Designing for FTC with TETRIX
Hints and Tips

Presented by:
Team Unlimited, FTC0001
ftc0001.org

We acknowledge the efforts and copyrights of FIRST, LEGO Education and LEGO with regards to the contents of this workshop. Without their generosity, the FIRST Tech Challenge would not exist!
Outline

- Introduction
- The TETRIX System - designing & building
  - Documentation - notes, diagrams, photos, website
  - Design process - for autonomous and operator control
  - Chassis design - drive-train and drivability
  - Tools for TETRIX & FTC
  - Manipulator design - suitability to the task
  - CAD - for design and documentation
  - Mindstorms NXT microcontroller & sensors
  - Coding environments
- Resources and Summary

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Goal

- To expand on the basics of how to build a robot
- Using the TETRIX System
- For use in the FIRST Tech Challenge

To contact Team Unlimited:

website [ftc0001.org](mailto:ftc0001.org)  
email [syraweb@comcast.net](mailto:syraweb@comcast.net)
Challenges past . . .
Tasks in competition (so far) . . .

- Climb a step or ramp
- Hang from a bar
- Pickup and place objects, from/to various positions
  - From floor level to far above robot starting height
  - Small to large, light to heavy
  - Objects - balls (small to large), rings, batons, pucks . . .
- Move structures to various locations on field
- End with robot at a designated location
- Have team member perform tasks
- Have the robot “shoot” balls
- Balance the robot
Our current challenge - Block Party!
Challenge current . . .
2013-14 FTC Block Party!

- Blue alliance vs. red alliance (2 robots each)
- 100 plastic cubes as scoring objects
- Autonomous - 30 seconds
  - Score a pre-loaded block into floor or pendulum goals (bonus for IR beacon marked goal) and/or park on bridge
- Operator-control - 120 seconds
  - Score blocks into floor or pendulum goals (only 4 at once)
  - During last 30 seconds, can raise alliance flag and hang from bridge pull-up bar
  - Bonus for balanced pendulum goals
Pay attention to the rules!

- The Game Manual (and other documents) is your FTC bible!
- Important new rulings and clarifications are posted at the official FTC forum (supersedes the Game Manual)
- The Head Inspector and Head Referee are the final authority at competitions - no appeal will change results

These sources determine the rules of the game, and the allowable content of your robot - all else is speculation

- Post forum questions only after you have determined that the info is not already available
- Bound single notebook
- All entries in pen, from each team member
- Each session dated and initialed
- A working document, used continuously and consistently
- Never erase, everything has important, especially the things that didn’t work
  - Edison, 1000 ways not to, 1% inspiration
- Key part of judging at Championships
  - Label key pages w/sticky notes to highlight
- We like the BookFactory.org oversize lab notebooks
  - Big enough for full page inserts, expandable bindings
  - One for engineering activities, one for other activities
Having a designated notebook coordinator helps
Leave space to insert photos and diagrams
  - Illustrations can clarify more quickly than words
  - Photos of white board during brainstorming
Drawings - hand diagrams are valuable in design stages
Use of CAD software for design & documentation
  - PTC Creo/Pro for 3D CAD
  - Alternate - we have used Visio & Maya as well
  - Paste pages into place in notebook
Photography - digital more convenient
  - Natural for capturing stages of development
  - Also document other team activities

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- On-line collaboration
  - Use tools like PTC Windchill and Dropbox to coordinate
  - E-documents, printed and assembled into final notebook
  - Print or paste photos
  - Transparent page sleeves can keep it neat
Safety glasses are NOT forehead protectors
Power tools REQUIRE training and supervision
Parts need to be finished - no ragged/sharp edges
Safe environment - neat, no obstacles
Proper attire - footwear, anything long and loose
First Aid kit at hand
Remove power BEFORE working on a robot
  - Kill switch, battery disconnection, release mechanical tensioning
Design & Build - TETRIX System
Origins of the TETRIX System

- Intended as an enhanced platform for the FIRST Tech Challenge
  - Replaced the Vex Robotic Development System
- LEGO Education (Pitsco) integrates the system
  - Supplies technological education systems to schools
  - Represents LEGO to educational markets
- Components available at a 30% discount to FTC teams

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Design & Build - TETRIX System
FTC Competition Kit

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**TETRIX® Education Base Set**, which includes:
- Brackets and mounts
- Structural channel and plates
- Structural tubing and hubs
- Wheels and gears and omniwheels
- Battery pack and charger
- Hard Point Connectors for attaching TETRIX elements to LEGO Technic elements
- Servos, DC motors, and associated HiTechnic controllers
- Fasteners and tools
- Storage bin
- NEW TETRIX Getting Started Printed Guide and DVD

**LEGO® MINDSTORMS® Education NXT Base Set**, which includes:
- *NXT Intelligent Brick*
- Rechargeable NXT battery and charger
- Servo motors, gears, LEGO Technic beams
- Storage bin
- Install CD & one-year FTC team license for *LabVIEW™* for LEGO MINDSTORMS
- Install CD & one-year team license for PTC Creo/Pro 3D CAD/CAM design s/w
- One Logitech joystick controller

$665 w/LEGO NXT kit, $450 w/o it, order at team registration

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Kit provides more than 40 useful TETRIX™ parts
Includes the larger gears and longer channel that are not included in the TETRIX Education Base Set.
Includes two additional DC motors and one Logitech joystick controller, and a sturdy plastic storage bin.

$199, order at team registration or at LEGO Education site

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Design & Build - TETRIX System
Samantha Wi-Fi for Operator Control

- 802.11b wireless-to-USB adapter for use with the LEGO Mindstorms NXT Brick and Tetrix in the FTC program.
- Connects through computer Wi-Fi adapter or Wi-Fi router/access point
- LED lights used for status monitoring and troubleshooting.

Study documentation carefully
- Critical - power and mounting
- Samostat diagnostic program
- Your robot won’t do well if out of communication

$85, order (only one) at team registration

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Design & Build - Alternate FTC Robotics Kit - Matrix

- New at the 2012-13 season
  - Now generally available
- Uses LEGO Mindstorms controller & Samantha
  - Alternate motors and controllers
  - Alternate aluminum building components
    - Holes spaced for LEGO bricks

- [http://matrixrobotics.com/](http://matrixrobotics.com/)

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Robot systems block diagram

- Chassis
- Computer (microcontroller)
- Motors
- Power
- Sensors
- Communications/control

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Design & Build - TETRIX System
Motor Systems

10-cell battery pack

HiTechnic Servo Controller

On/off switch

Servo

HiTechnic DC Motor Controller

DC Motor

1 2 3 4 5 6 7 8

NXT Intelligent Brick

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Design & Build - TETRIX System
Motor Systems

- NXT Microcontroller
- HiTechnic DC Motor Controller
- DC gearmotor(s)
- HiTechnic Servomotor Controller
- Servomotor(s)
- 10-cell 12 volt battery pack
- On/Off switch
- Interconnecting wires
Servomotor Controller - up to 6 individual servomotors

- Servo motor throw - 180°
- Chains from NXT/other motor controllers
DC motor controller - up to 4 DC motors (in pairs)
Connection pair for PID loop control
Chains from NXT/other motor controllers
Design & Build - TETRIX System
DC motor - direct drive

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Design & Build - TETRIX System
DC motor - direct drive

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Design & Build - TETRIG System
LEGO Motor Systems
Design & Build - TETRIX Chassis

Drive train

- Drive-train configuration
  - 2 or 4 motor drive (could be more, not usually)
  - 2, 4 or 6 wheel drive
  - Gearing for torque or speed, as well as power transmission
  - Gearing up for speed can stress gear motors, failures
  - Gearing or sprockets and chain to link motors together
- **TETRIX DC motors** - 152 rpm (full rotation), 300 oz-in. of torque
  - Gearing can adjusting speed/torque ratio
- Most drive designs use differential steering
  - “tank-style”
- **TETRIX Servomotors** rotate 180°, 76 oz-in of torque
  - Gearing to increase torque, decreases speed & throw-angle
- **TETRIX Continuous Rotation Servomotor** rotate full circle, NEW
- **LEGO motors** - 11 RPM (full rotation), 24 oz-in of torque
  - Connect only to LEGO axles

- Pairing motors increases overall drive-train torque
  - Software to control combined motors

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Design & Build - TETRIX System
Gears & wheels

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Design & Build - TETRIX System
Omni Wheels

- Allow for easy turns, holonomic designs
  - Rollers allow free motion perpendicular to the axis of wheel rotation

Exclusive use of omniwheels can result in a robot that is pushed around easily
Available gears - 40, 80 & 120 teeth in aluminum
- Also LEGO plastic

Gear trains
- Gears must space at fixed distances
  - Gear teeth counts (gear x/gear y) result in gearing ratios
  - Power losses at each gear intersection
  - Rotation direction inverted at even gears
- Multiple stages for large gearing ratio changes
Design & Build - TETRIX Chassis
Gears - Torque vs. Speed, Rotation

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TETRIX system enhancement in 2009/10

- 15, 24 and 32 tooth aluminum sprockets
- 5 feet of .250 inch steel chain
- 4 master links

Chain breaker to cut chain
Available sprockets - 15, 24 & 32 tooth

Chain & sprockets
- Works like a bicycle chain (connect a loop w/master link)
- Span any distance - two sprockets, one chain
- Tensioning important - don’t overdo tension
  - Can use idler to tension, under elastic tension, adjustable
- Sprocket teeth ratios work like gear ratios
• Spanning distances
  • One stage for chain (up to 95% efficient)
  • Multiple stages for gears (each stage up to 85% efficient)
• Adjustment of chain drive-train
  • Don’t under- or over-tighten
  • Chain tensioning w/idler sprocket
• Backlash and power loss in gear drive-trains
• Gears only in base TETRIX kit
• Redundancy & reliability
  • Dual chains - run in opposing directions
Design & Build - TETRIX System
Servo structural components

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Design & Build - TETRIX System
Structural metal and hardware

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Design & Build - TETRIX System

Outside Materials

- Sheet and bulk materials
  - New rules allow any materials, in any quantity
  - When using plastic or metal sheets, prototyping with cardboard or foam board saves money
  - Prototyping parts can be used as templates for permanent replacements

- Springs
  - Rubber bands and surgical tubing
  - No pre-formed metal springs
    - Spring materials are allowed now
    - For example: spring steel & piano wire
Major material rule changes for 2012-13
- More materials allowed, with few quantity limits
- Some pre-formed assemblies allowed

Raw materials allowed
- If not pre-processed into functional form, & if available from standard sources (McMaster-Carr, Home Depot, etc)

Some formed materials allowed
- Bearings, bushing, fasteners
- Rope, cord, cable, rubber bands, latex tubing
- Cable management products, non-slip pad (non-adhesive)

Miscellaneous materials allowed
- Lubricants, solder, tape, glue, zip ties (non-metallic)
Design & Build - TETRIX System
Outside Materials

- COTS (Commercial Off The Shelf) assemblies not allowed, with the exception of:
  - Linear slides
  - Non-motorized turntables
  - Lead screws & threaded rod, plus compatible
  - Servo blocks (ServoCity)
  - #25 chain & connector links
- Anderson Powerpole connectors and power distribution blocks (as one example)
  - More efficient and reliable DC power connections
Tetrix Resources

  - By the Pope John XXIII High School Regional Robotics Team
- [http://www.ftc0001.org/Resources.htm](http://www.ftc0001.org/Resources.htm)
- [http://ftcforum.usfirst.org/](http://ftcforum.usfirst.org/)
- [http://www.robotc.net/ftc/](http://www.robotc.net/ftc/)

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Design & Build - Tools Useful for building

- Wrenches and combination wrenches, vise grips
- Bondhus ball hex driver L-wrenches 10945
  - 7 pc, 5/64-3/16”, ball heads allow angle entry up to 15°, rather than just square to the bolt.
- Xcelite series 99 pieces:
  - Regular handle (99-1), stubby (99-3), ratcheting tee (99-4-R)
  - Slotted screwdriver 1/8" (99-125), 3/16" (99-811)
  - Phillips screwdriver #0 (99-820), #1 (99-821)
  - Allen 1/16" (99-21), 5/64" (99-22), 3/32" (99-23), 7/64" (99-764)
  - Driver 4" extension (99-X5)
Design & Build - Tools
Hex drivers for Tetrix

- Remember - righty, tighty; lefty, loosey
  - Helps to avoid damaging hex heads!
- 1/16" (4/64")
  - Axle collar and motor encoder set screws
- 5/64"
  - Button head cap screws
- 3/32" (6/64")
  - Axle and motor shaft hub set screws
- 7/64"
  - Socket head cap screws

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Design & Build - Tools
Useful for building

- Cutters and shapers
  - Hacksaws (regular & mini)
  - Aviation shears (straight)
  - Files (flat, for smoothing cut edge)
  - Reamer (for enlarging holes)
  - Electric hand drill, drill bits & driver bits
  - Electric sander & sandpaper
  - Electric jigsaw & blades

- Misc.
  - Tape Measure
  - Steel rulers
  - Vises
Design & Build - Tools Useful for building

- Handling additional materials
  - Bending polycarbonate - heat gun
  - Cutting polycarbonate - hacksaw, jigsaw
  - Bending sheet aluminum - bending brake, vise
  - Cutting sheet aluminum - aviation shears, nibbling tool

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Physical layout

- Chassis usually rectangular
  - Short wheelbase & wide body better for turns & side stability
  - Long wheelbase & narrow body better for front-back stability
  - Square chassis a compromise for both
Holonomic chassis

- Omniwheels on each corner (usually 3 or 4) driven by independent motors
- By mixing direction of rotation and power by software, can go in any direction without turning
- Tends to lack power and traction, fairly easily pushed
Characteristics of Champion Robots

- Reliability of robot
- Consistency of performance
- Rugged construction
- KISS (as much as possible)
- Good autonomous mode
- Large size
- Minimal LEGO components
- Simple 4 wheel, independent drive motors, ungeared
  - TETRIX tires have very good traction, long wheelbase will resist differential turning
Axles are best supported on both sides

- Brass axle bearings
- If supported on only one end, keep axle short
- Shaft collars lack stability when used alone
- Nylon spacers enhance stability

4 or 6 wheel configurations

- 6 wheel - shift mid wheels down slightly for better pivoting

Taller wheels climb steps better

- Extend wheels beyond chassis edge to improve climbing ability
• One 12 volt NiMH rechargeable battery pack, fused
  ▪ Order spare batteries

• Powers all the secondary non-LEGO systems

• Charge at lower rate only!

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- Must use NiMH battery packs during competitions
- Should use freshly-charged batteries to compete
- Extra charged battery packs are key
  - Label date put in service, tag charged/not charged
- Voltage draw-down can cause microcontroller to reset
  - Can restart in autonomous mode, no remote control
- More weight/more motors drain batteries more quickly
- Make sure that you obtain spare fuses (auto supply)
Design & Build - TETRIX Chassis
Examples from Team Unlimited robot

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Design & Build - TETRIX Chassis
Examples from Team Unlimited robot

Ganged and Geared servomotors
Design & Build - TETRIX Chassis
Examples from Team Unlimited robot

Lifting platform expanding beyond 18” cube

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- Create modular structures
  - left and right drive-trains mirror images
- Don’t maximize to 18” cube design early
  - Leave room for inevitable add-on pieces
  - Must fit in the inspection test box!
- Clearance
  - Game elements under your chassis can be disabling
  - Side guards and/or high clearance
- Defensive bumpers and guards
- CAD software is valuable for both design and documentation
  - PTC Creo/PRO (free from PTC!)
  - We have also used MS Visio and Autodesk MAYA
Design & Build - TETRIX Chassis
Structural design

- Gearing and power decisions
  - Balance speed v. torque
    - Increase speed by gearing up or adding motors
      - Limit gear ratio to 3:2, avoid motor damage
    - Increase torque by gearing down or adding motors
    - Middle ground, direct drive with a gear motor on each wheel

- Motor comparisons
  - Gearmotors are powerful, propulsion and heavy lifting
    - Use separate motor encoder as rotation sensor
  - Servomotors are less powerful but offer precise control
    - 180 degree throw (control angle) or continuous rotation (control speed)
  - LEGO motors are less powerful
    - NXT motor has integrated rotation sensor
Design & Build - TETRIX
Structural design

- Planning - what do you want to achieve and how will you achieve it?
- Design iteration
  - Brainstorm (what to build)
  - Design (how to build it)
  - Build it!
  - Test it!
  - Repeat until it’s perfect (or good enough)
- Trade-offs: Good, Quick, Cheap - pick two (at most)!
  - Quality - Schedule - Budget
- Order parts for final assembly with plenty of lead time
  - Rush shipped from LEGO Education is expensive!

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- Murphy’s Law (and its many corollaries)
  - Whatever can go wrong will go wrong, and at the worst possible time, in the worst possible way
    - Murphy was an optimist!

- Testing
  - Build at least a half-field if you don’t have regular access to a regulation field
  - Backup strategies - alternatives if mechanical failure or opposing alliance counters
  - Anticipate points of failure
  - Spares kit and tools close by in competition
  - Design for easy access - ease of repair
  - Build sparring robot and participate in scrimmages

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Trade-offs: Good, Quick, Cheap - pick two (at most)!
  - Quality - Schedule - Budget
Robot speed - quick on field v. precision motion
Robot complexity - simplicity v. capability
Think Defensively!
  - Protect vulnerable areas - contact sport
  - Guard wheel (and support both sides) - bumpers?
  - Protect all critical components while maintaining access
    - NXT, Samantha module, motor controllers, wires (through channels?), chains, switches . . .
Design & Build - TETRIX
Structural design

- Prototyping
  - Avoid cutting structural materials early on
  - Measure once, cut twice - it’s still too short!
  - Use simple sheet materials (cardboard, foamboard) to test concepts, can be used as a template later
- Keep important structures accessible for repair
- Do not use thread locker until design is stable
  - Locktite Blue, can be removed w/o heat application
- Replacement stainless steel screws are best!
- Nylox nuts are more secure
- Tape and glue are now legal
  - Team Duct Tape should be pleased!

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- Sensors v. dead reckoning in autonomous mode
  - Timed movement inherently inaccurate
  - Motor encoders more precise, for measured motion & turns
  - Gyro sensor can yield accurate turns
  - Line following can help navigation
  - Touch and ultrasonic sensors can indicate position

- Remember - 3 other robots are on the field, and movement of field elements is not always predictable!

- Driver teams need practice!
  - Second robot chassis for driver drills and sparring partner
- Robot that reach high, alter their center of gravity as they do
- Variable weights, variable angles of floor (ramp, step) and manipulator
- Aluminum components can reduce the manipulator weight
- If robot can turn over, useful to have a manipulator that can be used to right the robot
Design & Build - TETRIX Manipulators
Various designs

- Lifting mechanisms (can be combined)
  - Sliding/telescoping arms
  - Pivoting lever arms
  - Articulated arms
  - Converyer rollers/belts
  - Scissors lifts

- Grasping mechanisms
  - Claws/clamps
  - Scoops/baskets
  - Brushes
Design & Build - manipulators
Design criteria

- So far, challenges have manipulated balls, rings, pucks, batons . . .
  - Of various sizes (usually, larger is worth more)
  - To various heights (usually, higher is worth more)
- Also, lifting robot to bar (“hanging”)
- Critical issues - all interrelated
  - Center of Gravity (COG)
  - Moment arm
  - Length and height of reach
  - Load capacity
Design & Build - manipulators

Design options

- Pivoting arms
  - Multiple stages of gearing?
  - Counter-weights?
  - Tension (rubber bands, surgical tubing)?

- Lifts
  - Extension (slide/telescope)
  - Scissors

- Grippers (grabbing or gathering)
  - Plows/scoops
  - Conveyor belts (treads)
  - Grasping mechanism
Feel free to mine our archival pages for photos of previous competitions - thousands of photos of teams and robots from competitions back to the first FVC demonstration (spring 2005).

http://www.ftc0001.org/SeasonsPast.htm

In various seasons, competitions from MA, RI, CT, NJ, and close-up photos from 3 FTC World Championships

- Field competition from ring-side!
LEGO NXT Education kit is included with the full version of the FTC TETRIX competition kit
- Can use any non-electric LEGO components that are not specifically limited (including pneumatics), as many as you like

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Design & Build - LEGO sub-systems
Mindstorms NXT

- Motors
- Controller
- Sensors

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Special LEGO components allow for the mounting of LEGO components to the TETRIX metals

- NXT and motor controllers
- Beams, et al (especially for manipulators)
Robot systems - NXT Controller

- Sensor ports - four input ports to attach sensors - 1, 2, 3 & 4.
- Motor ports - 3 output ports to attach motors - A, B & C
- USB port - for code loading
- NXT Buttons
  Orange button: On/Enter /Run
  Light grey arrows: Used to move left & right in the NXT menu
  Dark grey button: Clear/Go back
- LEGO attachment points
- Loudspeaker

Specifications
- 32-bit ARM7 microcontroller
  256 Kbytes FLASH, 64 Kbytes RAM
- 8-bit AVR microcontroller
  4 Kbytes FLASH, 512 Byte RAM
- Bluetooth wireless (Class II V2.0)
- USB full speed port (12 Mbit/s)
- 4 input ports, 6-wire cable digital
- 3 output ports, 6-wire cable digital
- 100 x 64 pixel LCD graphical display
- Loudspeaker - 8 kHz sound quality.
- Power source: 6 AA batteries

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Your robot is able to move using up to 3 servo motors.

- Turning speed is from 100-170 rpm
- NXT servo motors have an integrated rotation sensor.
- Two motors can be synchronized so that your robot will move in a straight line.
Additional LEGO motors are now allowed

- Need adapter cables, no rotation sensor

“Philo’s Home Page”

- Includes a thorough comparison of LEGO motors
- Batteries are placed inside of the NXT microcontroller
- 6 AA cells or 1 Lithium Ion rechargeable battery
Robot systems - NXT sensors from LEGO

- Sensors are used to provide information about the environment to the microcontroller
- Provided by LEGO
  - light, color, touch, ultrasonic
- Provided by HiTechnic
  - Magnetic, gyro, accelerometer/tilt, IR seeker, angle
Robot systems - NXT sensors from HiTechnic

IR Seeker

Magnetic

Angle

Gyro

Acceleration

Tilt

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Robot systems - NXT sensors
Touch Sensor Multiplexor

- Allows the connection of up to 4 touch sensors to the multiplexor, and then to a single NXT sensor port
  - Only works with touch sensors!
Robot systems - NXT sensors
Sensor Multiplexor

- Allows the connection of up to 4 of any sensors to the multiplexor, and then to a single NXT sensor port
- Powered by separate battery pack
Rotation sensor

- Use to measure motion of robot
  - Critical for accurate dead reckoning
  - Built into motors
- Returns a logic signal to show rotation trigger
  - Senses above or below trigger point
  - Can read or reset values to zero
- Can return current rotation reading (degrees or turns)
The FIRST Tech Challenge

- Competition is what ties the program together
- Motivation!
  - Failure of robotics kits in the retail marketplace
  - For Inspiration and Recognition of Science and Technology
- Our opportunity is to help move this program forward!
  - Promote the program at every opportunity!
  - Make the benefits available to every interested high school student!
  - And . . . encourage them to be interested!

To contact Team Unlimited:
website ftc0001.org  email syraweb@comcast.net

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Designing for FTC with TETRIX
Hints and Tips

Questions?

ftc0001.org