Virtual radar sensor for USARSim

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Abstract

This paper proposes a method to simulate a radar sensor to be used in the USARSim environment. A multi-sensor dataset has been analysed to show the behaviour or a radar system in the real world.

Contents

1 Introduction

In the field of robotics one of the most important aspects is to gather information about the environment around you. A large task within this aspect is to localize the robot and surroundings in a possible hostile environment.

This is practised in the Urban Search And Rescue (USAR) Virtual Robot Rescue League (RoboCupRescue), part of the international annual competition RoboCup[1]. Robocup is an initiative to stimulate research and education by having teams compete in a broad field of robotics. In the RoboCupRescue a virtual team of robots enter a disaster environment to explore the area and get as much information as possible. There is limited time for the robots to gather information so it's important to have the robots work as efficient and accurate as possible.

Various sensors are used to gather information about the environment, a Simultaneous Localization And Mapping (SLAM) algorithm is used to construct a map of the area using common sensors including laser-scanners, video, sonar and odometry. In order to stay up-to-date all sensors available to be used on real robots should be available in the RoboCup world.

The question here is raised how realistic a new sensor based on radar technology can be added to the USARSim world.

1.1 Radio detection and ranging

The classical pulse radar has a transmitter sending radio waves of a certain frequency which will scatter upon meeting an obstacle, illustrated at figure 1. A small part of the radio waves will return and be received by an antenna at the radar system. Using the time it takes for the signal to return the distance to the obstacle can be calculated.

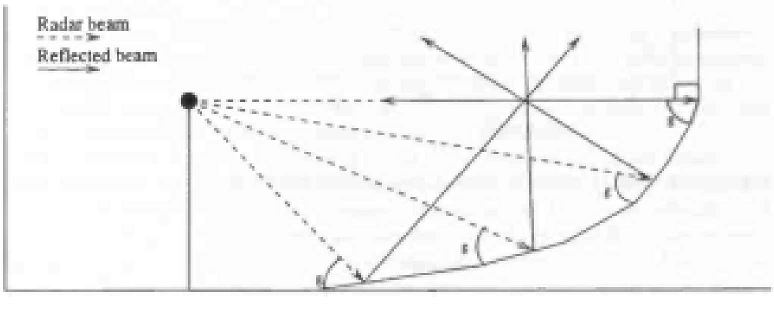

Figure 1: Radar beam scatter, image from Bosman [1, fig 4.3]

A simple radar system has one antenna to send and one antenna to receive signals. Because this will cause large interference usually a device makes the

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[1] http://www.robocup.org/

system switch very fast between sending and receiving signals so the transmitter and receiver can share one antenna. The direction/bearing (in angles) which the transmitter sends the signal to goes from 0 to 360° with steps called the beamsize. With a smaller beamsize smaller objects can be detected but more scans will be needed than with a larger beamsize.
A signal could partially scatter at an object making it possible for the rest of the signal to scatter at another object in the same direction thus making the radar system see two objects at the same direction on a different range.

For the field of robotics measurements on a short-range (maximum 100 metre) are needed requiring electromagnetic waves with a high frequency. A low attenuation (loss of signal intensity) is preferred to keep the transmission energy as low as possible. Attenuation through the air depends on the frequency, it has a local minimum at 94GHz which is reserved for military and experimental applications [3] such as robotics. This falls in the microwave range (with frequencies between 300 Mhz and 300 GHz quite a broad range) which includes millimetre waves between 40 and 300 GHz, roughly corresponding to wavelengths between 1 and 10mm [7].

The classical radar is not a good choice for these measurements because a classical radar system with high precision needs very fast and thus expensive equipment. Radar using the Frequency Modulation Continuous Wave (FMCW) principle solves this issue, the frequency shifts making it easyer to calculate the time it took a signal to return. For robotics the largest advantage of the FMCW for measurements up to hundreds of metres is the lower transmission power, making it safer to use and requiring less energy [6].

There are several possible advantages for this microwave radar; the key advantage is that radar is less affected by visibility conditions such as smoke, dust, weather and day/night cycles compared to common visual based sensors such as laser and video [2]. Using microwave radar it is possible to build maps of the environment as shown by Rouveure, Monod, Faure, and Aubière [6] using a K2Pi (360° scanning at 24 GHz) radar.

1.2 The Marulan Datasets

The Marulan Datasets[2] are "large, accurately calibrated and time-synchronised datasets, gathered in controlled environmental conditions, using an unmanned ground vehicle equipped with a wide variety of sensors" [4]. These datasets are made public available to give everyone a chance to work on the data to analyse it or to evaluate algorithms.

There are 39 datasets: 23 static tests from a motionless vehicle with (small) known objects with a mostly static environment and 16 dynamic tests with a moving vehicle in different environments. Each of the Marulan Datasets has its own directory containing all data from all sensors. For the static environments only the RadarSpectrum data is used, for the dynamic environment the navigation data is needed aswell.

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[2] http://sdi.acfr.usyd.edu.au/

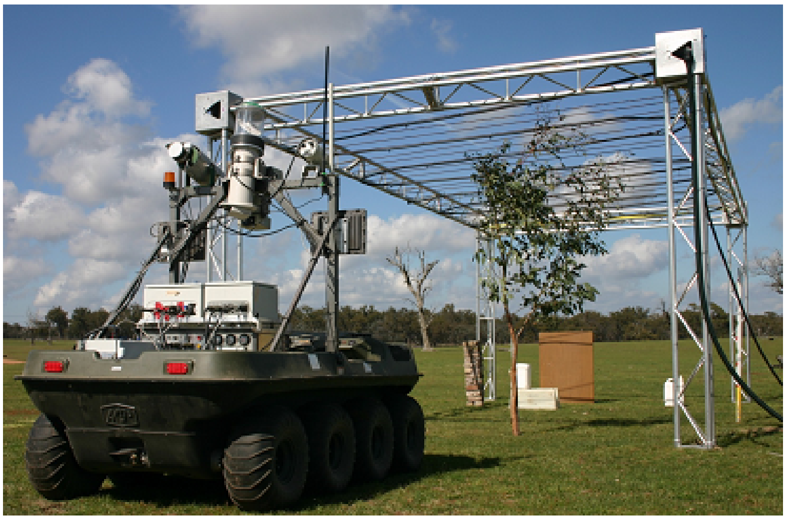


Figure 2: Static trial area, picture from Peynot and Scheding [4, fig 5]

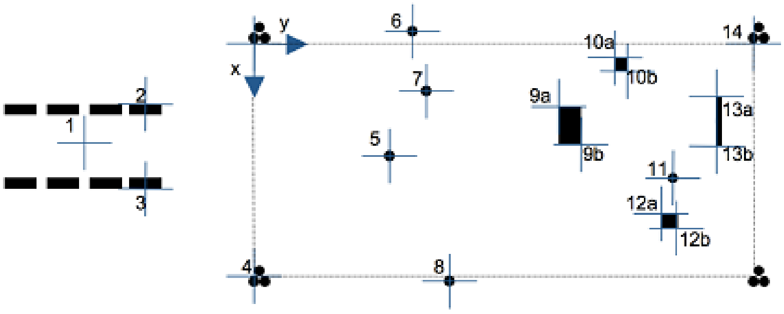


Figure 3: Static trial setup, figure from Peynot, Terho, and Scheding [5, fig 7]

1.2.1 Basic environment

The basic environment as shown in figure 2 and 3 is static, the vehicle stands still during all the tests. In the dynamic tests several area's are visited including an area with houses and an environment with a rich nature.

Conditions known to be difficult for some sensors, making current state systems fail, are especially included in the datasets. In some of the datasets one or more of the following are present:

- A person walking through the environment. In static tests 03, 06, 09 and 23-24; in dynamic test 34.
- Generated dust clouds using an air compressor. In static tests 04-06 and 15-16; in dynamic tests 30-31.

- Smoke bombs generating smoke carried through the wind. In static tests 07, 17, 20; in dynamic test 38.
- Rain created by sprinklers, in the static tests 08-10 and 18-19, or by a person spraying water in the dynamic test 39.

In figure 3 the following objects are close to the robot in the static environment [5]:

- xy, Support pole of frame at 0, 0.
- 1 Centre of the vehicle at 190, -293.
- 4 Support pole of frame at 431, 0.
- 5 Tree around 208, 252 (reported to be at 108, 252)

Note: these coordinates are the same coordinates as written in the technical report to make it easyer to compare them.

1.2.2 Calibration parameters

The radar sensor is placed at the centre of the vehicle and calibration parameters are supplied in the technical report to give the exact position and rotation angles of the radar sensor in respect to the vehicle. The sensor is at 1.40 metre height, has a dX offset of -0.026 and dY offset of -0.047 compared to the vehicle. The RollX is -0.15°, the PitchY 191.16° and the YawZ 173.28° [5].

After applying these calibration parameters using linear algebra the radar sensor direction at 0° is pointing towards the front of the vehicle and a little bit to the right side (mostly east and a bit south on the figure). The direction at 90° is almost parallel to the x-axis in reversed direction. The sensor is slightly pointed towards the ground in front of the vehicle thus at some range the ground should be detected in front of the vehicle but not at the back, if the vehicle is on a flat environment.

1.2.3 Specification custom built radar

The radar system used at the Marulan Datasets is custom built at ACFR for environment imaging. According to the specification the radar can measure maximal 4000 centimetre with a range resolution of 20 centimetre, the frequency is 94GHz, maximum rotation of scanhead 360 degrees at approximately 8Hz with 1KHz samplerate. [5].

Given this specifications approximately 1000 measurements and 8 rotations of the scan head are expected every second. The range resolution is the ability to seperate two or more targets which are at the same angle, the resolution of 20 centimetre means targets within 20 centimetre at the same angle will not be seen apart.

2 Data analyses

The first step taken here in order to be able to interpret the data is to analyze if the given radar specifications match the measurements. To do this for each dataset all the information in the RangeBearing file is read. Each single line of this file contains one measurement with the time, range, angle and reflection. The translation offset and rotation angles are only taken into account when comparing the radar sensor data with the static trial setup figure.

2.1 Statistical information

The amount of measurements for each dataset have a minimum of 40000 and a maximum of 209000. The datasets from the dynamic environments are about 2 times as large as the datasets of the static environment.

Peynot et al. [5] list the start and endtime for each dataset as the moment on which all the connected sensors have data. Because it takes a while for some of the other sensors to receive measurements the radar data starts before the given startdate. Because the other sensors are not considered here the full radar data files are used thus the duration of the data used here is not exactly the same as in the technical report.

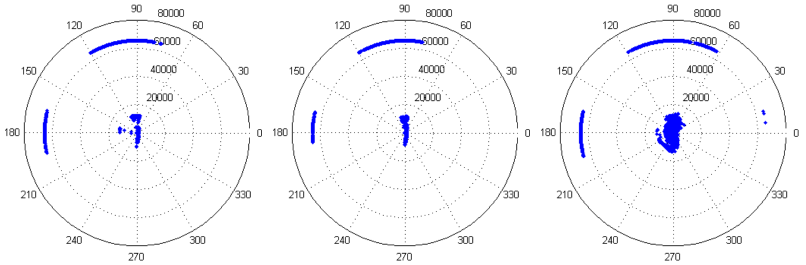
The total duration one dataset takes ranges from 73 seconds till 380 seconds. To get the number of measurements per second for one dataset the total amount of measurements is divided by the total duration of this dataset. For all datasets the number of measurements per second is between 542 and 554, with a mean of 549 and variance of 5. This corresponds to a 550 Hz sample rate, about half of what was expected given the specification. Each measurements is roughly 2 milliseconds (one second divided by 550) later then the previous one.

To get the number of rotations of the scanhead for a dataset each angle is compared to its predecessor. The angles vary from 0 to $2pi$, if the new angle is lower than the previous one the scanhead has made one round and the amount of data for this round is saved. The number of times the new angle is lower is summed for each file. The total amount of measurements for this file is divided by the number of angle-switches to get the average measurements collected in one rotation of the scanhead. The average data per rotation is between 185 and 189 with the average at 187,6 for all datasets.

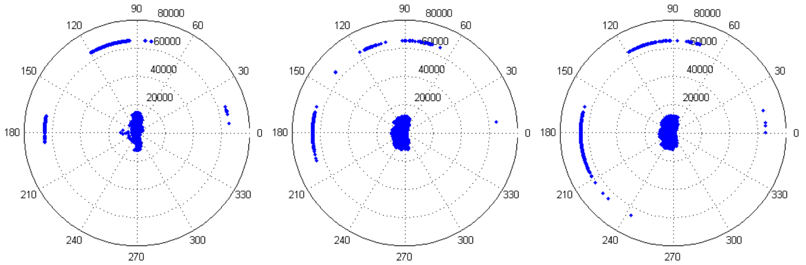
The average time for one rotation of the scanhead is calculated by taking the total number of rotations and dividing this with the duration of this dataset. In all the datasets the rotation of the scanhead takes a little less than three seconds; 2,92 is the minimum, 2,96 the max and 2,93 the average rotations the scanhead takes overall.

Appendix A and B show a table with all these measurements.

2.2 Figures of measurements



(a) Static 18 (b) Static 19 (c) Dynamic 29



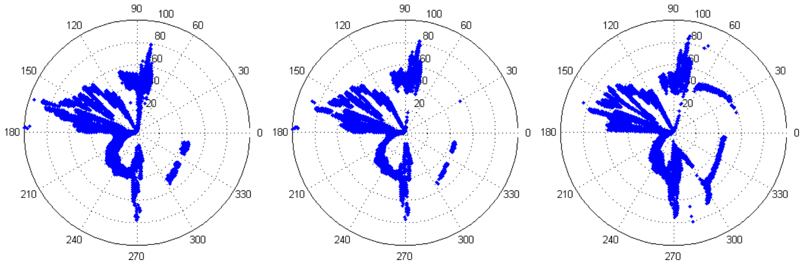
(d) Dynamic 32 (e) Dynamic 36 (f) Dynamic 37

Figure 4: Angle and Range using all measurements of selected datasets

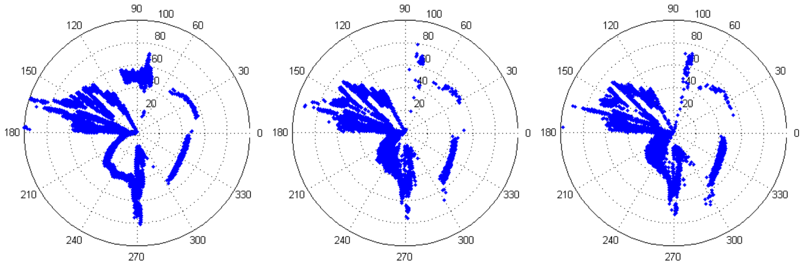
In figure 4 for six different datasets all the measurements are shown with the range (in centimetres) and angle (in degrees) of the measurements, the reflectivity is not taken into account here. The datasets pictured here are randomly chosen and for consistency also used for the next subsections.

Near 90° and 180° are measurements far exceeding the maximum specified range. These far-off measurements appear in all of the datasets with not much difference between the static and dynamic environment and are concentrated in the same area. On average 7% measurements for the static tests and 11% measurements for the dynamic tests have a range larger than 4000 cm. These are obviously no realistic measurements, most of these measurements are near 65536 ($= 2^{16} - 1$). There could be some overflow occuring because this is the maximum you can save in 2 bytes.

The measurements close to the vehicle are shown in figure 5. There are a lot of measurements in this range, between 49% and 60% with average 55% for the static tests; between 9% and 60% with average 33% for the dynamic tests of all data with a range shorter than 100 cm. For all the datasets including both the static and dynamic environments the measurements close to the vehicle look quite simirlar.

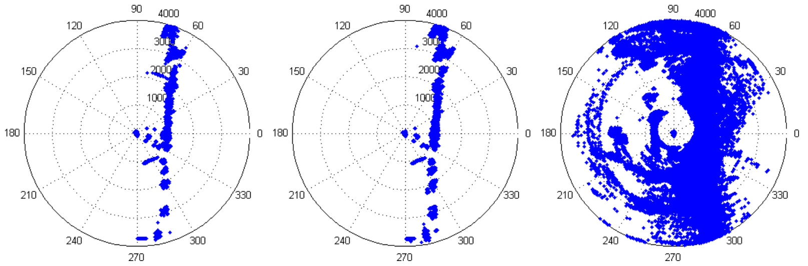


(a) Static 18 (b) Static 19 (c) Dynamic 29

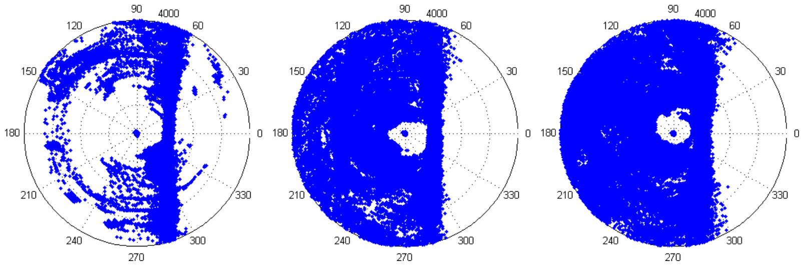


(d) Dynamic 32 (e) Dynamic 36 (f) Dynamic 37

Figure 5: Angle and Range using measurements with range <= 100 cm



(a) Static 18 (b) Static 19 (c) Dynamic 29



(d) Dynamic 32 (e) Dynamic 36 (f) Dynamic 37

Figure 6: Angle and Range using measurements with range <= 4000 cm

Most likely it's the built of the behicle causing these measurements to appear the way they are. It looks like a lot of interference from the vehicle, all the measurements within 100cm of the vehicle can not be taken directly as usefull measurements. Due to the way radar works even a very small signal standing out from the noise, which might be part of the noise, will be seen as object.

When these measurements near the vehicle occur there is most-likely no object in the beam of the radar but some of the signals in this close range might actually always be seen as an object and possibly hiding real objects behind is. At dynamic environment 37 (fig **??**f]fig:polar4000 there is not a single angle where no measurements are shown thus it is not likely that the vehicle physics makes other objecs invisible to the radar sensor.

The same measurements are in figure 6 but only the data with a range of less then 4000 cm. In the static environment there are appearantly no obstacles at all behind the vehicle. Because the vehicle moves around in the dynamic environment there is a lot more variation, the difference between the static and dynamic environments is obvious. For the static environment the measurements seem to be concentrated on a line, however the camera images don't show any obstacles at most of these locations.
On average 37% for the static and 49.0% for the dynamic tests contain measurements in a usefull range.

2.3 Single objects

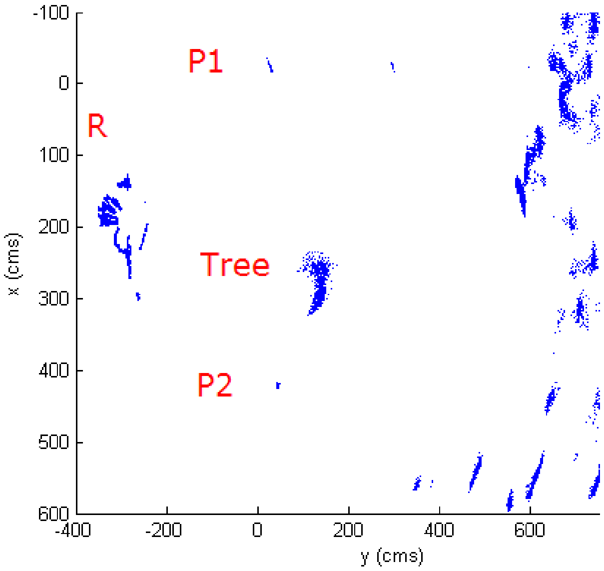
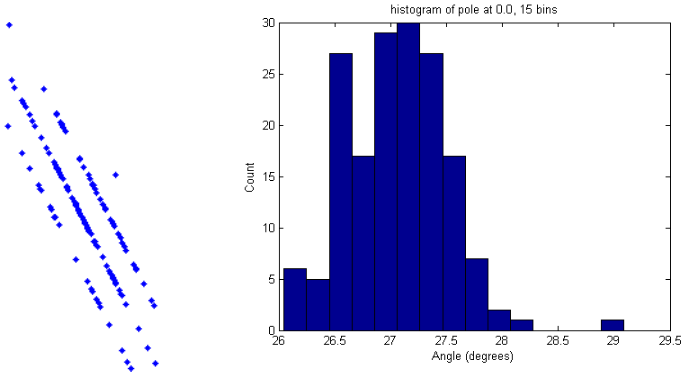


Figure 7: Dataset 02 showing close objects

This section has a focus on objects close to the vehicle as mentioned in section 1.2.1. The calibration parameters as described in 1.2.2 are used here, the maxrange is set to 1000 centimetre resulting in the picture shown at figure 7.

In this picture the robot (R)is on the left side shown with the same characteristic close-by measurements as in the previous section. From left to right as seen from the robot there is the left pole (P1) around (0,0), the Tree and the right pole (P2) around (400,0). Both of the poles are actually 3 poles next to eachother.

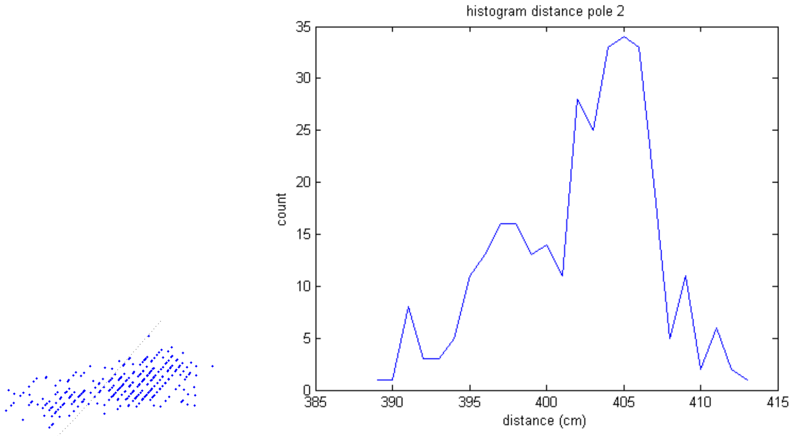


(a) Plot pole 1

(b) Histogram angle

Figure 8: Dataset 02 pole 1

Figure 8a shows a close-up of the measurements near the left pole. There are 169 measurements in this area with the (original) angle between 26 and 29 degrees and range between 387 and 390 cm with an average of 388 centimetre. This shows that in the data the ranges are rounded to centimetres. Histogram at figure 8b shows the count of the different angles for these dots.



(a) Plot pole 2

(b) Histogram angle

Figure 9: Dataset 02 pole 2

Figure 9a shows a close-up of the measurements near the right pole. The histogram at figure 9b shows the count of the different angles for the points from pole 2 from the same dataset. A smaller binsize is chosen here because there are more different angles for this pole.

From a view of the vehicle the difference between the two poles is that at the left pole one 'subpole' is the closest part with 2 'subpoles' behind it but at the right pole there are 2 'subpoles' with 1 behind it. As visible for on the histograms this matters a lot for the radar signal. The signal for pole 1 will mostly scatter in other directions but for pole 2 a large part of the signal will scatter from a 'subpole' to the other 'subpole' and head back to the radar.

3 Radar in USARSim

When implementing the radar in USARSim an important consideration is the resource use. In USERSim processing time is limited thus the radar sensor cannot be simulated achieving real-life performance. Constraints can be places on the speed at which the scan head rotates or at the beamsize. Creating a very large beamsize is not recommended due to lower accuracy, small objects might not be seen for example.

To simulate a radar sensor accurate information can be used with in most cases only a slight bit of noise on actual objects. As shown it depends a lot on the kind of obstacles what radar signal shall return to the sensor.

The basic rule for the model would be:

```
For grades 0-360 stepsize x:
 - Follow the beam from radar.
   * Obstacle hit AND chance() > treshold? -> return (angle AND noise + distance)
   * Otherwise -> return (angle AND noise + (very high value OR very small value)
```

The chance ¿ treshold part could partially be replaced by detecting if the object has surface pendicular to the beam. If there is no surface pendicular to the beam the chance of getting a beam returned is a lot lower.

4 Conclusions, Discussions and Future work

The main conclusion is that a sensor based on radar technology can be implemented in the USARSim world but making it as realistic as a real radar sensor is not possible due to processing time.

The Marulan Datasets provide a great source of sensor data to be analysed, although a few minor errors occur in the description of the data. Unfortunatly no measurements have been found where two or more objects are detected at the same angle on the same time.

Because of the limited processing power in the USARSim world the normal way of using a Fast Fourier radar signal processor is not considered at all in this work, in the future it should be used.

As future work materials which can absorb radio waves could be analysed.

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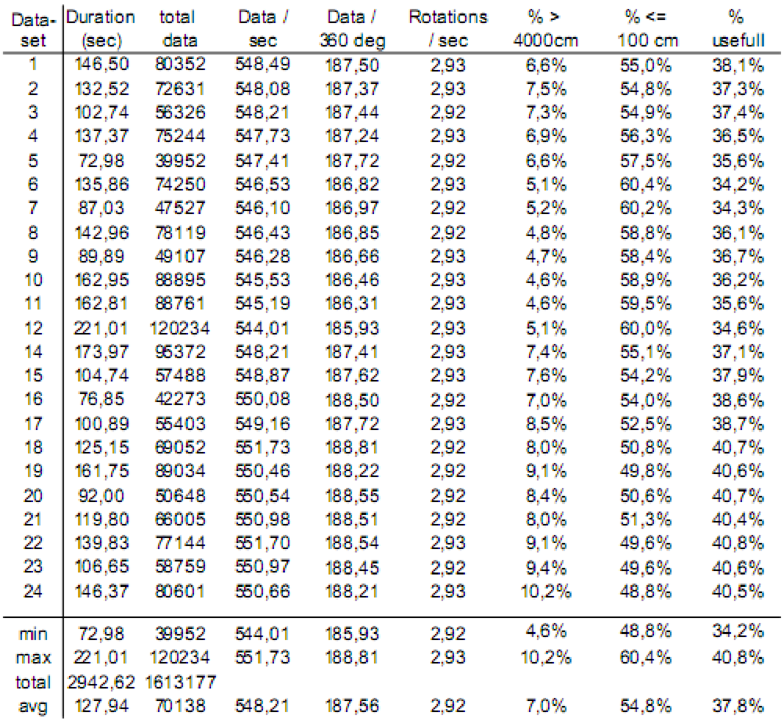
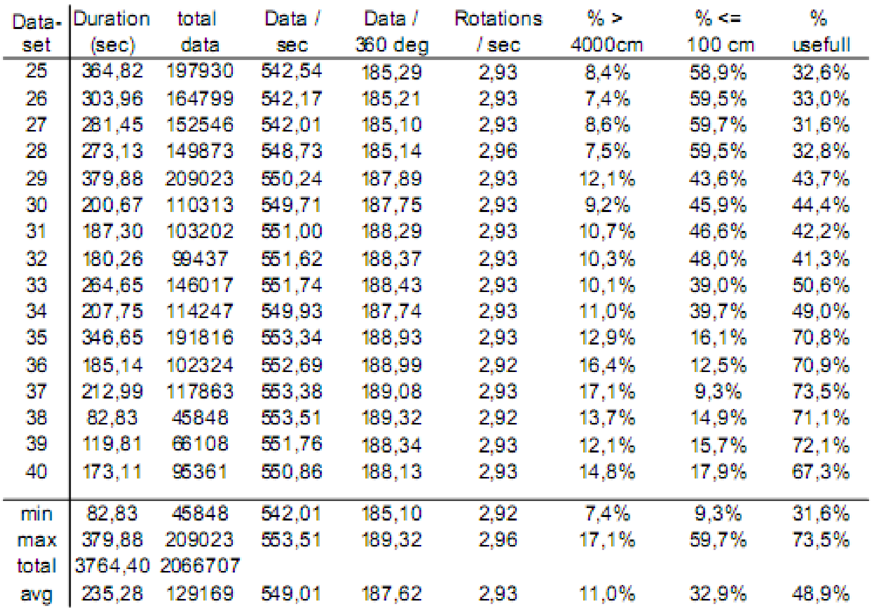
A Statistical data static environments



Data-set	Duration (sec)	total data	Data / sec	Data / 360 deg	Rotations / sec	% > 4000cm	% <= 100 cm	% usefull
1	146,50	80352	548,49	187,50	2,93	6,6%	55,0%	38,1%
2	132,52	72631	548,08	187,37	2,93	7,5%	54,8%	37,3%
3	102,74	56326	548,21	187,44	2,92	7,3%	54,9%	37,4%
4	137,37	75244	547,73	187,24	2,93	6,9%	56,3%	36,5%
5	72,98	39952	547,41	187,72	2,92	6,6%	57,5%	35,6%
6	135,86	74250	546,53	186,82	2,93	5,1%	60,4%	34,2%
7	87,03	47527	546,10	186,97	2,92	5,2%	60,2%	34,3%
8	142,96	78119	546,43	186,85	2,92	4,8%	58,8%	36,1%
9	89,89	49107	546,28	186,66	2,93	4,7%	58,4%	36,7%
10	162,95	88895	545,53	186,46	2,93	4,6%	58,9%	36,2%
11	162,81	88761	545,19	186,31	2,93	4,6%	59,5%	35,6%
12	221,01	120234	544,01	185,93	2,93	5,1%	60,0%	34,6%
14	173,97	95372	548,21	187,41	2,93	7,4%	55,1%	37,1%
15	104,74	57488	548,87	187,62	2,93	7,6%	54,2%	37,9%
16	76,85	42273	550,08	188,50	2,92	7,0%	54,0%	38,6%
17	100,89	55403	549,16	187,72	2,93	8,5%	52,5%	38,7%
18	125,15	69052	551,73	188,81	2,92	8,0%	50,8%	40,7%
19	161,75	89034	550,46	188,22	2,92	9,1%	49,8%	40,6%
20	92,00	50648	550,54	188,55	2,92	8,4%	50,6%	40,7%
21	119,80	66005	550,98	188,51	2,92	8,0%	51,3%	40,4%
22	139,83	77144	551,70	188,54	2,93	9,1%	49,6%	40,8%
23	106,65	58759	550,97	188,45	2,92	9,4%	49,6%	40,6%
24	146,37	80601	550,66	188,21	2,93	10,2%	48,8%	40,5%
min	72,98	39952	544,01	185,93	2,92	4,6%	48,8%	34,2%
max	221,01	120234	551,73	188,81	2,93	10,2%	60,4%	40,8%
total	2942,62	1613177						
avg	127,94	70138	548,21	187,56	2,92	7,0%	54,8%	37,8%

Figure 10: Statistical data static environments

B Statistical data dynamic environments



Data-set	Duration (sec)	total data	Data / sec	Data / 360 deg	Rotations / sec	% > 4000cm	% <= 100 cm	% usefull
25	364,82	197930	542,54	185,29	2,93	8,4%	58,9%	32,6%
26	303,96	164799	542,17	185,21	2,93	7,4%	59,5%	33,0%
27	281,45	152546	542,01	185,10	2,93	8,6%	59,7%	31,6%
28	273,13	149873	548,73	185,14	2,96	7,5%	59,5%	32,8%
29	379,88	209023	550,24	187,89	2,93	12,1%	43,6%	43,7%
30	200,67	110313	549,71	187,75	2,93	9,2%	45,9%	44,4%
31	187,30	103202	551,00	188,29	2,93	10,7%	46,6%	42,2%
32	180,26	99437	551,62	188,37	2,93	10,3%	48,0%	41,3%
33	264,65	146017	551,74	188,43	2,93	10,1%	39,0%	50,6%
34	207,75	114247	549,93	187,74	2,93	11,0%	39,7%	49,0%
35	346,65	191816	553,34	188,93	2,93	12,9%	16,1%	70,8%
36	185,14	102324	552,69	188,99	2,92	16,4%	12,5%	70,9%
37	212,99	117863	553,38	189,08	2,93	17,1%	9,3%	73,5%
38	82,83	45848	553,51	189,32	2,92	13,7%	14,9%	71,1%
39	119,81	66108	551,76	188,34	2,93	12,1%	15,7%	72,1%
40	173,11	95361	550,86	188,13	2,93	14,8%	17,9%	67,3%
min	82,83	45848	542,01	185,10	2,92	7,4%	9,3%	31,6%
max	379,88	209023	553,51	189,32	2,96	17,1%	59,7%	73,5%
total	3764,40	2066707						
avg	235,28	129169	549,01	187,62	2,93	11,0%	32,9%	48,9%

Figure 11: Statistical data dynamic environments

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