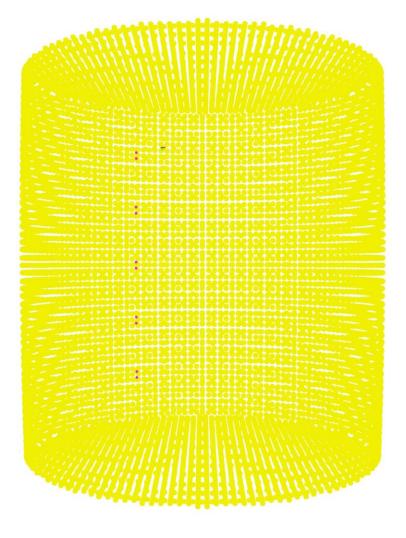
Aug 23, 2021

Feature Recognition and labelling for Photogrammetry Calibration of the Super-Kamiokande Detector

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Acknowdgements: Supervisor: Blair Jamieson Ali Ajmi





Introduction

Neutrino

- Subatomic particle, similar to an electron (but no electrical charge).
- One of the most abundant particles in the universe.
- Incredibly difficult to detect.

Standard Model of Elementary Particles

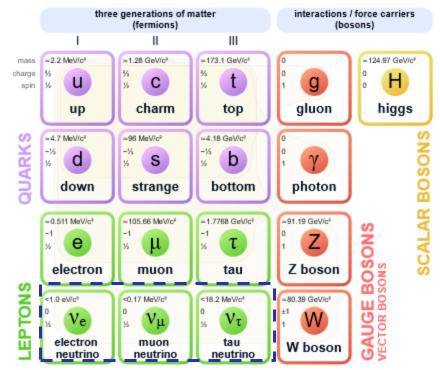


Fig: standard model[1]

How is neutrino detected?

Super Kamiokande (Super-K)

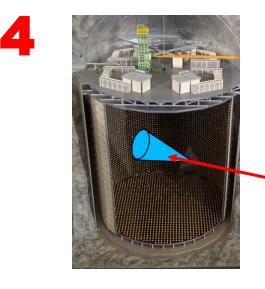


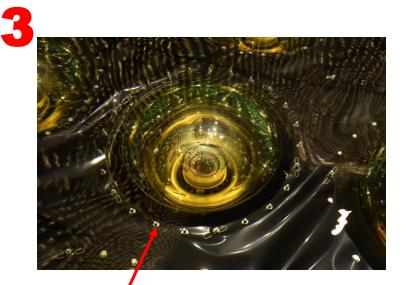
Fig: Model of Super-Kamiokande detector[2]

~11,000 PMTS



PMT[3]





Bolts for mounting PMT to wall.

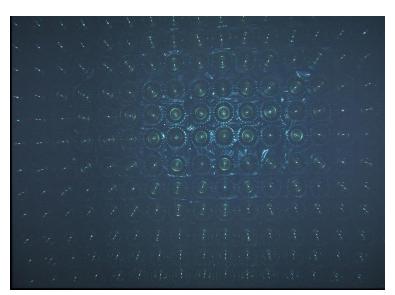
Cherenkov radiation

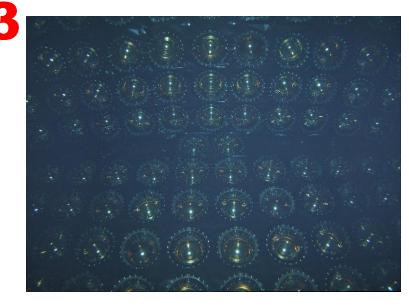
 Produced when charged particles move faster than speed of light in a medium(water).[2]

Photographing detector wall with Underwater drone



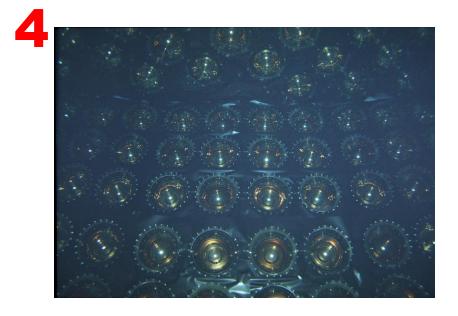
>15000 img





239.jpg

379.jpg



Need for automation?

• Over 15000 images.

Problem statement:

Feature detection:

• Want to identify pixel locations of bolts in an image.

Feature labelling:

• Identify each PMT in all images and assign a unique ID(identity/label) to each PMT.

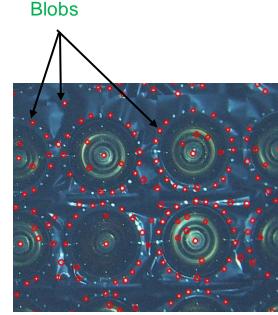
Ultimately: Find the geometry of entire detector / location of PMTs in the detector wall.

Method

1. Blob detection:

• To find bolts.

Blob: In computer vision, blob detection methods are aimed at detecting regions in a digital image that differ in properties, such as brightness or color, compared to surrounding regions.



2. Hough-Ellipse detection:

- Find ellipses in some range of size(minor axis) in the image.
- (Manually set First, but were able to automate.)

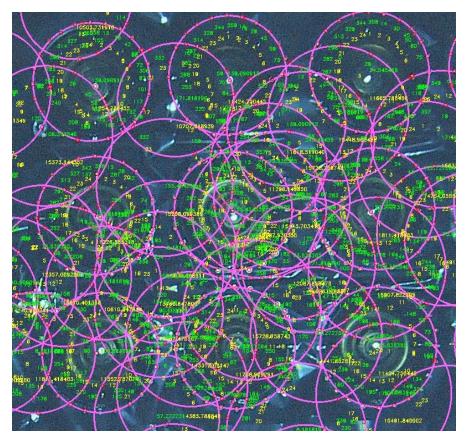


Fig: cropped image after ellipse detection

3. Remove false PMTs:

- Remove bolts that are not in 15-degree angle pattern from PMT center.
- Remove intersecting ellipse that has fewer number of bolts.

Gallery of Success

Barrel Far 010

Barrel Far 020

Barrel Far 100

Barrel Far 60

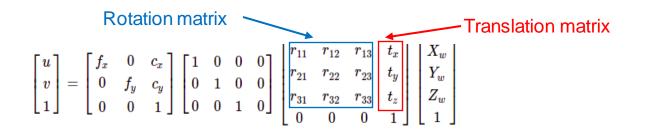
Feature labelling

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	1070	1 019	<mark>.968</mark>	. 917	866	8 15	.764	713	662	611	2 560	. 509	458	4 07	356	305	1 0	012 - 961	9 10	4 59	200			AN		and the		450	300	34.9	297	246
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																	105	5 •1004	953	902	as 1	ρ00 -	49 . 05	¹⁰ ¹⁰ 4	, <mark>\$</mark> 96	P 45	494	443	392	341	290	

Image Labelling approach.

- Use PMT coordinate from design.
- Perform R³ -> R² transformation.

(Using camera's transformation matrix.)

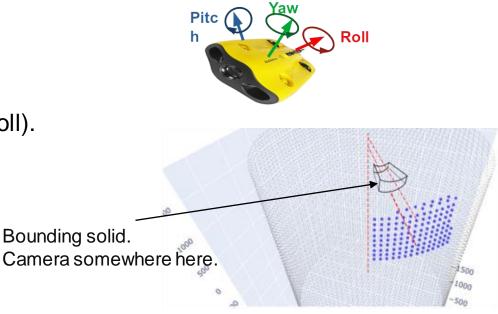


Knowns and unknowns

- Orientation is can be calculated from drone data(using yaw, pitch, roll).
- Drone position is unknown. Only Z coordinate known.
- **t**=-R***p** (**t**= translation vector, **p**=drone position)

ID	Х	у	Z	
00018-00	1690	2	- 569	
00019-00	1690	2	-491	
00020-00	1690	2	- 424	
00021-00	1690	2	-357	
00022-00	1690	2	-279	
00023-00	1690	2	-212	
00024-00	1690	2	-145	
00025-00	1690	2	-67	

Fig: location of all PMTs in detector wall (from design)



Pattern matching

Fig. Hough-ellipses

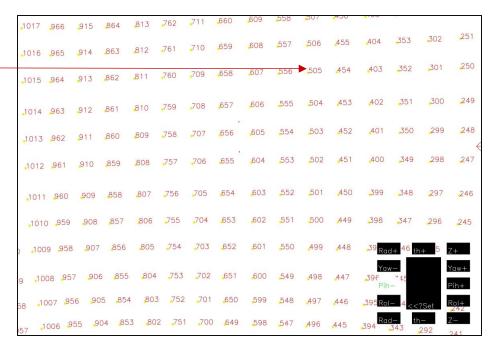


Fig. Perspective projected points

Fig. Cropped img

50

398

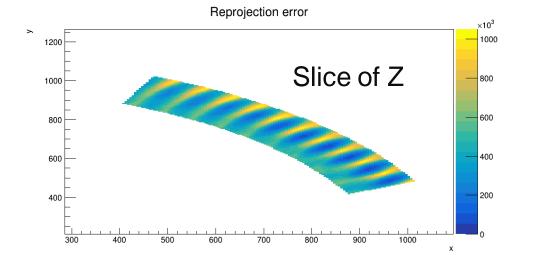
397

396

395

{A} = set of coordinates of all hough-ellipses. {B_j} = set of all reprojected points for specific camera position(j). d_{ij} = min distance between ith element of A and members of set B_j.

 $d_j = \Sigma d_{ij}$ (Find min d among all j)



650

Results:	238	865 814 763	712 661	610 559 508 457 ;	214 262 e11 86	0 809 758	707 656	.605 .554 . .30001	503 4 52		247
	066 915	.864 813 762	711 660	609 558 507 456		808 757	706 655	604 553	p02 ,+31		
2°44 457 906 855 804 753 702 851 644 497	.965 .914	863 812 761	710 659	608 557 506 455		a 807 .756	705 654	603 5 52	5 01 4 50	399 348	297 246
1007 956 905 854 803 802 1006 955 904 853 802 751 700 649 598 547 496	1015 964 913	.862 .811 (.760	709 658	507 555 305 A54	050 008 85	7 806 755	704 653	\$02 551	50.0 449	4 398 - 2 47	-290 -2+3
	062 912			(606 5554 9041 453) (_1009_958 907 B	6 8 05 (. 75	703 652		499 (0448	; 397 ; 346	-295 -244
1005 954 903 901 JKB2 1004 953 902 851 800 749 698 647 596 545 494 KB2	1012 962 911	860 809 758	707 656	20001 005 054 503 +452	ا ل 906 57 و _{م 1008 1}	55 ,8 04 , 75	3 702 \$51	600 5 49	498 447	3 96 3 45	294 243
,1003-952 901 850 799 748 697 645 595 644 4934	1012 961 910	859 808 757	7 706 655	30001 604 553 502 451	ه 905 و956 J007 و	54 , 803 , 78	2 701 650	5 99 548	4 97 4 46	3 95 3 44	293 242
1002-951 900 849 798 747 596 645 594 543 492				£03 £52 £01 ¥50	له ⁹⁰⁴ و 55 ⁹ و 006 لو	353 , 802 , 7	1 ,700 ,649	98 5 47	496 445	394 343	292 241
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9198 9100 9060 9019 8976 91 30 7 5 9139 9101 9051 9019 8977 7)∕⊈Q •51 , 900 ↓	849 7 98 747	696 645	594 543 492 441 ³¹	080 938 £87 £	36 7 85 7 3	40 608 64 4 683 632	7 896 845 2 581 530	479 428	, 120 y 1000	
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1068 1017 966 915 864 813 769 717 3660 609	997 946 ⁸⁹⁵	B44 793 742	59) <u>5</u> 40	689 638 487 436 3	_984 _933 _882 d	331 ,780 ,7	29 678 62	7 576 52	5 #74 #2	3 372 321	-270 -21
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Future work:

- Investigate the failure cases.
- Try to further constrain the camera location.
- Label the ring of the detector to reconstruct part of the detector.
- Label the whole detector.
- Perform pattern matching by scanning not only the camera position but also the camera orientation.

References

[1] "Standard model of elementary particles" by chriswalf, is licenced under <u>CC-BY-SA-3.0</u>

[2] <u>"スーパーカミオカンデタンク内公開 Super-Kamiokande insidetank"</u> by nvslive is licensed under <u>CC BY-NC</u> <u>2.0</u>

[3] "Photomultiplier Tube (PMT) at Kamioka SkyDome" by kawanet is licensed under CC BY 2.0

Backup slides

3. Hough-Ellipse detection:

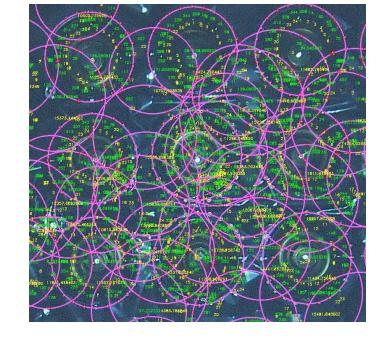
- Find ellipses in some range of size(minor axis) in the image.
- (Manually set First, but were able to automate.)

4. Remove false PMTs:

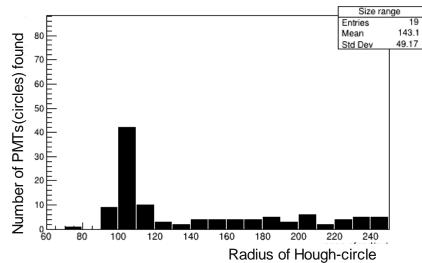
- Remove bolts that are not in 15-degree angle pattern from PMT center.
- Remove intersecting ellipse that has fewer number of bolts.



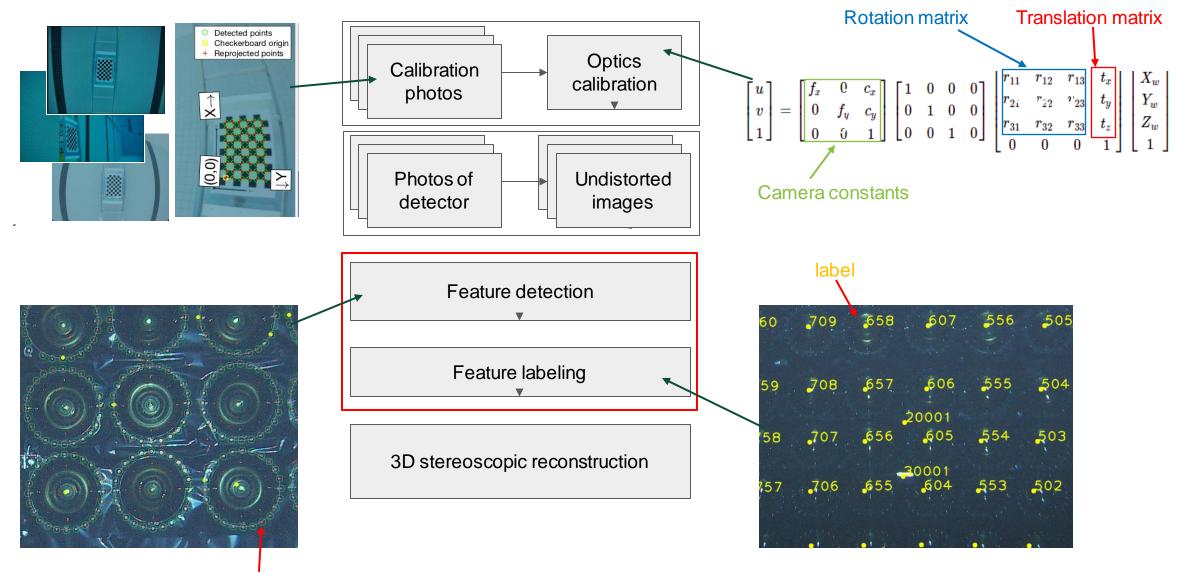
• To get the estimate of min and max radius of PMTs in the image.



Radius of Hough-Circle vs Number of PMTs found

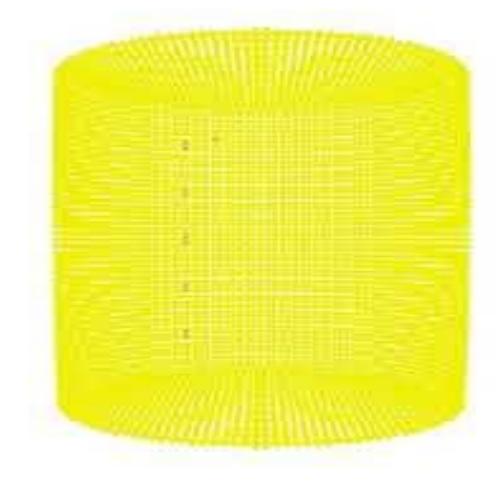


Overview of photogrammetry analysis



Feature(bolt)

Tool to visualize camera position and image of detector





Bounding the Unknowns

- Intended to point camera radially outwards.
 (Not true. So far noticed offset of up to 17⁰).
- Can estimate bound for radial position(cylindrical coordinate) using size of PMTs in image.
- Can estimate the angle made by r as Camera dir+-range(20 for now).
- Can estimate Z as z from drone data+-offset.



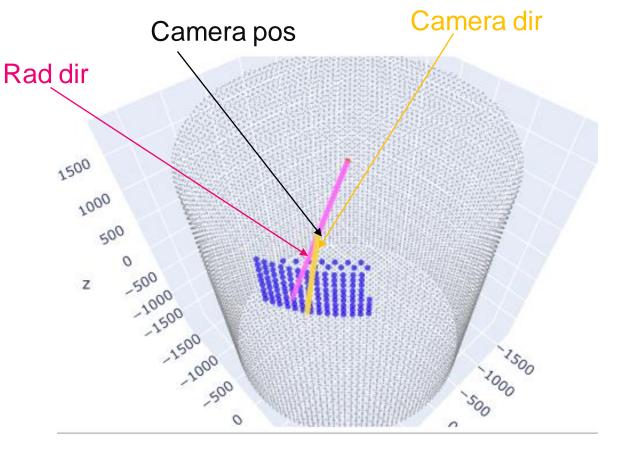


Fig: Detector. Showing radial direction, camera position, and direction camera is pointing.

18

Example of a Correctly labelled image

1017	966	<mark>.</mark> 915	864	813	/62					in in the second se			25.2	, 302	2 51
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	054	. 913	. 862	8 11	760	709	6 58	<mark>.</mark> 607	556	5 05	4 54	4 03	352	,301	250
1 015	9 64	¥13							E É É	504	4 53	4 02	" 351	_300	2 49
1014	. 963	. 912	861	8 10	. 759	708		606 0001	555	504					
1 013	_ 962	<u>911</u>	860	809	.758	707		1 3	54	503	4 52	401	_ 350	_299	_ 248
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19

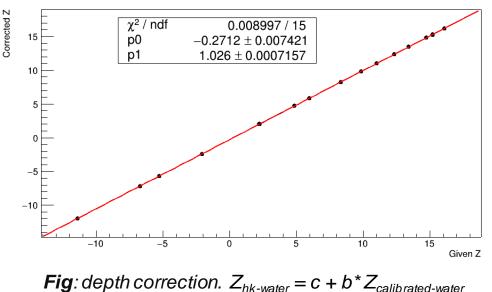
Narrowing search volume

• b=p1=density of calibrated water(salt)/density of hk-water.

Can be easily derived assuming that the pressure sensor Is reading the pressure correctly.

Try to relate offset of brightest point from the center to predict if the camera was pointing at angle less than or more than radially outward direction.

The brightest spot should have been in the center if the camera was pointing radially outward.



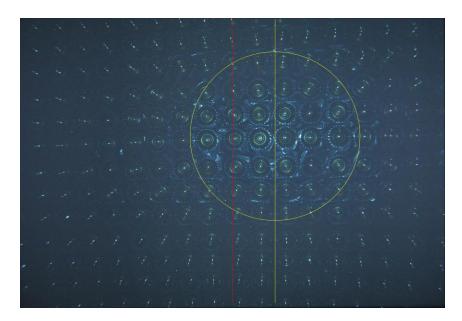


Fig: Finding brightest spot in the image.

Z-Coordinate correction

See the pattern?

- Now match the pattern.
- Best match pattern is correct label(actual camera position).

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Introduction to camera (simply R³ -> R² transformation)

