A. Additional experiment results

This appendix includes the full set of results for each experiment type: illumination change, viewpoint change and weather change. For each experiment, we show

1) Plot of failure rate vs. the main experiment parameter;
2) Correlation plot of the failure and recall rates;
3) Table of the failure rates for each value of the main experiment parameter;
4) Table of the recall rates measured by driving the route by autopilot with access to ground truth vehicle state;

For the illumination change we show results from two environments (Town01 and Town10). The viewpoint experiments were conducted only in Town01, the weather experiments in Town10. For full experiment specifications see the main paper.

A.1. Illumination change results - Town01

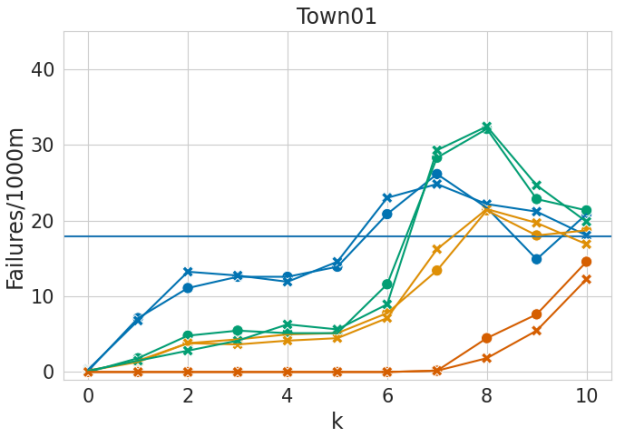

Figure A.1.1: Relationship of failure rate with illumination levels k. Marker color indicates type for local features, shape for global features.

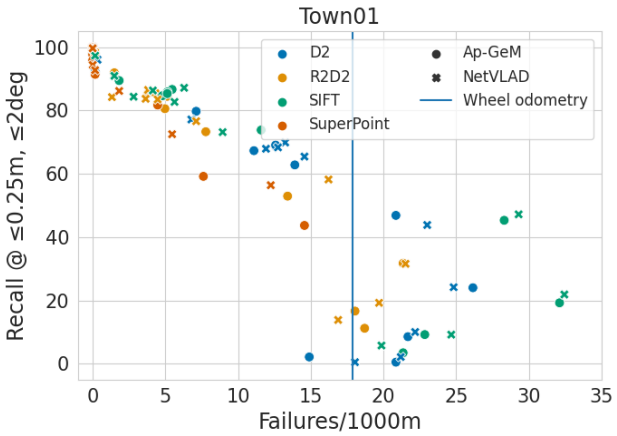

Figure A.1.2: Relationship between the failure rate and recall rate T1. Marker color and shape indicate feature type.

		Town01										
PR	LF	$k=0$	1	2	3	4	5	6	7	8	9	10
Ap-GeM	Sift	**0.0**	1.8	4.8	5.5	5.1	5.1	11.6	28.3	32.1	22.8	21.4
	D2-net	0.2	7.1	11.1	12.6	12.6	13.9	20.9	26.2	21.7	14.9	20.9
	R2D2	0.2	1.5	3.8	4.3	5.0	5.1	7.8	13.4	21.4	18.0	18.7
	SuperPoint	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	4.5	7.6	14.6
NetVLAD	Sift	0.2	1.5	2.8	4.1	6.3	5.6	8.9	29.3	32.5	24.7	19.9
	D2-net	0.3	6.8	13.2	12.7	11.9	14.6	23.0	24.8	22.2	21.2	18.0
	R2D2	0.2	1.3	3.8	3.6	4.1	4.5	7.1	16.2	21.5	19.7	16.9
	SuperPoint	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**1.8**	**5.5**	**12.3**
Wheel odometry							17.9					

Table A.1.1: Navigation failure rates over 5 repeated runs of the same route at each illumination level k. Smaller is better. PR = place recognition method, LF = local feature type.

		Town01										
PR	LF	$k=0$	1	2	3	4	5	6	7	8	9	10
		T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3
Ap-GeM	Sift	98.0 / 98.2 / 99.8	89.5 / 92.9 / 99.0	84.7 / 89.6 / 96.5	86.7 / 89.3 / 96.1	85.9 / 89.3 / 96.7	85.4 / 89.5 / 95.4	73.8 / 78.5 / 90.5	45.3 / 51.6 / 63.9	19.2 / 23.8 / 29.8	9.2 / 11.8 / 16.4	3.5 / 5.8 / 8.6
	D2-net	92.3 / 95.7 / 99.8	79.8 / 86.7 / 97.5	67.3 / 74.7 / 90.1	68.8 / 74.8 / 90.1	69.1 / 74.7 / 88.0	62.8 / 70.9 / 85.7	46.9 / 58.1 / 73.8	24.0 / 28.5 / 39.3	8.6 / 10.9 / 15.6	2.1 / 3.1 / 6.2	0.5 / 0.8 / 2.0
	R2D2	98.0 / 98.4 / **100.0**	91.9 / 94.1 / 98.7	85.5 / 90.4 / 97.7	85.7 / 90.6 / 96.2	80.6 / 88.2 / 97.0	84.5 / 88.0 / 96.5	73.3 / 79.7 / 93.6	53.0 / 62.8 / 79.1	31.7 / 37.5 / 50.5	16.6 / 20.4 / 23.6	11.2 / 12.9 / 15.0
	SuperPoint	**100.0 / 100.0 / 100.0**	**100.0 / 100.0 / 100.0**	**99.8 / 99.8** / 99.8	97.7 / 99.8 / **100.0**	99.5 / **100.0 / 100.0**	99.2 / 99.3 / 99.7	**95.9** / 98.5 / 99.0	91.4 / 94.6 / 96.5	81.7 / 86.3 / 90.5	59.2 / 65.0 / 71.5	43.7 / 48.9 / 57.9
Net-VLAD	Sift	97.4 / 98.5 / 99.8	91.0 / 93.3 / 99.2	84.4 / 87.7 / 97.5	86.3 / 89.5 / 96.9	87.2 / 89.8 / 97.4	82.7 / 87.5 / 96.5	73.2 / 79.6 / 92.3	47.2 / 53.1 / 67.6	21.9 / 27.0 / 34.4	9.2 / 13.8 / 20.5	5.8 / 8.2 / 13.0
	D2-net	96.1 / 96.9 / 99.7	77.2 / 85.1 / 98.7	69.9 / 75.8 / 90.1	68.4 / 74.8 / 90.0	67.9 / 75.7 / 87.3	65.5 / 71.9 / 86.3	43.8 / 52.4 / 75.0	24.2 / 29.9 / 42.6	10.0 / 13.0 / 17.9	2.1 / 4.4 / 8.0	0.5 / 1.2 / 1.8
	R2D2	98.4 / 98.5 / 99.7	84.3 / 91.8 / 98.7	86.5 / 91.0 / 97.5	83.7 / 87.0 / 97.2	86.2 / 89.5 / 97.5	83.5 / 87.3 / 96.2	76.6 / 82.4 / 93.1	58.2 / 66.1 / 83.1	31.6 / 37.7 / 49.2	19.2 / 22.2 / 27.6	13.8 / 15.3 / 18.3
	SuperPoint	**100.0 / 100.0 / 100.0**	99.7 / 99.8 / **100.0**	99.7 / 99.7 / **100.0**	**100.0 / 100.0 / 100.0**	**99.8 / 100.0 / 100.0**	**99.7 / 100.0 / 100.0**	94.4 / **99.2 / 99.5**	**92.8 / 96.7 / 99.7**	**86.2 / 90.8 / 96.1**	**72.5 / 78.1 / 87.2**	**56.4 / 60.4 / 68.1**

Table A.1.2: The localization recall rates for the reference paths at illumination levels k with thresholds T1 ($\leq$ 0.25m, $\leq 2°$), T2 ($\leq$0.50m,$\leq 5°$) and T3 ($\leq$5.00m, $\leq 10°$).

A.2. Illumination change results - Town10

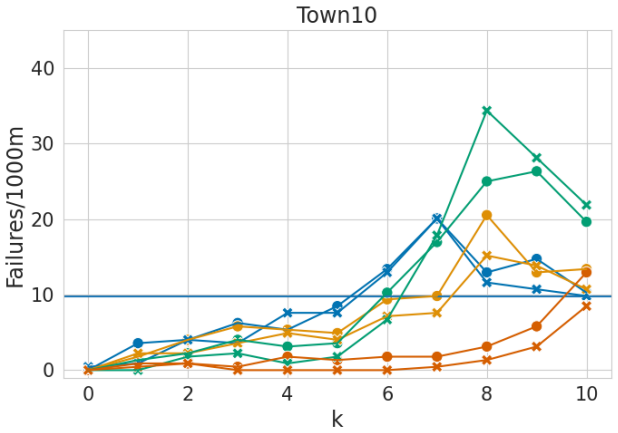

Figure A.2.1: Relationship of failure rate with illumination levels k. Marker color indicates type for local features, shape for global features.

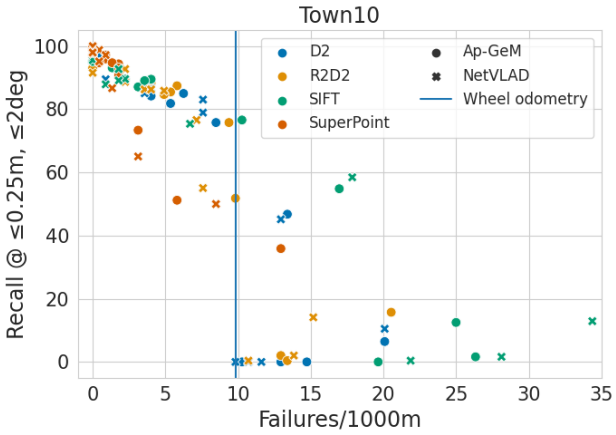

Figure A.2.2: Relationship between the failure rate and recall rate T1. Marker color and shape indicate feature type.

		Town10											
PR	LF	$k=0$	1	2	3	4	5	6	7	8	9	10	CT
Ap-GeM	Sift	**0.0**	1.3	2.2	4.0	3.1	3.6	10.3	17.0	25.0	26.3	19.6	169
	D2-net	**0.0**	3.6	4.0	6.2	5.4	8.5	13.4	20.1	12.9	14.7	10.3	165
	R2D2	**0.0**	1.8	4.0	5.8	5.4	4.9	9.4	9.8	20.5	12.9	13.4	194
	SuperPoint	**0.0**	0.9	**0.9**	0.4	1.8	1.3	1.8	1.8	3.1	5.8	12.9	193
Net-VLAD	Sift	**0.0**	**0.0**	1.8	2.2	0.9	1.8	6.7	17.9	34.4	28.1	21.9	**134**
	D2-net	0.4	0.9	4.0	3.6	7.6	7.6	12.9	20.1	11.6	10.7	9.8	139
	R2D2	**0.0**	2.2	2.2	3.6	4.9	4.0	7.1	7.6	15.2	13.8	10.7	167
	SuperPoint	**0.0**	0.4	**0.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.4**	**1.3**	**3.1**	**8.5**	166
Wheel odometry							9.8						

Table A.2.1: Navigation failure rates over 5 repeated runs of the same route at each illumination level k. Smaller is better. PR = place recognition method, LF = local feature type, CT = computation time (*ms*).

		Town10										
PR	LF	$k=0$	1	2	3	4	5	6	7	8	9	10
		T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3
Ap-GeM	Sift	95.2 / 96.4 / 99.6	93.1 / 93.1 / 94.4	89.5 / 90.3 / 92.7	89.5 / 91.1 / 92.3	87.1 / 87.9 / 91.5	89.1 / 90.7 / 91.9	76.6 / 79.0 / 83.9	54.8 / 60.5 / 67.3	12.5 / 16.5 / 33.5	1.6 / 2.4 / 8.1	0.0 / 0.4 / 3.6
	D2-net	94.7 / 98.4 / 99.2	87.5 / 90.3 / 93.5	84.2 / 88.7 / 91.9	85.0 / 90.3 / 92.7	81.9 / 87.1 / 92.7	75.8 / 81.9 / 90.7	46.8 / 53.6 / 65.3	6.5 / 12.5 / 24.2	0.0 / 0.0 / 1.2	0.0 / 0.0 / 0.4	0.0 / 0.0 / 0.0
	R2D2	93.1 / 94.7 / 99.6	91.5 / 91.9 / 94.4	88.3 / 90.7 / 92.3	87.4 / 88.7 / 91.5	85.5 / 87.9 / 90.3	84.7 / 87.5 / 89.9	75.8 / 78.2 / 83.5	51.8 / 56.7 / 63.6	15.7 / 21.4 / 31.5	2.0 / 2.8 / 5.6	0.4 / 0.8 / 2.8
	SuperPoint	99.6 / **100.0** / **100.0**	97.2 / 97.2 / 97.2	96.0 / 96.0 / 96.0	94.8 / 95.2 / 95.2	94.4 / 94.4 / 94.4	94.7 / 94.7 / 94.7	93.1 / 93.5 / 93.5	90.7 / 94.0 / 94.4	73.4 / 75.4 / 76.2	51.2 / 53.2 / 56.5	35.9 / 37.5 / 41.5
Net VLAD	Sift	96.4 / 97.2 / **100.0**	95.6 / 96.8 / 98.0	92.7 / 94.0 / 94.8	89.6 / 91.2 / 93.2	87.9 / 90.7 / 93.5	89.1 / 91.1 / 92.3	75.4 / 77.8 / 85.1	58.5 / 63.3 / 68.5	12.9 / 17.3 / 35.5	1.6 / 4.4 / 9.3	0.4 / 0.4 / 2.0
	D2-net	97.2 / 99.6 / **100.0**	89.5 / 91.9 / 96.0	86.7 / 89.5 / 94.0	85.1 / 89.1 / 94.0	83.1 / 88.3 / 92.7	78.9 / 85.8 / 90.3	45.2 / 58.5 / 69.4	10.5 / 14.5 / 28.6	0.0 / 0.0 / 0.8	0.0 / 0.0 / 0.4	0.0 / 0.0 / 0.0
	R2D2	91.6 / 92.8 / 99.6	92.7 / 94.4 / 96.4	88.7 / 91.1 / 92.7	86.3 / 89.1 / 91.1	85.9 / 89.1 / 90.7	86.3 / 89.5 / 91.5	76.6 / 80.6 / 87.1	55.1 / 59.9 / 66.0	14.1 / 20.2 / 33.9	2.0 / 2.z8 / 6.5	0.4 / 0.8 / 2.0
	SuperPoint	**100.0 / 100.0 / 100.0**	**98.8 / 99.2 / 99.2**	**97.2 / 97.2 / 97.6**	**98.4 / 98.8 / 98.8**	**97.6 / 98.0 / 98.0**	**98.0 / 98.0 / 98.0**	**98.0 / 98.0 / 98.0**	**95.2 / 96.4 / 96.4**	**86.7 / 87.9 / 88.7**	**65.1 / 69.5 / 72.7**	**50.0 / 55.2 / 58.1**

Table A.2.2: The localization recall rates for the reference paths at illumination levels k with thresholds T1 ($\leq$ 0.25m, $\leq 2°$), T2 ($\leq$0.50m,$\leq 5°$) and T3 ($\leq$5.00m, $\leq 10°$).

A.3. Viewpoint change results - Town01

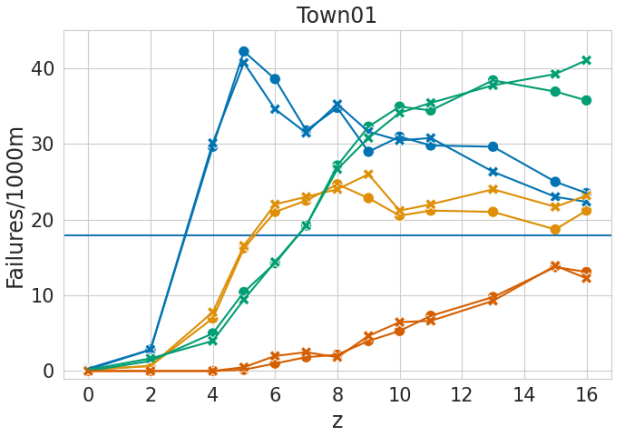

Figure A.3.1: Relationship between failure rate and elevation and pitch offsets z, θ. See Table A.3.1 (below) for elevation and pitch pairs.

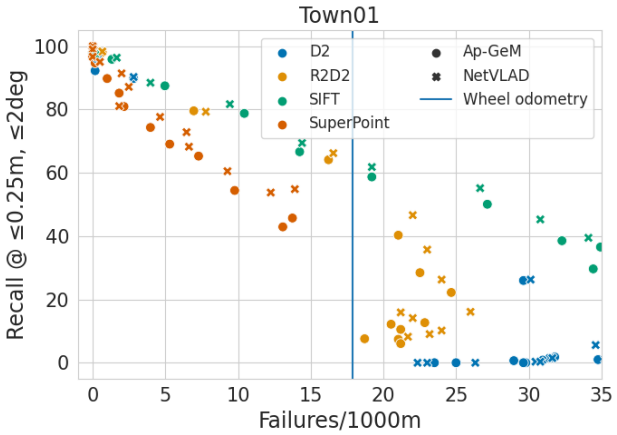

Figure A.3.2: Relationship between the failure rate and recall rate T1. Marker color and shape indicate feature type.

PR	LF	Town01 $z=0$ $\theta=0$	2 10	4 22.5	5 27.5	6 32.5	7 35	8 37.5	9 40	10 40	11 40	13 40	15 40	16 40
Ap-GeM	Sift	**0.0**	1.3	5.0	10.4	14.2	19.2	27.2	32.3	34.9	34.4	38.4	36.9	35.8
	D2-net	0.2	2.8	29.6	42.2	38.6	31.8	34.8	29.0	31.0	29.8	29.6	25.0	23.5
	R2D2	0.2	0.7	7.0	16.2	21.0	22.5	24.7	22.8	20.5	21.2	21.0	18.7	21.2
	SuperPoint	**0.0**	**0.0**	**0.0**	**0.2**	**1.0**	**1.8**	2.2	**4.0**	**5.3**	7.3	9.8	**13.7**	13.1
Net-VLAD	Sift	0.2	1.7	4.0	9.4	14.4	19.2	26.7	30.8	34.1	35.4	37.7	39.2	41.1
	D2-net	0.3	2.8	30.1	40.7	34.6	31.5	35.3	31.6	30.5	30.8	26.3	23.0	22.4
	R2D2	0.2	0.7	7.8	16.6	22.0	23.0	24.0	26.0	21.2	22.0	24.0	21.7	23.2
	SuperPoint	**0.0**	**0.0**	**0.0**	0.5	2.0	2.5	**1.8**	4.6	6.5	**6.6**	**9.3**	13.9	**12.3**
Wheel odometry		17.9												

Table A.3.1: Navigation failure rates over 5 repetitions of the same route at each gallery to-query camera pose (viewpoint) offset. z = elevation shift, θ = pitch shift.

PR	LF	Town01 $z=0$ $\theta=0$	2 10	4 22.5	5 27.5	6 32.5	7 35	8 37.5	9 40	10 40	11 40	13 40	15 40	16 40
		T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3
Ap-GeM	Sift	98.0 / 98.2 / 99.8	95.9 / 96.9 / 97.9	87.5 / 89.3 / 93.1	78.8 / 83.4 / 88.3	66.7 / 72.1 / 78.8	58.7 / 65.8 / 74.0	50.1 / 57.8 / 65.7	38.6 / 47.1 / 55.8	36.6 / 41.5 / 49.2	29.7 / 38.4 / 46.3	21.4 / 26.5 / 33.3	17.8 / 21.9 / 31.2	17.4 / 22.2 / 29.7
	D2-net	92.3 / 95.7 / 99.8	89.8 / 95.2 / 98.2	26.0 / 46.4 / 76.8	10.3 / 21.8 / 53.9	4.1 / 9.5 / 23.5	1.8 / 8.2 / 21.2	1.0 / 3.8 / 13.5	0.7 / 2.3 / 8.7	0.8 / 1.3 / 8.1	0.0 / 0.3 / 5.6	0.0 / 0.2 / 2.3	0.0 / 0.0 / 1.0	0.0 / 0.0 / 0.5
	R2D2	98.0 / 98.4 / **100.0**	98.0 / 98.0 / 98.5	79.6 / 81.4 / 88.8	64.1 / 67.6 / 75.5	40.3 / 49.7 / 59.9	28.5 / 38.5 / 50.2	22.2 / 29.9 / 44.1	12.7 / 21.2 / 36.0	12.2 / 20.2 / 31.7	10.5 / 18.3 / 28.6	7.4 / 14.8 / 22.9	7.6 / 13.0 / 21.1	6.1 / 11.5 / 21.1
	SuperPoint	**100.0 / 100.0 / 100.0**	**99.5 / 99.5 / 99.7**	**96.7 / 96.7 / 98.5**	94.7 / 94.9 / **97.4**	89.8 / 90.3 / 94.1	85.2 / 86.8 / 92.4	81.0 / 83.3 / 88.2	74.3 / 76.6 / 83.9	69.1 / 72.7 / 80.1	65.3 / 70.1 / 76.0	54.4 / 60.7 / 66.4	45.7 / 52.3 / 57.1	42.9 / 49.8 / 54.9
Net-VLAD	Sift	97.4 / 98.5 / 99.8	96.4 / 96.9 / 97.9	88.5 / 90.1 / 93.8	81.7 / 85.2 / 89.3	69.5 / 75.5 / 82.9	61.8 / 67.3 / 73.5	55.2 / 61.1 / 68.6	45.3 / 52.2 / 63.3	39.5 / 46.9 / 55.1	38.6 / 44.7 / 52.2	26.5 / 33.8 / 43.8	23.6 / 27.8 / 36.6	20.1 / 23.9 / 30.8
	D2-net	96.1 / 96.9 / 99.7	90.3 / 96.7 / 98.7	26.3 / 46.6 / 78.5	12.3 / 21.2 / 57.2	5.6 / 11.3 / 28.2	1.5 / 7.4 / 23.0	1.2 / 4.8 / 16.8	1.5 / 3.0 / 14.1	0.3 / 1.3 / 8.9	0.3 / 0.8 / 5.9	0.0 / 0.0 / 3.3	0.0 / 0.0 / 1.3	0.0 / 0.0 / 1.6
	R2D2	98.4 / 98.5 / 99.7	98.4 / 98.4 / 99.0	79.3 / 81.1 / 88.7	66.2 / 70.8 / 79.3	46.6 / 53.5 / 63.4	35.7 / 44.1 / 53.3	26.3 / 33.3 / 45.5	16.1 / 25.6 / 38.6	15.9 / 23.0 / 33.4	14.1 / 19.0 / 29.2	10.2 / 17.2 / 23.8	8.2 / 12.6 / 21.2	9.0 / 12.8 / 20.2
	SuperPoint	**100.0 / 100.0 / 100.0**	99.0 / 99.0 / 99.2	**96.7 / 96.7** / 98.0	**95.1 / 95.1 / 97.4**	**91.4 / 92.3 / 96.2**	**87.2 / 88.3 / 95.1**	**81.1 / 84.9 / 91.4**	**77.7 / 81.1 / 88.3**	**72.9 / 77.0 / 84.5**	**68.3 / 73.8 / 79.4**	**60.5 / 68.3 / 73.7**	**54.9 / 66.1 / 71.3**	**53.8 / 62.0 / 68.1**

Table A.3.2: The localization recall rates for the reference paths at elevation and pitch changes z, θ with thresholds T1 ($\leq$ 0.25m, $\leq 2°$), T2 ($\leq$0.50m,$\leq 5°$) and T3 ($\leq$5.00m, $\leq 10°$).

A.4. Weather change results - Town10

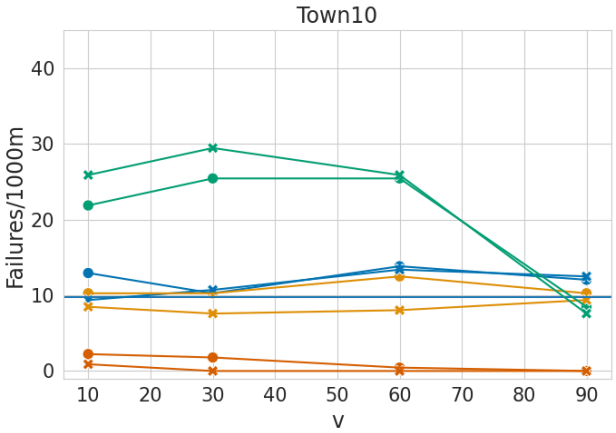

Figure A.4.1: Relationship between failure rate and visual range v.

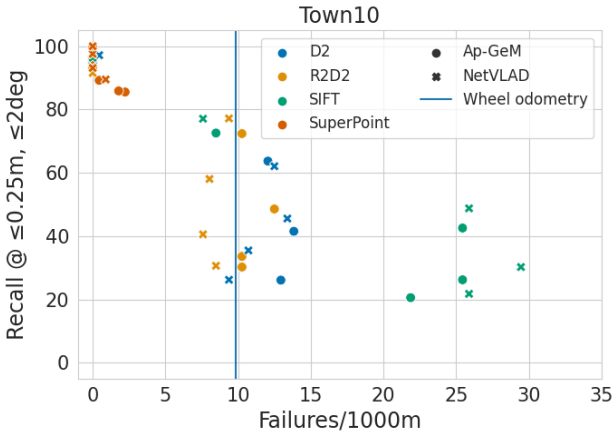

Figure A.4.2: Relationship between the failure rate and recall rate T1. Marker color and shape indicate feature type.

		Town10			
PR	LF	$v = 90$	60	30	10
Ap-GeM	Sift	8.5	25.4	25.4	21.9
	D2-net	12.1	13.8	10.3	12.9
	R2D2	10.3	12.5	10.3	10.3
	SuperPoint	**0.0**	0.4	1.8	2.2
Net-VLAD	Sift	7.6	25.9	29.5	25.9
	D2-net	12.5	13.4	10.7	9.4
	R2D2	9.4	8.0	7.6	8.5
	SuperPoint	**0.0**	**0.0**	**0.0**	**0.9**
Wheel odometry			9.8		

Table A.4.1: Failure rates at gallery-to-query weather (visibility) changes v.

		Town10			
PR	LF	$v = 90$	60	30	10
		T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3	T1 / T2 / T3
Ap-GeM	Sift	72.6 / 79.0 / 86.3	42.6 / 43.0 / 49.0	26.2 / 28.2 / 31.5	20.6 / 23.4 / 28.2
	D2-net	63.7 / 71.0 / 81.5	41.5 / 44.4 / 54.8	30.2 / 33.1 / 40.3	26.1 / 29.7 / 35.3
	R2D2	72.4 / 76.8 / 82.8	48.6 / 51.4 / 56.3	33.6 / 36.8 / 40.9	30.2 / 31.5 / 34.3
	SuperPoint	96.0 / 96.4 / 96.4	89.2 / 90.0 / 90.0	85.9 / 86.7 / 88.7	85.5 / 86.7 / 87.6
Net-VLAD	Sift	77.1 / 82.3 / 88.8	48.8 / 51.6 / 56.5	30.2 / 34.3 / 37.9	21.8 / 23.4 / 28.2
	D2-net	62.1 / 70.6 / 82.3	45.6 / 50.8 / 63.3	35.5 / 37.1 / 44.0	26.2 / 31.5 / 39.1
	R2D2	77.2 / 81.2 / 86.8	58.1 / 59.7 / 64.1	40.6 / 42.2 / 46.6	30.6 / 34.7 / 39.5
	SuperPoint	**97.6 / 97.6 / 97.6**	**97.6 / 97.6 / 97.6**	**93.1 / 94.0 / 94.0**	**89.5 / 90.7 / 91.5**

Table A.4.2: The localization recall rates for the reference paths at visual ranges v with thresholds T1 ($\leq$ 0.25m, $\leq 2°$), T2 ($\leq$0.50m,$\leq 5°$) and T3 ($\leq$5.00m, $\leq 10°$).