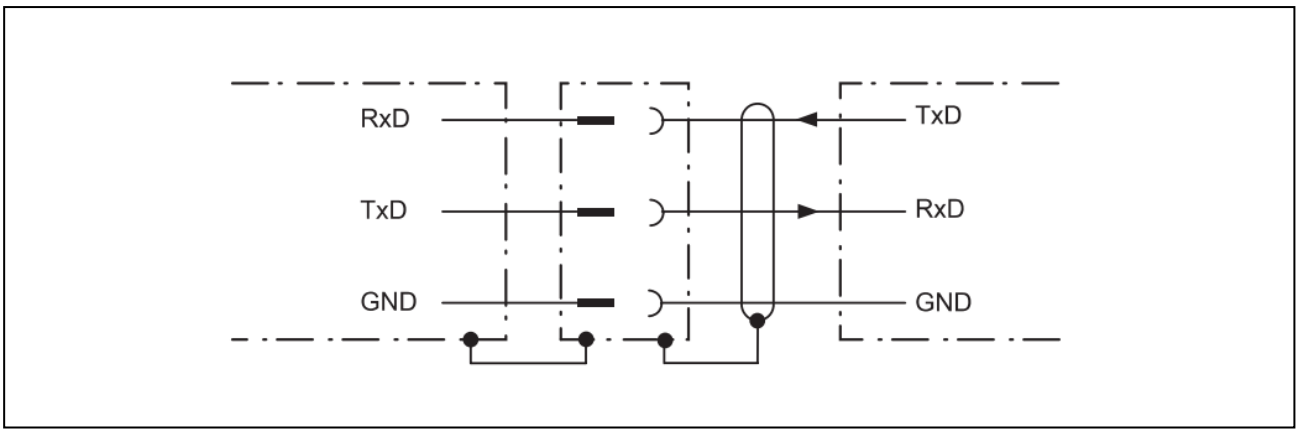


Figure 6 Wiring of the UART interface

NOTICE

To connect two devices for UART serial communication, the transmitter's TX should connect to the receiver's RX and the receiver's TX should connect to the transmitter's RX.

3.5 Wiring the CAN Interface

To wire the CAN interface a screened "twisted-pair" cable is required.

✧ Pay attention to max. cable length as per section 3.3 "General conditions for the data interface".

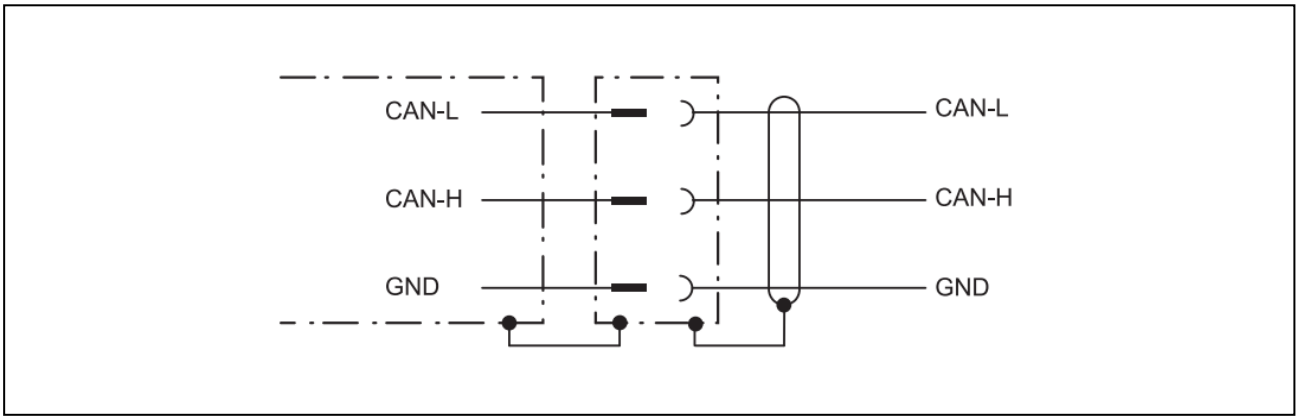


Figure 7 Wiring of the CAN interface

3.6 CAN Bus

Unlike a traditional network such as USB or Ethernet, CAN does not send large blocks of data point-to-point from one node to another under the supervision of a central bus master.

Once CAN basics such as message format, message identifiers, and bit-wise arbitration -- a major benefit of the CAN signaling scheme are explained, a CAN bus implementation is examined, typical waveforms presented, and transceiver features examined.

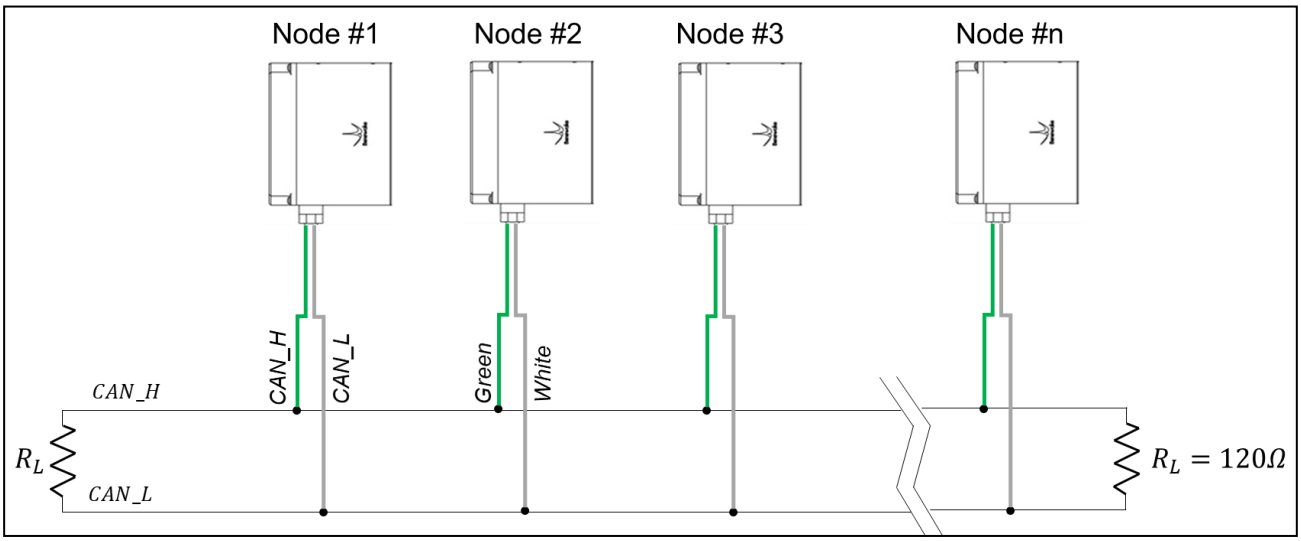


Figure 8 CAN networking of TF03

The High-Speed ISO 11898 Standard specifications are given for a maximum signaling rate of 1 Mbps with a bus length of 40 m with a maximum of 30 nodes. It also recommends a maximum unterminated stub length of 0.3 m. The cable is specified to be a shielded or unshielded twisted-pair with a 120-Ω characteristic impedance (Zo).

For CAN bus connection, there are two resistances need to be removed from TF03. See *Figure 9 Resistances needed to be removed from PCBA for CAN Bus* for the location of Resistance #2 and #3.

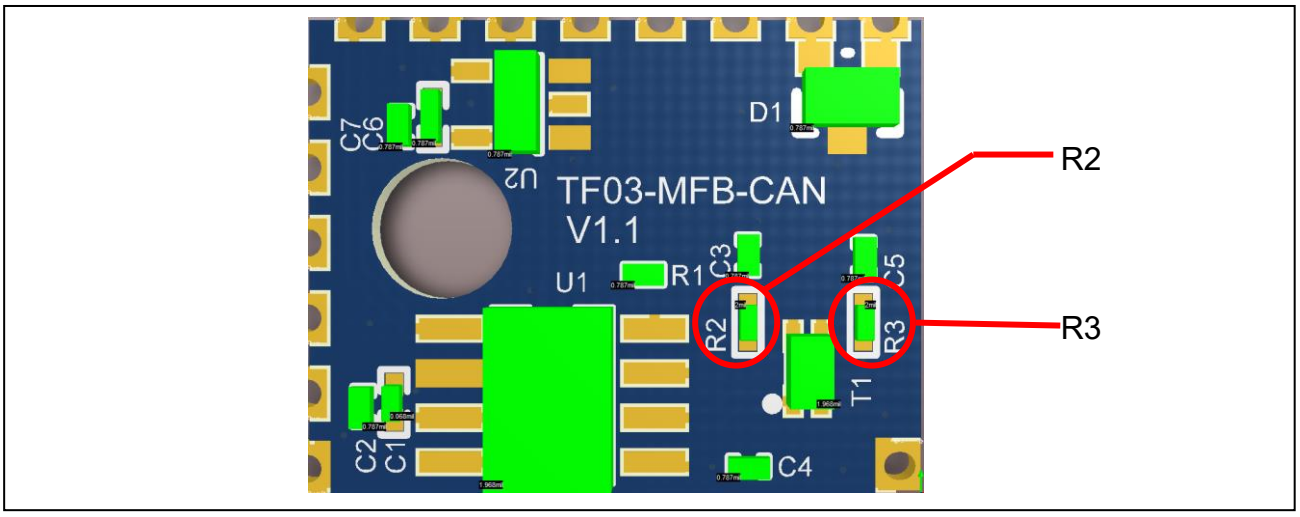


Figure 9 Resistances needed to be removed from PCBA for CAN Bus

WARNING

Removing resistance #2 and #3 needs to disassemble TF03. To avoid irreversible damage to TF03, please contact our technical support engineers for detailed instructions.

4 COMMUNICATION PROTOCOLS

The standard version of TF03 supports two communication interfaces, UART and CAN. The default interface is UART. These two interfaces cannot work simultaneously. The communication interface can be switched by certain command.

4.1 Communication protocol of UART

Table 6 Characteristics of UART

Character	Value	Configurability
Baud rate	115200	Configurable
Data bit	8	Non-configurable
Stop bit	1	Non-configurable
Parity	None	Non-configurable

NOTE

Baud rate of UART can be set to 9600, 14400, 19200, 38400, 56000, 57600, 115200, 128000, 230400, 256000, 460800, 512000, 750000, 921600, 1000000, 1500000 and 2000000. If other value were set, TF03 will automatically set it to 115200.

4.2 User protocol of UART

A standard data frame consists of 9 bytes of hexadecimal numbers, which contains distance and signal strength.

NOTE

Strength value is between 0 and 3500. Threshold of strength is 40, when strength is lower than 40, distance will output maximum value. When strength is between 40 and 1200, distance is more reliable. When there is a high reflectivity object, strength will be over 1500.

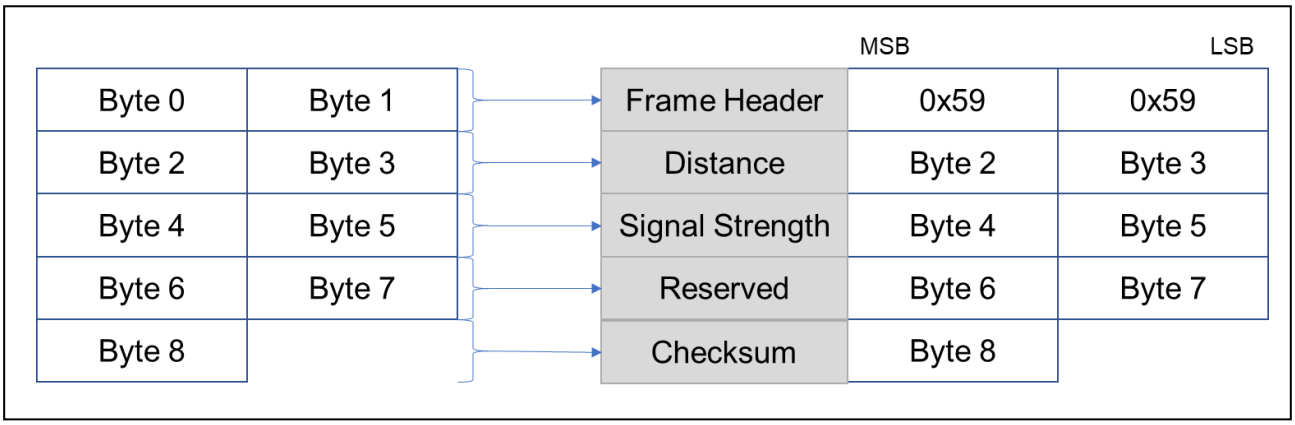


Figure 10 Data communication: User protocol frame format of UART

Each data frame consists of 9 bytes hexadecimal data which contains the distance and signal strength.

NOTE

Strength value is between 0 and 3500. Threshold of strength is 40, when strength is lower than 40, distance will output maximum value. When strength is between 40 and 1200, distance is more reliable. When there is a high reflectivity object, strength will be over 1500.

4.3 Communication protocol of CAN

Table 7 Characteristics of CAN

Character	Value	Configurability
Baud rate	1M Bit/s	Configurable
Receiving ID	0x3003	Configurable
Transmitting ID	0x03	Configurable
Message frames	Standard Frame Extended Frame	Configurable

NOTE

Baud rate of CAN can be set to 20000, 33330, 40000, 50000, 66660, 80000, 83330, 100000, 125000, 200000, 250000, 400000, 500000, 666000, 800000 and 1000000. If other value were set, TF03 will automatically set it to 1000000.

4.4 User protocol of CAN

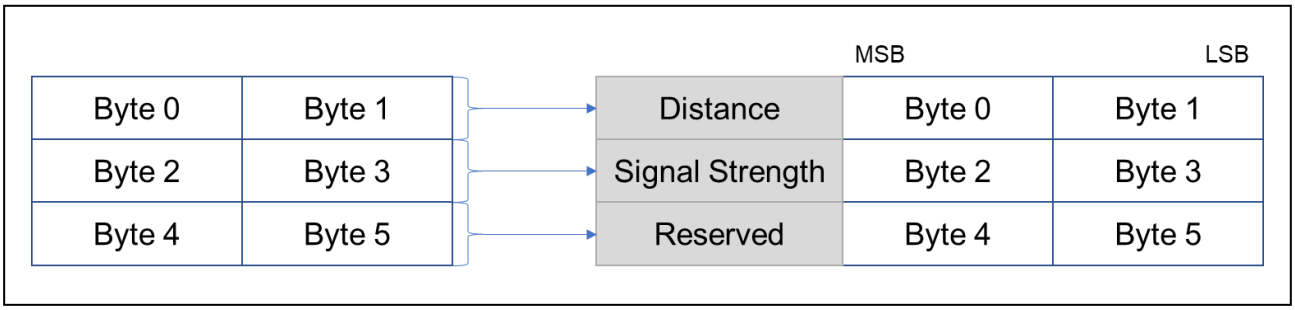


Figure 11 Data communication: User protocol frame format of CAN

5 CUSTOM CONFIGURATION

5.1 Command protocol

To meet the need of different customers, TF03 released several configuration parameters. These parameters, such as data format, frame rate, could be modified by certain command. All the parameters will be stored in flash after configured successfully and customers don't need to configure again when restart.

Table 8 Description of TF03 command protocol

Byte	Definition	Description
Byte 0	Header	Fixed to 0x5A
Byte 1	Len	The length of the command frame (unit: Byte)
Byte 2	ID	Identifies the function of each command
Byte 3~Byte N-2	Payload	Different meanings and lengths in different ID command frames
Byte N-1	Check sum	the lower 8 bits of the sum of the first N-2 bytes

5.2 Common commands

Table 9 List of TF03's common commands

Description	Command	Response	Remark	Default setting
Obtain firmware version	5A 04 01 5F	5A 07 01 VA VB VC SU	The version number VC.B.A	/
System reset	5A 04 02 60	5A 05 02 00 61	/	/
Modify frame rate	5A 06 03 LL HH SU	Same as command	LL: lower 8 bits HH: higher 8 bits	100Hz

Output control	On: 5A 05 07 01 67 Off: 5A 05 07 00 66	Same as command	/	Enabled
Enable command triggering mode	5A 05 07 00 66	Same as command	/	Disabled
Trigger measurement	5A 04 04 62	Data frame	Only works in command triggering mode	/
Change baud rate	5A 08 06 H1 H2 H3 H4 SU	Same as command	See 5.3 Command editing	115200
Restore default settings	5A 04 10 6E	5A 05 10 00 6F	/	/
Save settings	5A 04 11 6F	5A 05 11 00 70	/	/
Over range threshold setting	5A 06 4F LL HH SU	5A 05 4F 00 AE	Unit: cm LL: lower 8 bits HH: higher 8 bits	18000
Switch communication interface	UART: 5A 05 45 01 A5 CAN: 5A 05 45 02 A6	5A 05 45 00 A4	/	UART
Modify CAN arbitration ID	5A 08 50 H1 H2 H3 H4 SU	5A 05 50 00 AF	ID = (H4<<24) +(H3<<16) +(H2<< 8) +H1	0x03
Modify CAN	5A 08 51 H1 H2 H3 H4 SU	5A 05 51 00 B0	ID=(H4<<24) +(H3<<16) +(H2<< 8) +H1	0x3003
Modify baud rate of CAN	5A 08 52 H1 H2 H3 H4 SU	5A 05 52 00 B1	Baud rate=(H4<<24) +(H3<<16) +(H2<<8) +H1	1Mbits/s
Set frame type of CAN	Standard frame: 5A 05 5D 00 BC Extension frame: 5A 05 5D 01 BD	5A 05 5D 00 BC	/	Standard frame
Enable UAVCAN	5A 05 77 MD SU	5A 05 77 00 D6	MD：filter switch 0x00：filter off 0x01：filter on	/
Offset setting	5A 06 69 LL HH SU	5A 05 69 00 C8	Unit: cm LL: lower 8 bits HH: higher 8 bits	0

Low-power consumption mode	On: 5A 05 83 01 E3 Off: 5A 05 83 00 E2	Same as command	/	Off

WARNING

Do not send the command not listed in the table above.

5.3 Command editing

This section describes the Command Channel of TF03 which is used to read and set TF03's working parameters. The command channel is available via all the interfaces.

A standard TF03 command consists of frame header, command length, command ID, parameters and checksum. Follow these steps to generate a command:

- Choose the right command ID and confirm its length
- Convert parameter from the decimal value to hexadecimal value
- Fill the hexadecimal parameter into the command
- Calculate the checksum and fill its low 8-bits into the command

For example, changing the baud rate to 460800. Firstly, choose the ID of changing frame rate, which is 0x06. Secondly, change 460800 (decimal number) to hexadecimal number, which is 0x00 07 08 00. Thirdly, fill the parameter into the command, like ***5A 08 06 00 08 07 00 SUM***. Finally calculate the sum of the first 7bytes and take its low 8bits, we will have the complete command, ***5A 08 06 00 08 07 00 77***.

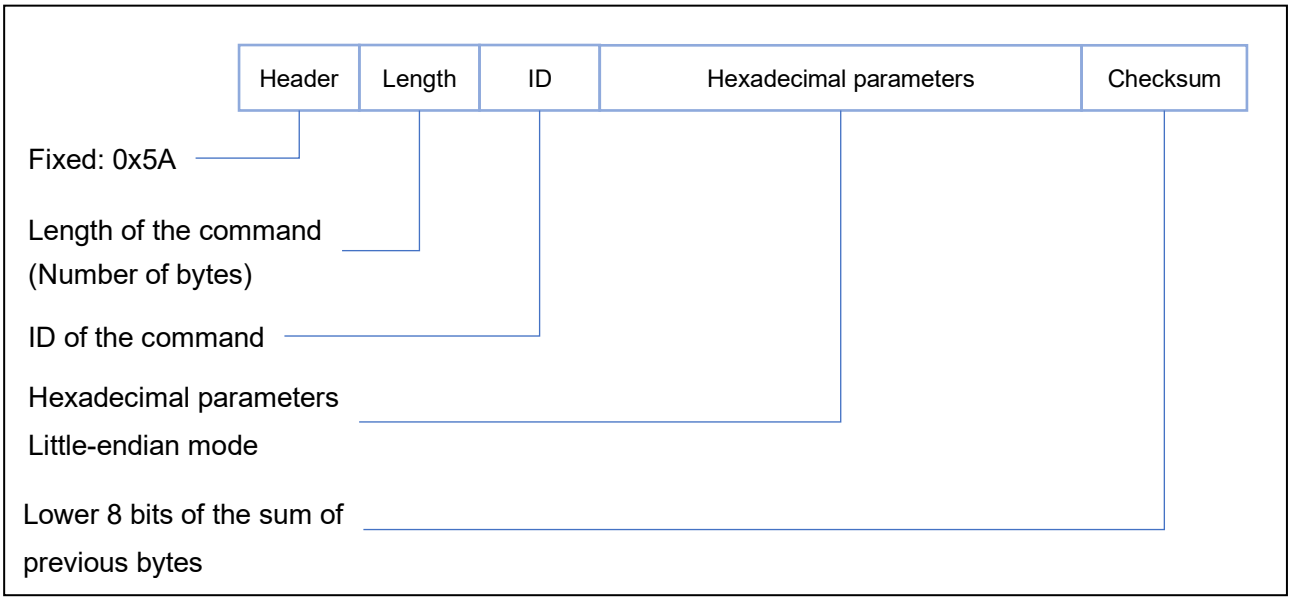


Figure 12 Command syntax of TF03

6 OPTIONAL ACCESSORIES

6.1 Self-cleaning module

In some outdoor scenes, dust adhering to the TF03's window will affect the performance of the TF03. We've designed the following self-cleaning module that can automatically clean the TF03's window regularly. The module drives the rocker arm and wiper with the steering gear to clean the TF03 window regularly.

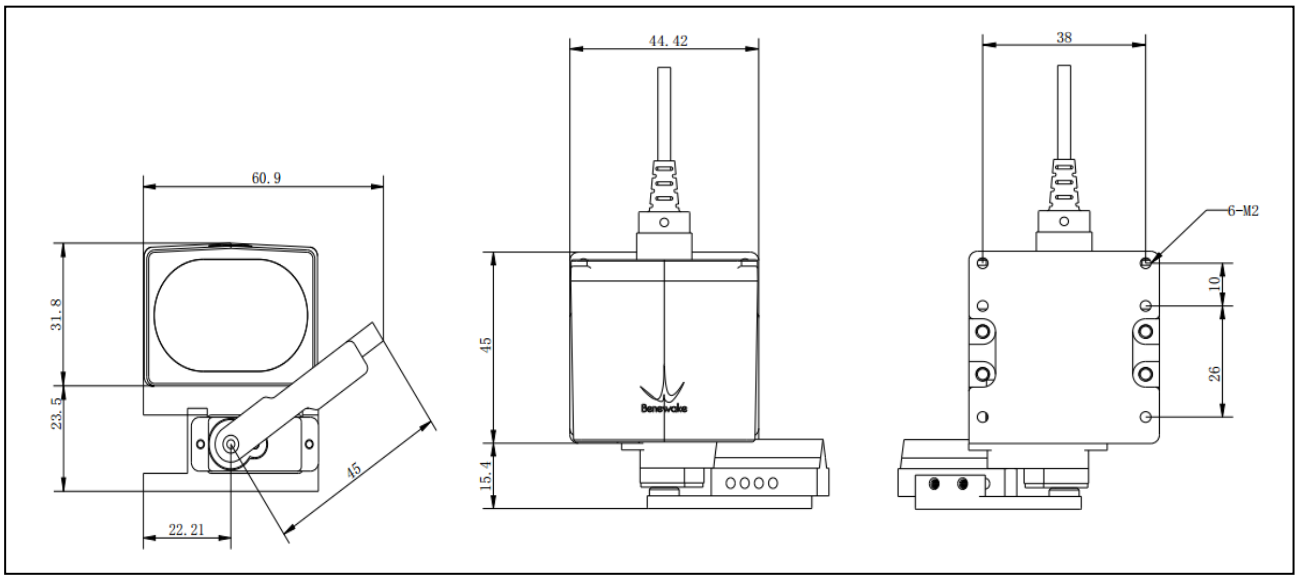


Figure 13 Dimension drawing of self-cleaning module

The self-cleaning module is fixed with TF03 through the metal base, its power supply and communication are completely independent from TF03.

Figure 14 Sketch map of steering gear

Table 10 Pin assignment of steering gear

Pin	Color	Signal	Function
1	Black/Brown	GND	Ground
2	Red	DC +5V	Supply voltage
3	Yellow	PWM	Signal channel

NOTE

The working pattern of steering gear is configurable, please contact us for detailed information.

6.2 Aiming beam module

The wavelength of TF03's detecting light is 905nm, which is invisible light. We've designed an aiming beam module to assist the installation.

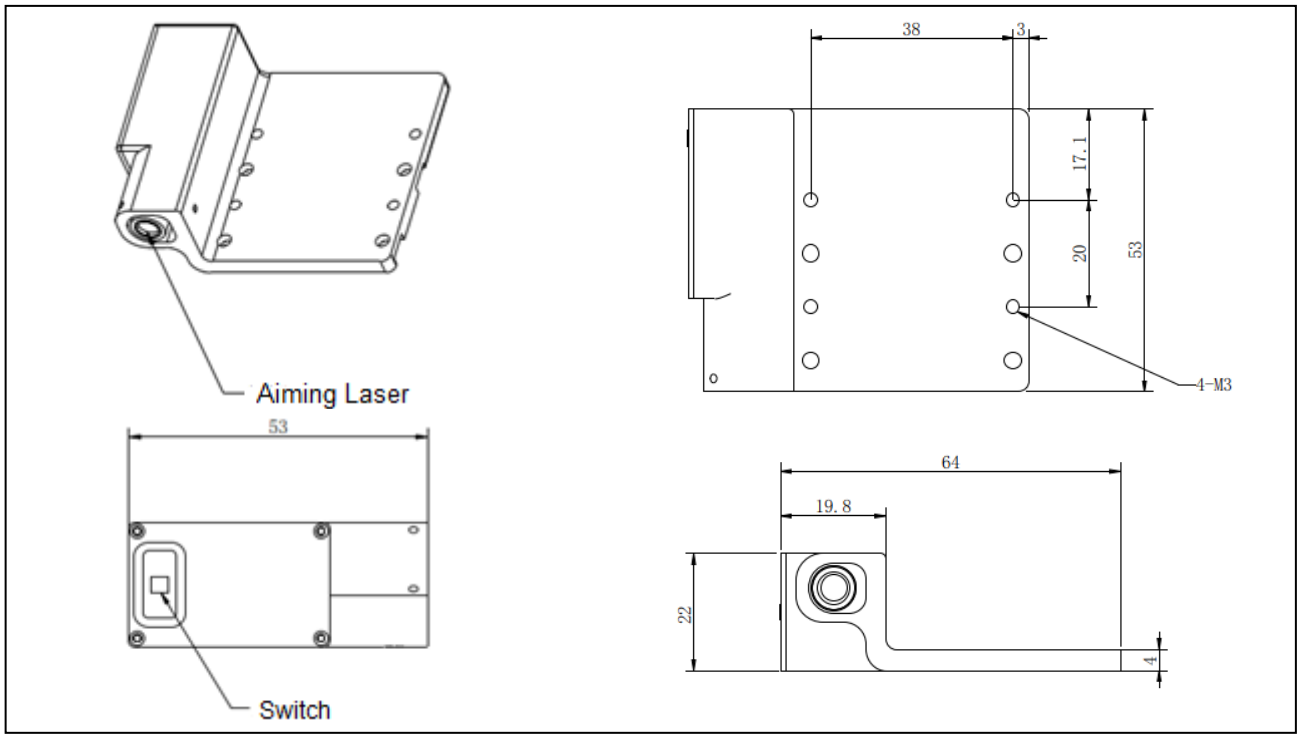


Figure 15 Sketch map of Aiming beam module

NOTE

The aiming beam powered by button battery is a low-power laser. Its indoor effective range is approximate 150 meters, and its outdoor effective range is about 30 meters.

6.3 Extension cord

For testing purposes, we prepared an extension Dupont cord. See *Figure 16 Extension cord for test* for detailed information.

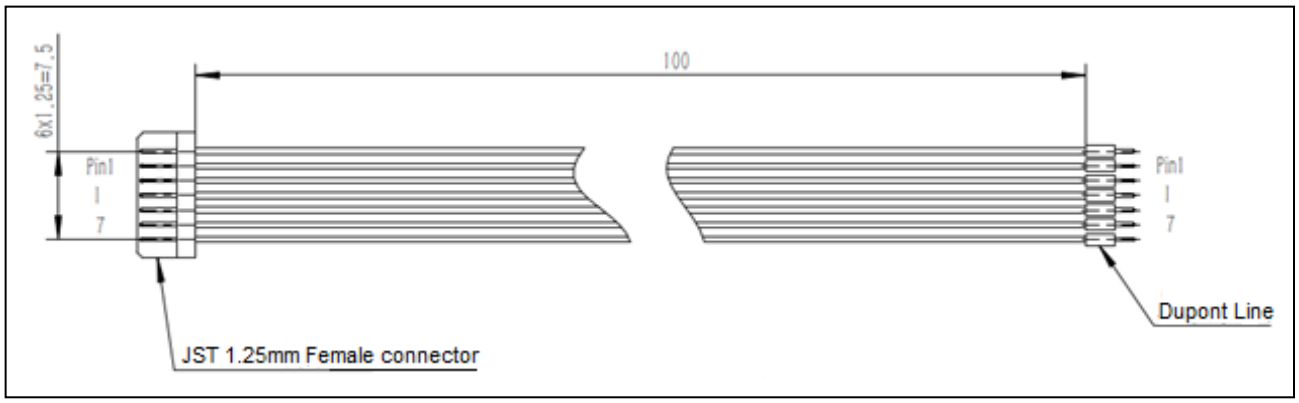


Figure 16 Extension cord for test

NOTE

This extension cord is free, but it's not a standard accessory. Please contact us if needed.

7 QUICK START GUIDE

7.1 Connection and basic test

NOTE

The product package contains only TF03 and factory certificate. If you need USB converter, please contact our sales or technical support.

- Download the latest version **BW_TFDS** from http://en.benewake.com/support onto your PC or laptop.
- See *Figure 18 Benewake testing GUI for TF series* for of the GUI.
- Connect TF03 to the PC or laptop with a **paired USB converter** cable as shown in *Figure 17 TF03 connecting to PC*. The UART version TF03 needs a UART-USB converter, and the CAN version TF03 needs a CAN-USB converter.

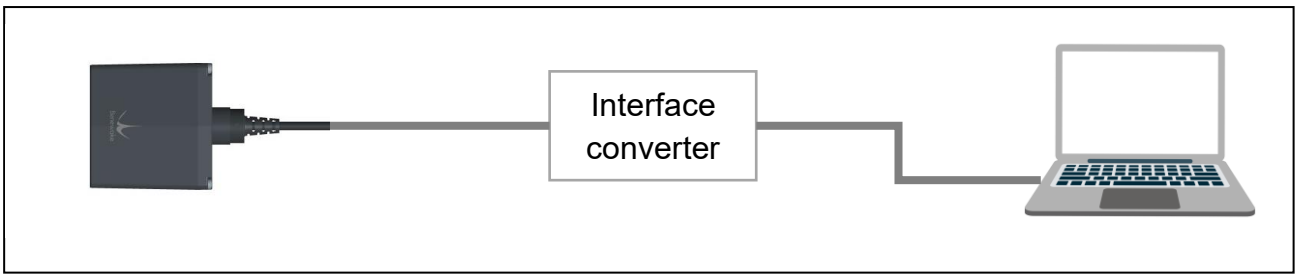


Figure 17 TF03 connecting to PC

- Run **BW_TFDS.exe**, choose the right baud rate and communication port, and click **CONNECT** to start the test.

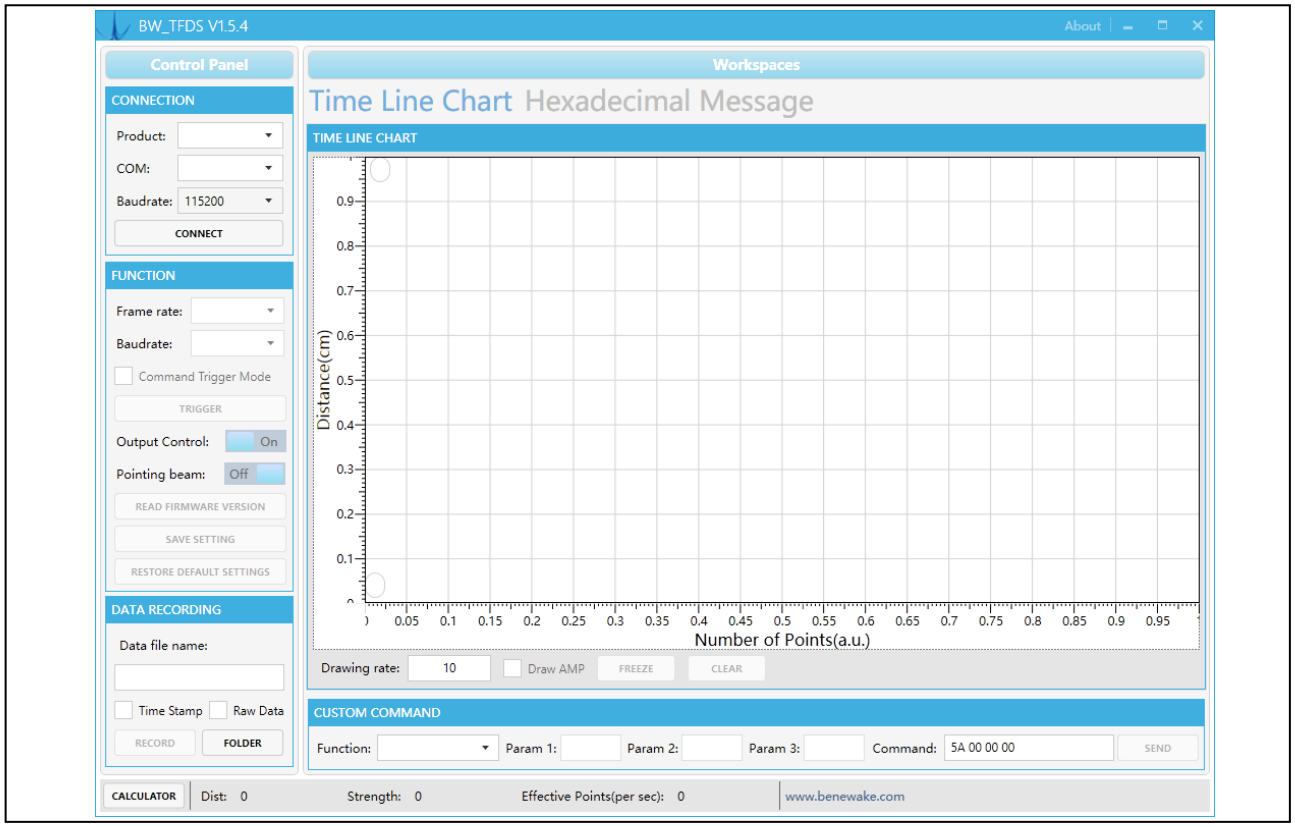


Figure 18 Benewake testing GUI for TF series

7.2 Troubleshooting guide for initial test

In the default working mode, TF03 will automatically output data when connected to the PC following *7.1Connection and basic test*. If you cannot read data from GUI properly, follow these steps to locate and solve problems.

S1. Check if there is red light inside TF03 through its window.

- No. Check power supply. If the power supply is normal, please contact Benewake service.
- Yes. Proceed to **S2**.

S2. Check whether the USB converter is paired with TF03. For example, TF03-100 CAN needs a USB-CAN converter.

- No. Change a paired USB converter then try again.
- Yes. Proceed to **S3**.

S3. Check signal wiring. See 3.4 Wiring the UART Interface and 3.5 Wiring the CAN Interface for detailed wiring information.

- Incorrect. Fix wiring.
- Correct. Proceed to **S4**.

S4. Some USB converters can generate more than one COM port. Try to connect through different COM port.

- If all the COM ports don't have data output, proceed to **S5**.

S5. Send the command of reading firmware version, **5A 04 01 5F**, through every COM ports. Try to read response.

- If all the COM ports have no response, please contact Benewake service.
- If one of the COM ports has correct response, send the command of restore default, **5A 04 10 6E**, through this COM port. After sending this command, if the TF03 still doesn't work, please contact Benewake service.

7.3 Working mode

TF03 has three different working modes.

- Automatic output mode. This is the default working mode. The default frame rate of this mode is 10Hz.
- Command triggering mode. In this mode, TF03 will not output data automatically. TF03 output measuring data only when it receives the triggering command.
- Low power consumption mode. In this mode, TF03 still output measuring data automatically. But the maximum frame rate has been restricted to 5Hz. Meanwhile its power consumption is reduced to 150mW.

NOTE

Only the UART interface supports low power consumption mode.

7.4 Influences of object surfaces on the measurement

The signal received from a perfectly diffuse reflecting white surface corresponds to the definition of a remission of 100%. As a result of this definition, the remissions for surfaces that reflect the light bundled (mirrored surfaces, reflectors), are more than 100%.

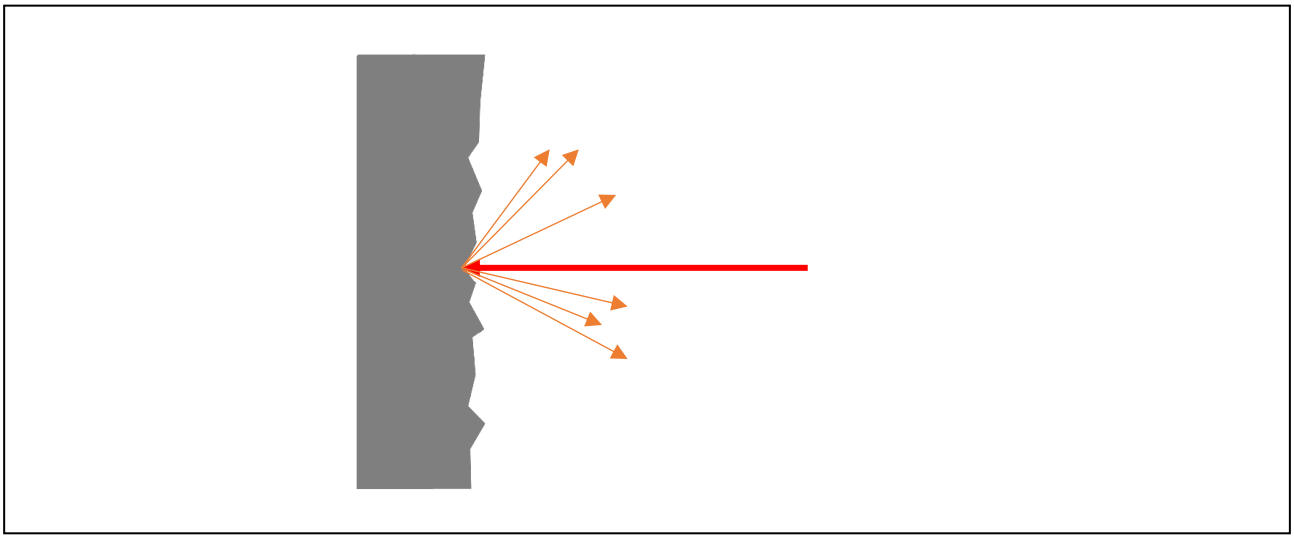


Figure 19 Reflection of the laser beam at the surface of an object

The majority of surfaces reflect the laser beam diffusely in all directions.

The reflection of the laser beam will vary as a function of the surface structure and color. Light surfaces reflect the laser beam better than dark surfaces and can be detected by the TF03 over larger distances. Brilliant white plaster reflects approx. 100% of the incident light, black foam rubber approx. 2.4%. On very rough surfaces, part of the energy is lost due to shading. The detecting range of the TF03 will be reduced as a result.

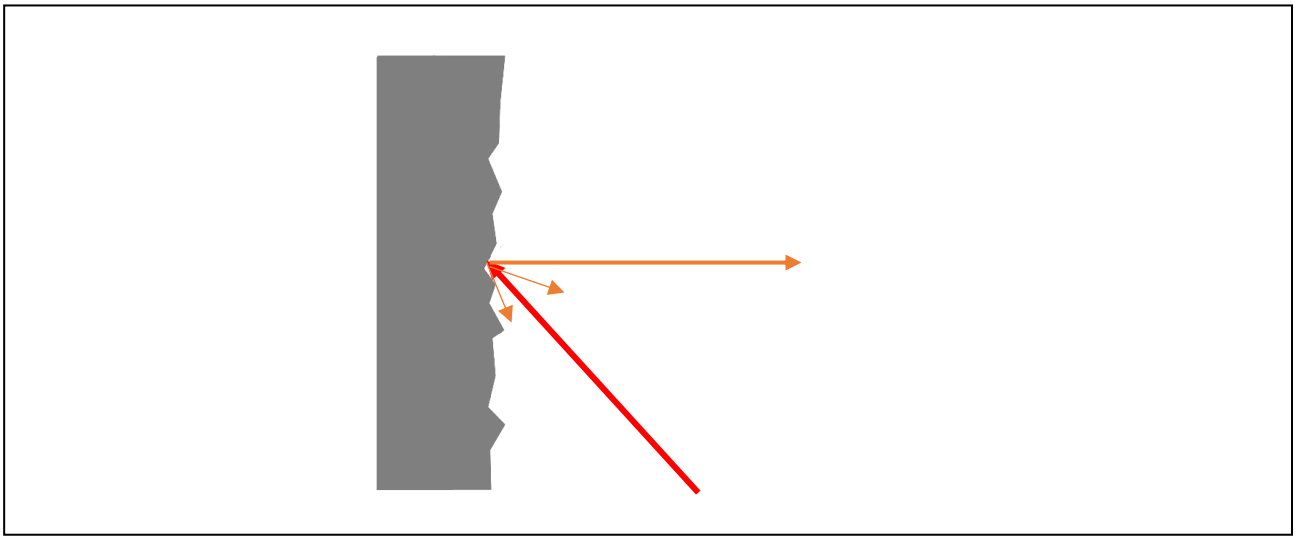


Figure 20 Reflection angle

The reflection angle is the same as the angle of incidence. If the laser beam is incident perpendicularly on a surface, the energy is optimally reflected (*Figure 20 Reflection angle*). If the beam is incident at an angle, a corresponding energy and detecting range loss is incurred.

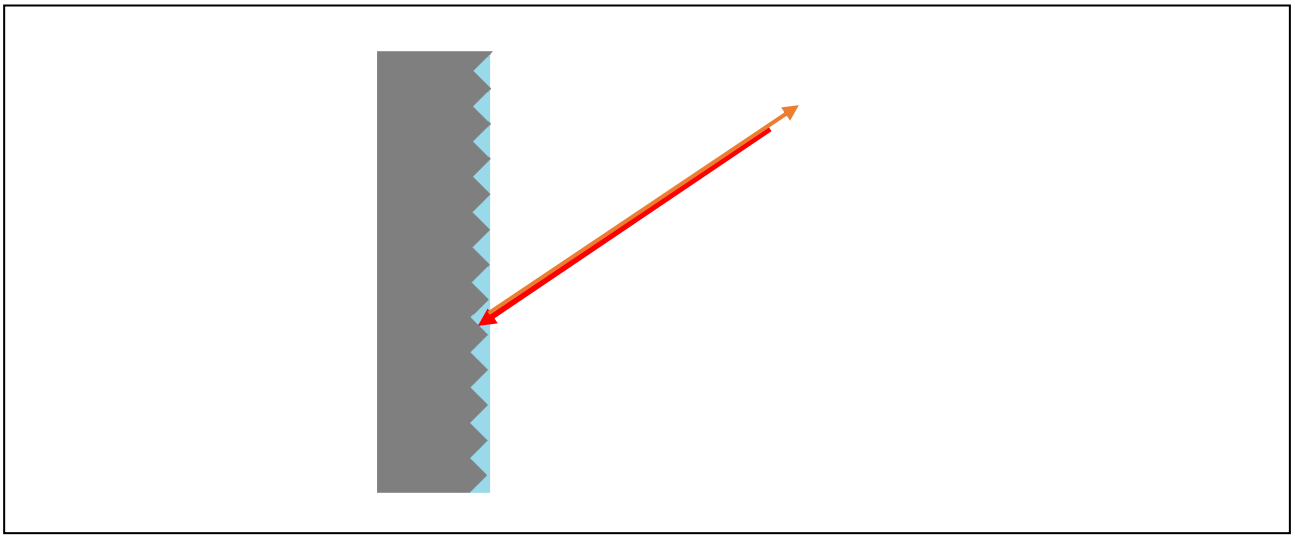


Figure 21 Degree of reflection

If the reflected energy returned is over 100% (basis: Kodak standard) the incident beam is not reflected diffusely in all directions, but is reflected in a specific direction. As a result, a large portion of the energy emitted can be received by the laser distance measurement

device. Plastic reflectors (“cats’ eyes”), reflective tape and triple prisms have these properties.

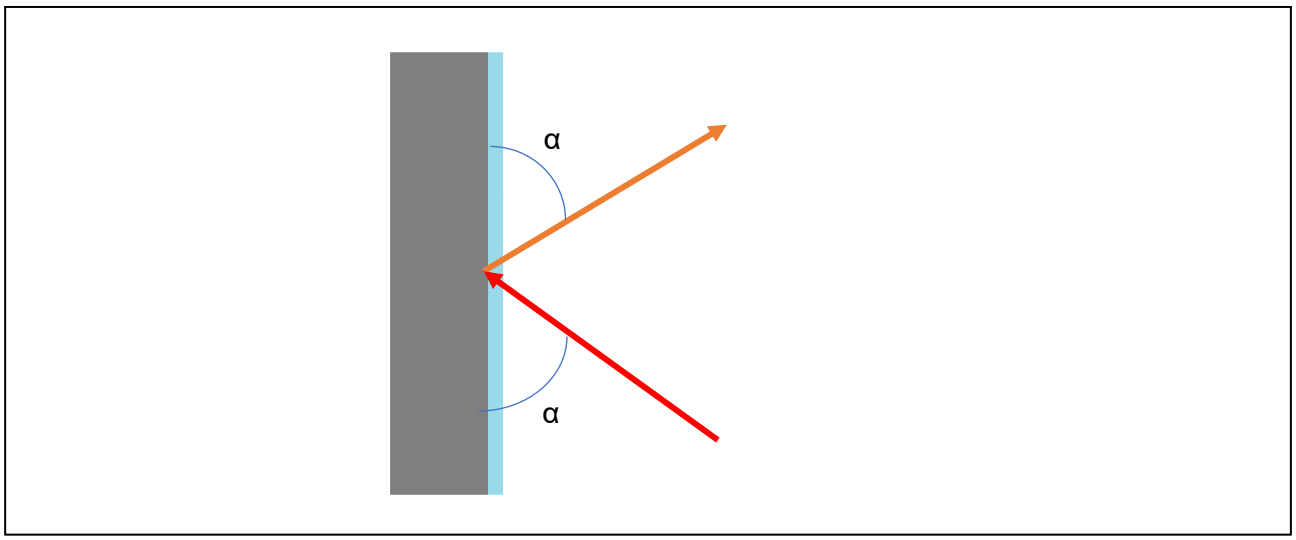


Figure 22 Mirror surfaces

At mirror surfaces the laser beam is almost entirely deflected (*Figure 22 Mirror surfaces*). Instead of the surface of the mirror, it is possible that the object on which the deflected laser beam is incident may be detected.

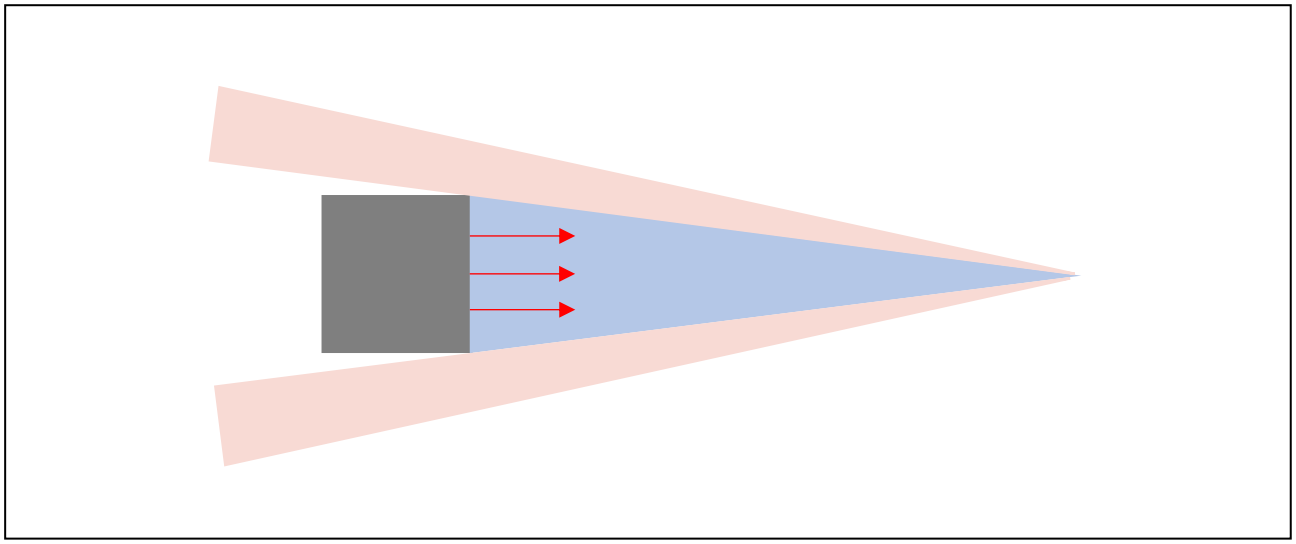


Figure 23 Object smaller than diameter of the laser beam

Objects that are smaller than the diameter of the laser beam cannot reflect all the energy of the laser light (*Figure 23 Object smaller than diameter of the laser beam*). The energy in the portion of the laser light that is not reflected is lost. This means that the detecting range is less than would be possible theoretically based on the surface of the object.

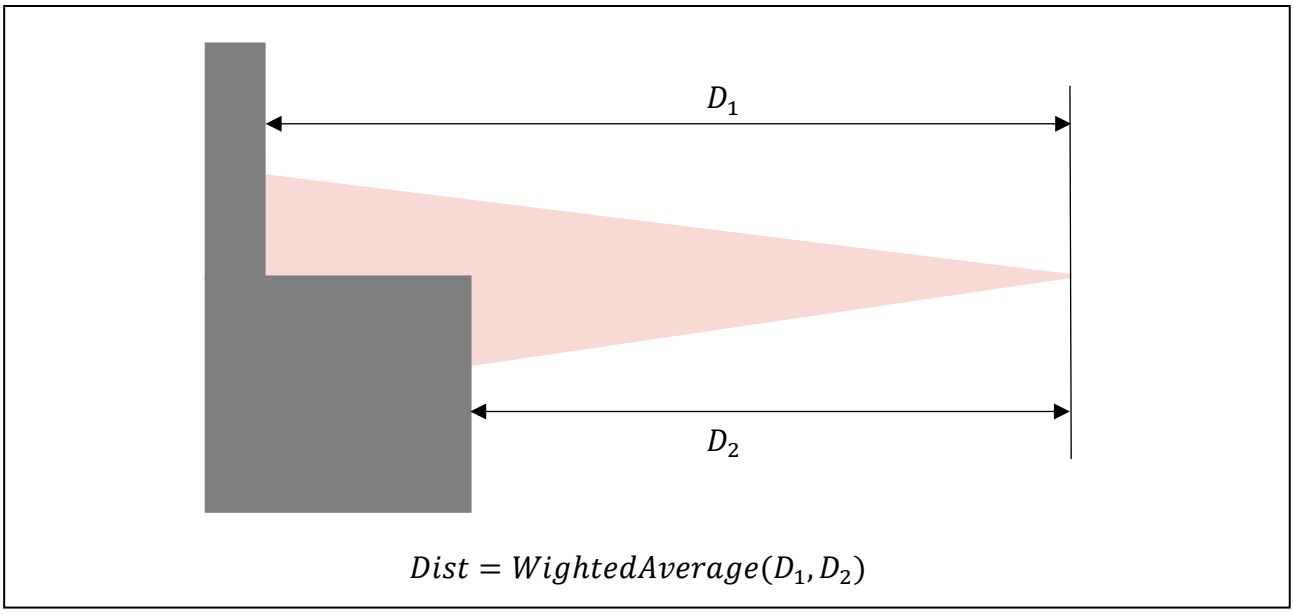


Figure 24 Staircase object

Staircase objects have two or more planes (*Figure 24 Staircase object*). The energy in the portion of the laser light that is reflected by different plane is different. TF03 will calculate a weighted averaging energy. The measured value will possible theoretically be the weighted average of distances from TF03 to different platform.

8 TROUBLESHOOTING

NOTICE

Claims under the warranty rendered void!

The housing screws of the TF03 are sealed. Claims under the warranty against Benewake will be rendered void if the seals are damaged or the device opened. s

This chapter describes how to identify and rectify errors and malfunctions during the operation of TF03.

Table 11 Troubleshooting and rectification

Fault	Possible cause	Solution
Measurement exceeds the allowed error.	● Optical signal was blocked.	➢ Remove the obstacle or adjust the detecting direction.
	● The target is a low reflectivity object.	➢ Paste a reflector on target object.
Measurements in the near range with no	● Protective film has not been removed.	➢ Remove the protective film.

measurement target.	● Contaminated or scratched window.	➢ Carefully clean optics using soft, fluff-free cloth. ➢ If the optics are scratched, contact Benewake service.
	● Rain or fog	➢ Enable rain-fog filter
TF03 is not transmitting a measured result.	● Wiring fault in the data connection.	➢ Check wiring.
	● Wrong USB converter.	➢ Check USB converter.
Data transmitted is garbage.	● Baud rate mismatch.	➢ Check baud rate of the receiving device. ➢ Check TF03's baud rate setting.
A certain target cannot be detected	● The target is too small.	➢ Replace it with a larger target.
	● The target is a low-reflectivity object.	➢ Put a sticker of high reflectivity on target object.

ATTACHMENT 1: REFLECTIVITY OF DIFFERENT MATERIALS

The reflectivity of different materials is listed below, ranging from low to high. According to the test target and the corresponding reflectivity, we can measure whether the range of TF03 and other parameters meet the requirements.

No.	Materials	Reflectivity
1	black foam rubber	2.4%
2	black cloth	3%
3	black rubber	4%
4	Coal (varies from coal to coal)	4~8%
5	Black car paint	5%
6	Black paper	10%
7	opaque black plastic	14%
8	Clean rough board	20%
9	newspapers	55%
10	translucent plastic bottles	62%
11	packing case cardboard	68%
12	Clean pine	70%
13	opaque white plastic	87%
14	white card	90%
15	Kodak standard whiteboard	100%
16	Unpolished white metal surface	130%
17	Shiny light metal surface	150%
18	stainless steel	200%
19	Reflective board, reflective adhesive tape	>300%