Indoor Robotic Terrain Classification Via Angular Velocity Based Hierarchical Classifier Selection

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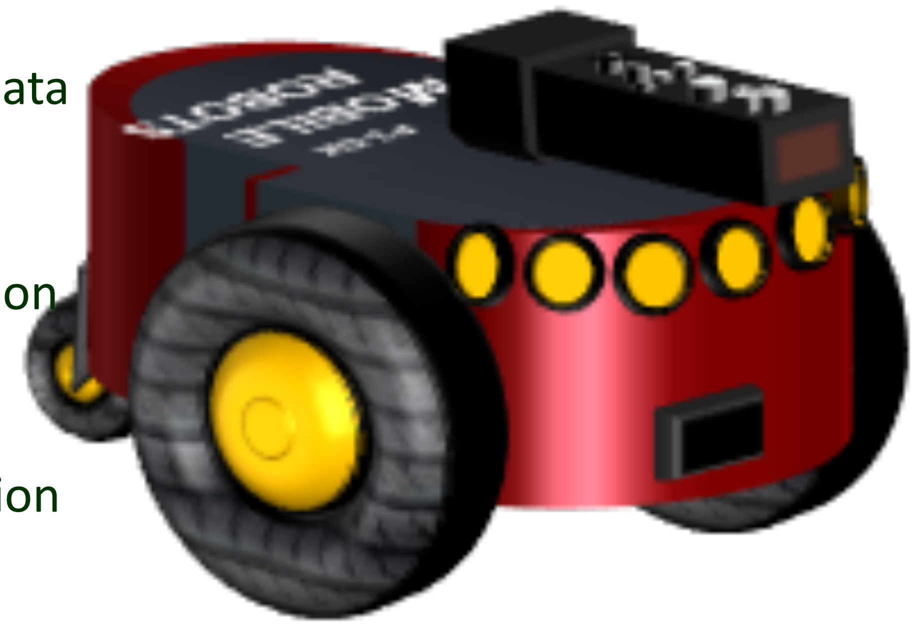
Robotic Terrain Classification (RTC) Problem

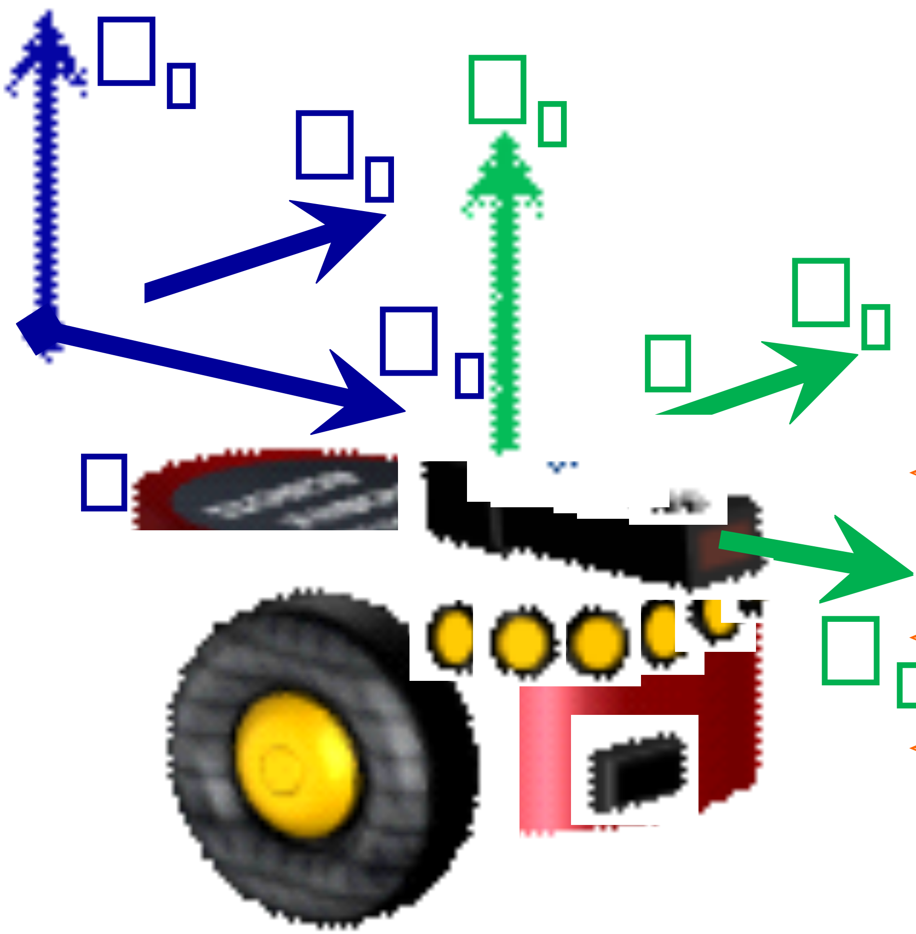
- Solving RTC motivated by localization problems.
- A mobile robot categorizes indoor terrain types simply by driving over them.
- Terrain classification is based on vibration data collected from a strap down inertial measurement unit.
- Sequential Forward Floating Feature Selection and a Hierarchical Linear Bayes Normal Classifier are used.
- Angular velocity of the robot during operation is used to dynamically switch between classifiers.
- Experimental results show 90% accuracy over twenty continuous minutes of driving across five different terrains while negotiating obstacles and human traffic.

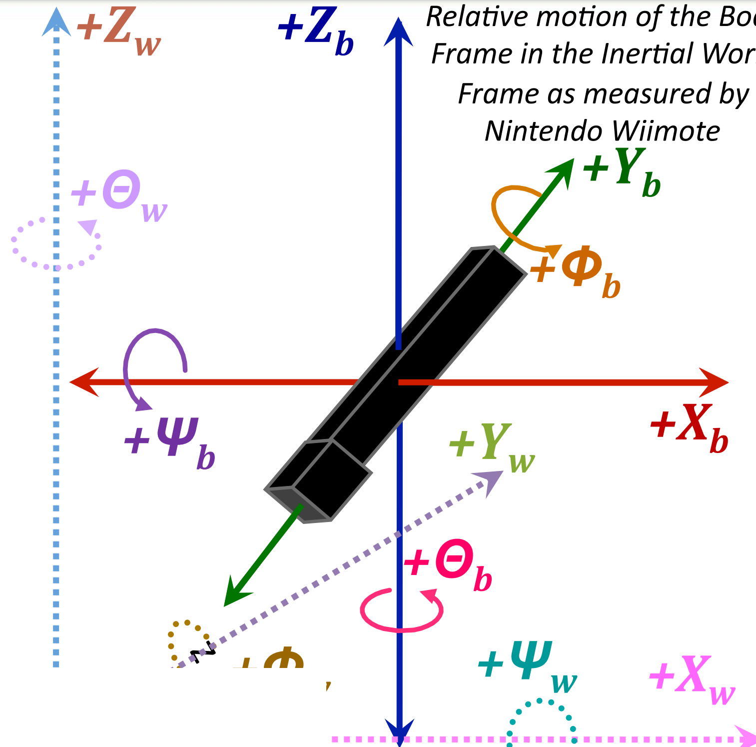


HALLEY: **P3-DX equipped with DIY Wiimote IMU ready for Robotic Terrain Classification**

System Setup

- ***HALLEY:*** (Adept) Mobile Robots Pioneer 3-DX, 2 wheel, differential drive robot (unicycle kinematics).
- Simple Kalman Filter (software) fuses measurements from optical wheel encoders with those from a single axis gyroscope to do dead reckoning localization.





- Nintendo Wiimote strapped down to the top of HALLEY's deck serves as 6-axis IMU.
- 3 Accelerometers measure linear acceleration.
- 3 Rate Gyros measure angular velocity.

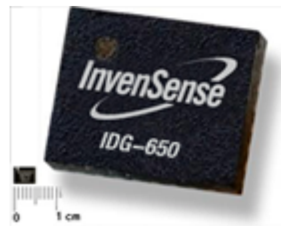
at 25Hz.

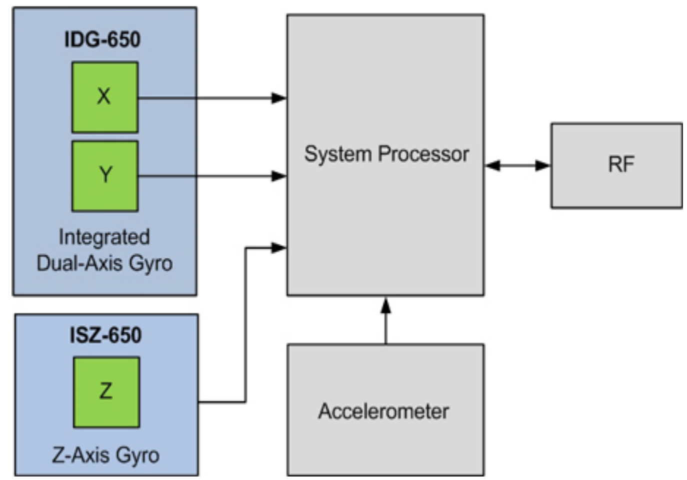
Inertial Measurement Unit

- **MEMS IMU:** Inertial Measurement Unit (IMU): An Integrated set of both rate–gyros and accelerometers that can detect movement on all 6 axes of linear & angular motion.
  - A Nintendo Wiimote provides us with a ***cheap ($50)*** MEMS IMU. But…
  - You get what you pay for: Rate gyros & accelerometers, have major ***Temporal Resolution*** issues…

Wiimote with Motion-Plus Accessory:

IDG-650 Integrated Dual-Axis Gyroscope:





ISZ-650 Integrated Dual-Axis Gyroscope:

ADXL330: 3-Axis ±3g iMEMS® Accelerometer:

http://wiiyourself.gl.tter.org/

Software is ***free***, and is actively being further developed/patched (good dev support).

- ***WiiYourself!***: Open-source, Cross-platform (Windows/Linux) C++ Wiimote Library

Feature Extraction

- **Six low level descriptors :** Linear acceleration and angular velocity along & about the X, Y & Z axes.
- **Functionals** : different measures of mean, moments, extremes, frequency spectrum, timing and duration, regression etc.
- **864 High level statistics.**

Selection Algorithm:

- **Starts with a empty set**
- **Loop start**
  - Create a new subset by adding a new feature
  - Eliminates features from the subset as long as performance does not decrease
- **End Loop**

Selected Features

Low level Descriptors	Functionals
acclx (19.12%)	de-skewness, de-amean, de-amean, de-qmean, de-nzamean, amean, absmean, kurtosis, max, iqr1-2, nzgmean, de-lpgain, left-ctime
accly (13.24%)	de-pctlrange0-1, amean, de-qmean, qmean, lpc2, variance, qregerrA, de-lpc1, de-qregc2
acclz (20.59%)	quartile1, maxameandist, peakMean, duration, risetime, kurtosis, variance, de-stddev, kurtosis, percentile99.0, linregerrA, de-iqr1-3, de-dct6, pctlrange0-1
gyrox (20.59%)	de-iqr1-2, qregc2, zcr, nnz, meanPeakDist, peakDistStddev, duration, qregerrA, quartile1, pctlrange0-1, de-lpc1, minPos, de-stddev, de-absmean
gyroy (13.24%)	de-pctlrange0-1, minameandist, dct5, qregerrA, qmean, de-absmean, nzgmean, lpc2, min
gyroz (13.24%)	quartile1,mcr, de-centroid, nzgmean, de-iqr2-3, lpc4, lpc3, de-falltime, de-downleveltime90

Hierarchical Linear Normal Bayesian Classifier

- **Bayes Rule:**

$$P(\theta_l|X) = \frac{p(X|\theta_l)P(\theta_l)}{p(X)}$$

- **Gaussian Distribution**

$$p(X|\theta_l) = \frac{1}{(2\pi)^{N/2}|\Sigma_l|^{1/2}} \times \exp\left\{-\frac{1}{2}(X-M_l)^T\Sigma_l^{-1}(X-M_l)\right\}$$

- **Maximization of A Posterori (MAP) Decision Rule:**

$$p(X|\theta_l)P(\theta_l) = \max_j\{p(X|\theta_j)P(\theta_j)\}$$

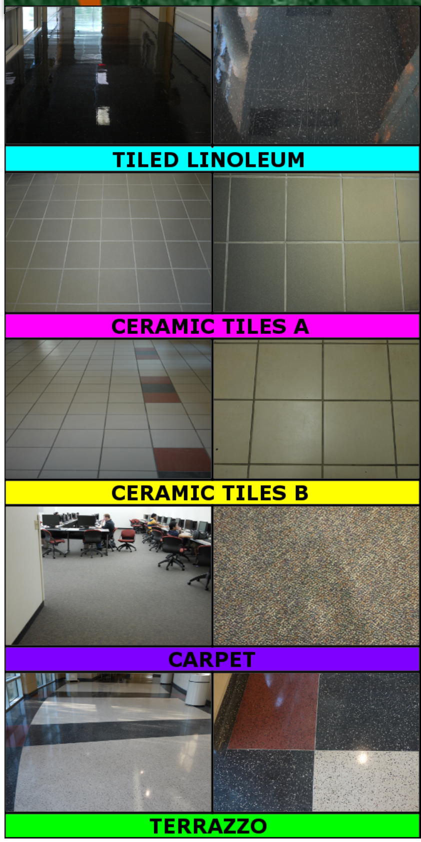
  - Minimizes error boundary
  - Estimates optimal boundary

Angular Velocity Based Classifier Switching

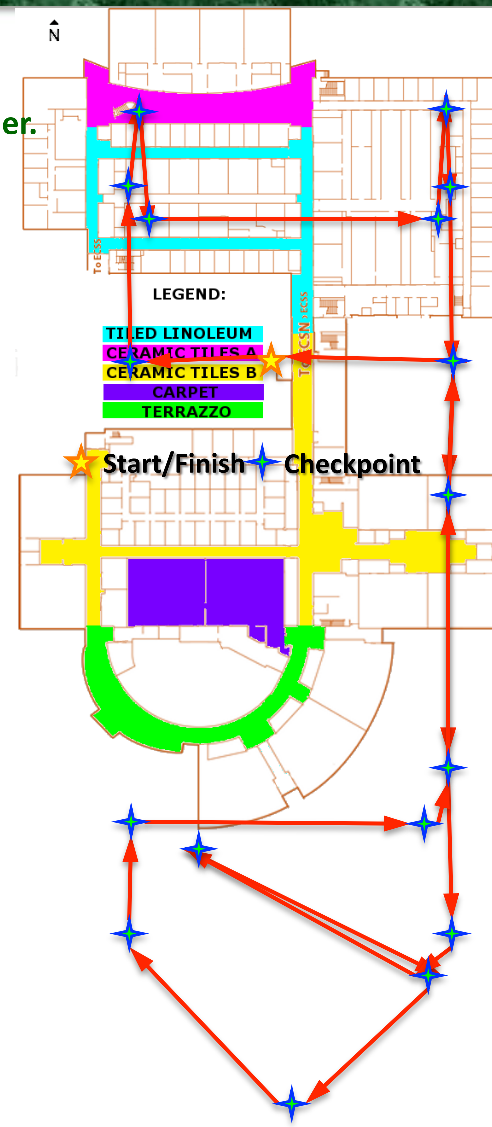
TABLE II: Training Results for Mode-based Classifier Models

Model	Train	Test	Accuracy %
A	STRAIGHT	STRAIGHT	90.69
B	CCW	CCW	93.16
C	CW	CW	92.54
D	STRAIGHT	CCW	57.45
E	STRAIGHT	CW	49.48
F	CCW	CW	31.22
G	CW	CCW	56.59
H	ALL	STRAIGHT	65.37
I	ALL	CCW	86.44
J	ALL	CW	67.65
K	ALL	ALL	74.37
L	ALL+Ang.vel	ALL+Ang.vel	80.65
M	Hierarchical	ALL	91.67

Experimental Test



- Two person team drives Halley around ECSC.
- Each check point is visited in order.
- Driver calls out check points as Halley arrives.
- Time keeper records time with stopwatch whenever a check point is called out.
- Test is conducted during midday while classes are in session so that the test environment matches near as possible that of an actual deployment scenario.
- Halley is kept moving at all times except when avoiding an obstacle or person requires stopping.
- Halley is required to visit all five terrain types before finishing.
- Halley is required to operate in all three modes (STRAIGHT, CW, and CCW) while on each terrain.
- Halley is required to label the terrain she is on at least once every second.



Experimental Results

TABLE III: Accuracy Results for Test Experiment

Terrain	TLin	CTA	CTB	Cpt	Trz	ALL
Accuracy %	93.03	82.93	89.21	88.29	89.08	89.65
Sample %	28.47	7.08	20.79	19.15	24.50	100.0

TABLE IV: Confusion Matrix for Test Experiment

	TLin	CTA	CTB	Cpt	Trz
Tiled Linoleum	307	2	2	10	9
Ceramic Tiles A	1	68	13	0	0
Ceramic Tiles B	1	24	215	0	1
Carpet	11	4	1	196	10
Terrazzo	16	2	2	11	253

TABLE V: Confusion Matrix with Merged CT Class

	TLin	CT	Cpt	Trz
Tiled Linoleum	307	4	10	9
Ceramic Tiles	2	320	0	1
Carpet	11	5	196	10
Terrazzo	16	4	11	253

TABLE VI: Accuracy Results with Merged CT Class

Terrain	TLin	CT	Cpt	Trz	ALL
Accuracy %	93.03	99.07	88.29	89.08	92.84
Sample %	28.47	27.87	19.15	24.50	100.0

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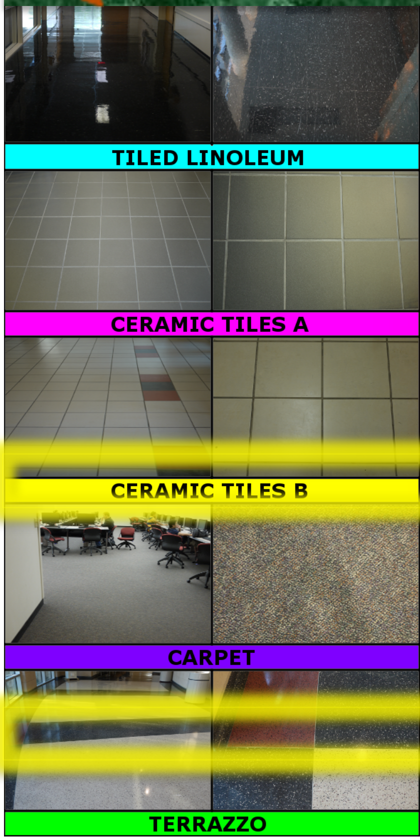
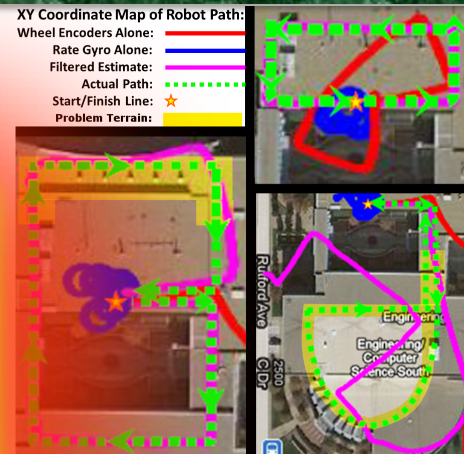
Future Work



Problem Terrains



- EKF localization fuses wheel encoders with a gyroscope.
- When on Tiled Linoleum the system performs very well.
- When on “Problem Terrains” the estimate drifts or pulls due to increased wheel slippage and vibration.
- This phenomena is consistent and reproducible.
- If the robot can tell when it’s traveling on “Problem Terrains” then it can compensate for or remove the drift/pull.
- Identifying the specific Terrain allows for localization corrections to be customized according to Terrain Class.

Thank You For Listening!

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http://dl.dropbox.com/u/20513147/ICRA2012.pptx

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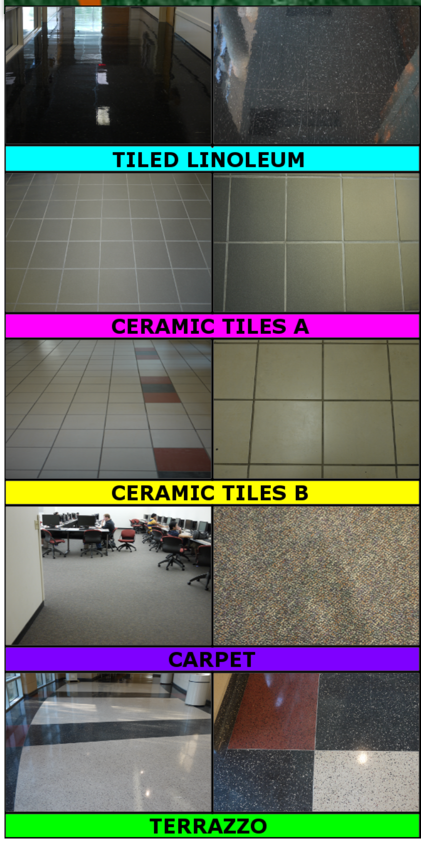
Experimental Test



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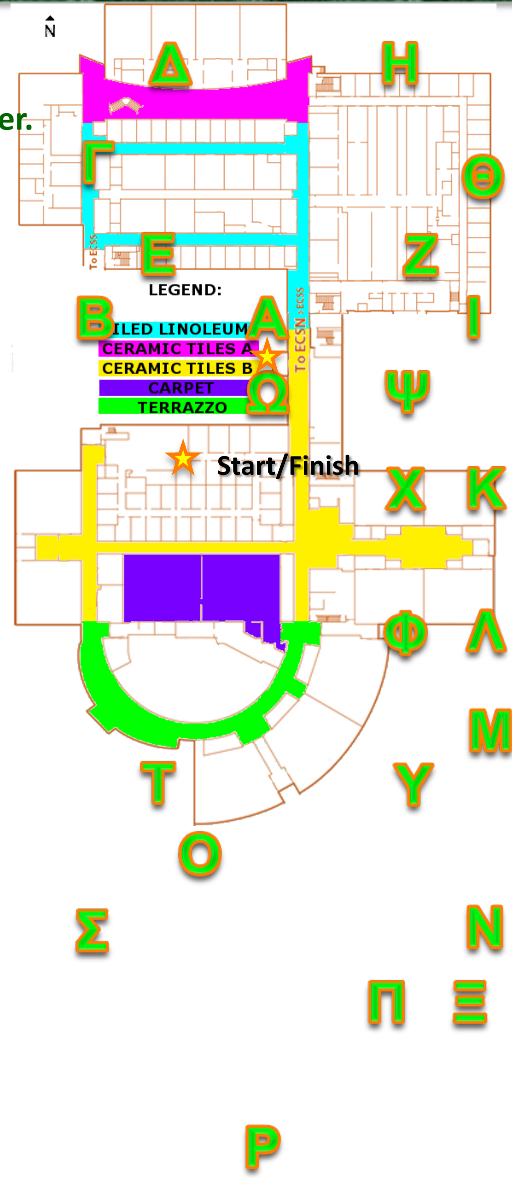

Scratch Space

ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦ
ΧΨΩ

ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩ

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Future Work

TeSLAM!!!