A Remote-controlled Robot-car in the TPS Tunnel

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**Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV)</td>
<td>3</td>
</tr>
<tr>
<td>Current (mA)</td>
<td>500</td>
</tr>
<tr>
<td>Circumference (m)</td>
<td>518.4</td>
</tr>
<tr>
<td>Straight section (m)</td>
<td>18 x 7 + 6 x 12</td>
</tr>
<tr>
<td>Bare lattice emittance (nm-rad)</td>
<td>1.6</td>
</tr>
<tr>
<td>Betatron tune (νₓ/νᵧ)</td>
<td>DMB 26.14/13.24</td>
</tr>
<tr>
<td>Natural chromaticity ξₓ/ξᵧ</td>
<td>-75/-26</td>
</tr>
<tr>
<td>Periodicity</td>
<td>6</td>
</tr>
<tr>
<td>Bending radius (m)</td>
<td>8.40338</td>
</tr>
<tr>
<td>Natural energy spread</td>
<td>8.86 x 10⁻⁴</td>
</tr>
<tr>
<td>Momentum compaction α₁/α₂</td>
<td>2.4x10⁻⁴/2.1x10⁻³</td>
</tr>
<tr>
<td>Revolution frequency (kHz)</td>
<td>578.3</td>
</tr>
<tr>
<td>RF frequency (MHz)</td>
<td>499.654</td>
</tr>
<tr>
<td>Harmonic number</td>
<td>864</td>
</tr>
<tr>
<td>Synchrotron tune</td>
<td>0.00609</td>
</tr>
<tr>
<td>Bunch length (mm)</td>
<td>2.86</td>
</tr>
</tbody>
</table>

**Milestone**

1. Oct. 2013 Accelerator installation
2. 31 Dec. 2014 Stored beam and first light in storage ring
3. Dec. 2015 Achieved 520 mA stored beam
4. May 2016 300 mA top-up operation
5. Sep. 2016 Opened to general users
6. Nov. 2017 Started 400 mA operation
7. Jan. 2019 Approval for 500 mA operation

Oct. 2019 Start 500 mA operation
What is it like inside the tunnel during normal operation?
**SPECIFICATIONS**

**TurtleBot3 Waffle Pi**

<table>
<thead>
<tr>
<th>Maximum translational velocity</th>
<th>0.26 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum rotational velocity</td>
<td>1.82 rad/s (104.27 deg/s)</td>
</tr>
<tr>
<td>Maximum payload</td>
<td>30kg</td>
</tr>
<tr>
<td>Size (L x W x H)</td>
<td>281mm x 306mm x 141mm</td>
</tr>
<tr>
<td>Weight (+ SBC + Battery + Sensors)</td>
<td>1.8kg</td>
</tr>
<tr>
<td>Threshold of climbing</td>
<td>10 mm or lower</td>
</tr>
<tr>
<td>SBC (Single Board Computers)</td>
<td>Raspberry Pi 3 Model B and B+</td>
</tr>
<tr>
<td>Actuator</td>
<td>Dynamixel XM430-W210</td>
</tr>
<tr>
<td>LDS(Laser Distance Sensor)</td>
<td>360 Laser Distance Sensor LDS-01</td>
</tr>
<tr>
<td>Camera</td>
<td>Raspberry Pi Camera Module v2.1</td>
</tr>
<tr>
<td>IMU</td>
<td>Gyroscope 3 Axis, Accelerometer 3 Axis, Magnetometer 3 Axis</td>
</tr>
<tr>
<td>Power connectors</td>
<td>3.3V / 800mA, 5V / 4A, 12V / 1A</td>
</tr>
<tr>
<td>Battery</td>
<td>Lithium polymer 11.1V 1800mAh / 19.98Wh 5C</td>
</tr>
</tbody>
</table>

Robot Operating System

**WORLD’S MOST POPULAR ROS PLATFORM**
TurtleBot is the world’s most popular open source robot for education and research.

**AFFORDABLE COST**
TurtleBot is the most affordable platform for education and prototype research & developments.

**SMALL SIZE**
Imagine the TurtleBot in your backpack and bring it anywhere.

**EXTENSIBILITY**
Extend ideas beyond imagination with various SBC, sensor, motor and flexible structure.

**MODULAR ACTUATOR**
Easy to assemble, maintain, replace and reconfigure.

**OPEN SOURCE SOFTWARE**
Variety of open source software for the user. You can modify downloaded source code and share it with your friends.

**OPEN SOURCE HARDWARE**
Schematics, PCB Gerber, BOM and 3D CAD data are fully opened to the user.

**STRONG SENSOR LINEUPS**
8MP Camera, Enhanced 360° LiDAR, 9-Axis Inertial Measurement Unit and precise encoder for your robot.

BASIC OPERATIONS

ROS_MASTER_URI = http://IP_OF_REMOTE_PC:11311
ROS_HOSTNAME = IP_OF_TURTLEBOT

ROS_MASTER_URI = http://IP_OF_REMOTE_PC:11311
ROS_HOSTNAME = IP_OF_REMOTE_PC

* Example when ROS Master is running on the Remote PC

BASIC OPERATIONS

Keyboard
Interactive Markers
Point Operation
Where is the robot?
POSITIONING

◆ GPS
◆ Indoor Positioning Sensor
  • Landmark (color, IR camera)
  • Indoor GPS
  • WiFi SLAM
  • Beacon
◆ Guide tape/wire

Where is the robot?
Simultaneous Localizaton And Mapping (SLAM)

◆ **Position:** estimating the robot’s position
  ● Dead reckoning
    • Using the encoder values of both wheel axes
    • Calculate moving distance and moving angle, and then estimate position
    • Floor slip, mechanical, cumulative errors
    • Position compensation with inertial sensor such as IMU
    • Particle filter, Kalman filter

◆ **Sensing:** measuring obstacles
  ● LiDar

◆ **Map:** building map with road and obstacles information
  ● Gmapping, Cartographer, Hector Mapping

*https://github.com/ROBOTIS-GIT/ros_seminar/blob/master/11_SLAM_and_Navigation.pdf*
Dynamic Window Approach

- The search space is restricted to safe circular trajectories that can be reached within a short time interval and are free from collisions.
- The optimization goal is to select a heading and velocity that brings the robot to the goal with the maximum clearance from any obstacle.


**Fig:** Robot’s velocity search space and dynamixel window

\( v \): Translational velocity (meter/sec)
\( \omega \): Rotational velocity (radian/sec)
\( V_s \): Maximum velocity area
\( V_a \): Permissible velocity area
\( V_c \): Current velocity
\( V_r \): Speed area in Dynamic Window
\( a_{max} \): Maximum acceleration / deceleration rate

Objective function:

\[
G(v, \omega) = \sigma \cdot (\alpha \cdot \text{heading}(v, \omega) + \beta \cdot \text{dist}(v, \omega) + 
\gamma \cdot \text{velocity}(v, \omega))
\]

* \( v \): Translational velocity (meter/sec)
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BEFORE INSERTING THE ROBOT INTO THE TUNNEL...

**Height**
- The base plane for the electron orbit is **1350mm** from floor level.
- Three more layers, separated by a 300mm space, were added to gain the final robot height of **1100mm**.

**Power**
- The 1800mAh Li-Po battery was replaced with three batteries in parallel for a total of **16000mAh**.
- **wireless charging module**

<table>
<thead>
<tr>
<th></th>
<th>XKT801-29</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output (volt)</td>
<td>12v</td>
<td>5v/9v</td>
</tr>
<tr>
<td>Power (watt)</td>
<td>40w</td>
<td>&lt;10w(5w)</td>
</tr>
<tr>
<td>Charging distance</td>
<td>~5cm</td>
<td>&lt;4cm (5mm)</td>
</tr>
</tbody>
</table>

**Sensors**
- **FLiR Dev Kit**
  - LWIR sensor, wavelength 8 to 14 μm
  - 51-deg HFOV, 63.5-deg diagonal
  - 80 (h) × 60 (v) active pixels
  - Thermal sensitivity <50 mK
  - MIPI and SPI video interfaces
  - Two-wire I2C-like serial-control interface
  - Fast time to image (< 0.5 sec)
  - Low operating power, nominally 150 mW (< 160 mW over full temperature range)
RESULTS
Virtual Reality
RESULTS

thermal images at 405mA stored beam

A strip line kicker

A flange

A flange and bellow

A quadrupole magnet
RESULTS

thermal images at 405mA stored beam

IU downstream BPM
• Robot arms
• Radiation detectors
• Imaging recognition
• Auto-parking
• Other sensors...

PhotonBot

1. Combines a variety of technologies such as a robot system, internet of things (IoT), wireless charging, VR and self-driving (SLAM, navigation and imaging recognition).

2. Quickly adapt to most environment, no infrastructure needed.

3. Based on open-source hardware and software, which offers a relatively cheap platform for development and integration.

4. The possibilities are endless.
THANK YOU

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