A APPENDIX

A.1 NETWORKS

Table 1: Network architectures.

FeatNet
2C9(6C9)-9C16-16C32-32C64-FC256-FC128-L2Norm for the COFW (300W) dataset
CoordNet
2C9(6C9)-9C16-16C32-32C64-64C128-FC128-L2Norm-FC2-Tanh for the COFW (300W) dataset
RelCoordNet
4C9(8C9)-9C16-16C32-32C64-64C128-FC128-L2Norm-FC2-2Tanh for the COFW (300W) dataset
dirPolNet
FC512-FC256-FC8-Softnax

All convolution layers have the same kernel height and width, $k_H = k_W = 3$, $s = 2$, $p = 1$.

Table 2: Hyperparameters used.

	FeatNet	(Rel)CoordNet	dirPolNet
Optimizer	Adam	Adam	Adam
# Epochs	2000	2000	1000
Batch size	256	64	128
Initial lr	1E-2	1E-2 for projection, 1E-3 for head	5E-4
Lr decay	0.1	0.1	-
Decay epoch	1500epochs	1000epochs	-

FeatNet.

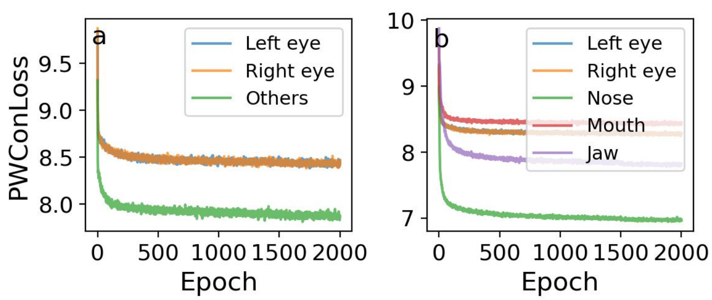

Figure 1: Learning curves of FeatNet for each group on **(a)** COFW and **(b)** 300W.

Fig. 1 represents the learning curves of FeatNet. Due to variations in inter-landmark spatial distances across different groups and differing probabilities that a randomly sampled observation becomes a positive pair for a specific landmark, the absolute values of the PWConLoss vary accordingly. Fig. 2 represents the results of using $\boldsymbol{o}_{0:2C,:,:}$ and the full observation $\boldsymbol{o}$ as the input to FeatNet. The results indicate that the difference is negligible.

CoordNet/RelCoordNet.

Fig. 3 represents the learning curves of CoordNet and RelCoordNet. Our CoordNet achieves highly accurate coordinate regression with errors of only 2.24 pixels. Although RelCoordNet shows slightly lower accuracy due to the more complex task, it still maintains high accuracy with an error of 3.49 pixels. Fig. 4 represents the results of using $\boldsymbol{o}_{C:3C,:,:}$ and the full observation $\boldsymbol{o}$ as the input to CoordNet. The results indicate that the difference is negligible.

dirPolNet. Fig. 5 represents the learning curves of dirPolNet. The cross-entropy loss is used. Similar to FeatNet, separate dirPolNet with distinct parameters is used for each group in the dataset.

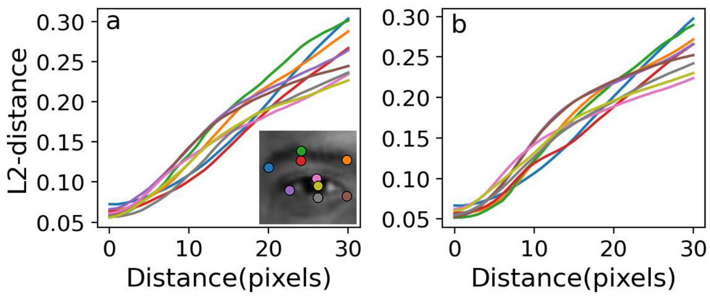

Figure 2: L2 distances between feature embeddings and landmarks at varying spatial distances from the landmarks in the inset for FeatNet (**a**) with $\boldsymbol{o}_{0:2C,:,:}$ and **(b)** with $\boldsymbol{o}$.

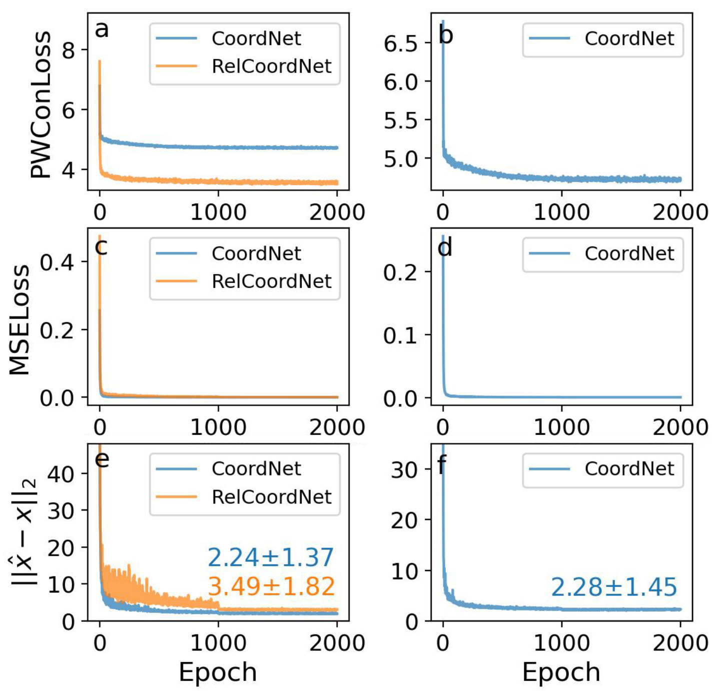

Figure 3: Learning curves of CoordNet and RelCoordNet. PWConLoss on **(a)** COFW and **(b)** 300W, MSELoss for regression head on **(c)** COFW and **(d)** 300W, coordinate regression error on **(e)** COFW and **(f)** 300W.

Table 3: Detection performance with different prior knowledge on COFW.

	$\boldsymbol{z}^*_{\text{c,ft}} = \boldsymbol{\mu}_{\boldsymbol{z}_{\text{ft}}\|\text{c}}$ $\boldsymbol{z}^*_{\text{c,cd}} = \boldsymbol{\mu}_{\boldsymbol{z}_{\text{cd}}\|\text{c}}$	$\boldsymbol{z}^*_{\text{c,ft}} \sim p(\boldsymbol{z}_{\text{ft}}\|\text{c})$ $\boldsymbol{z}^*_{\text{c,cd}} \sim p(\boldsymbol{z}_{\text{cd}}\|\text{c})$
NME	8.28	8.92
T_{d}	10.42	20.35

A.2 Prior knowledge

We used the means $\boldsymbol{\mu}_{\boldsymbol{z}_{\text{ft|c}}}$ and $\boldsymbol{\mu}_{\boldsymbol{z}_{\text{cd|c}}}$ as prior knowledge $\boldsymbol{z}^*_{\text{c,ft}}$ and $\boldsymbol{z}^*_{\text{c,ft}}$, respectively. Table 3 presents the results when the prior knowledge was sampled at each step using reparameterization trick with $\boldsymbol{\mu}_{\boldsymbol{z}_{\text{ft|c}}}$, $\boldsymbol{\mu}_{\boldsymbol{z}_{\text{cd|c}}}$, $\boldsymbol{\sigma}^2_{\boldsymbol{z}_{\text{ft|c}}}$, $\boldsymbol{\sigma}^2_{\boldsymbol{z}_{\text{cd|c}}}$. Using only means $\boldsymbol{\mu}_{\boldsymbol{z}_{\text{ft|c}}}$, $\boldsymbol{\mu}_{\boldsymbol{z}_{\text{cd|c}}}$ results in lower NME and T_{d}.

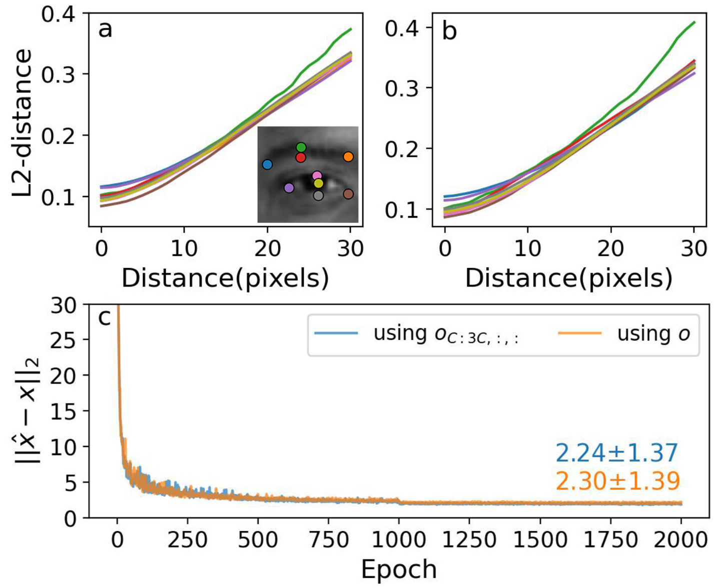

Figure 4: L2 distances between coordinate embeddings and landmarks at varying spatial distances from the landmarks in the inset for CoordNet with **(a)** $\boldsymbol{o}_{C:3C,:,:}$ and **(b)** $\boldsymbol{o}$. **(c)** Coordinate regression error for CoordNet with $\boldsymbol{o}_{C:3C,:,:}$ and $\boldsymbol{o}$.

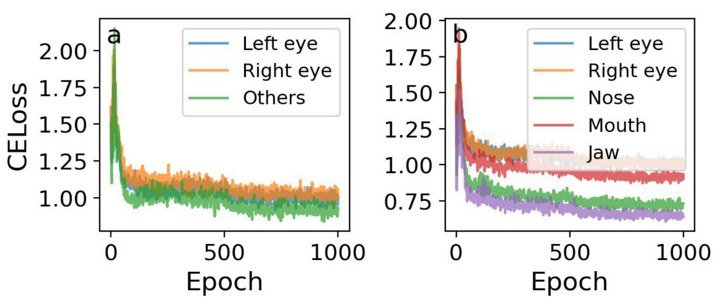

Figure 5: Learning curves of dirPolNet for each group on **(a)** COFW and **(b)** 300W.

Table 4: Detection hyperparameters.

Symbol	Definition
$\theta_{\text{d,min}}$	Initial threshold
$\Delta\theta_{\text{d}}$	Increase of threshold
$T_{\text{d,up}}$	Threshold increase starting time
$\lambda_{\text{ft,max}}$	Initial balance parameter
$\Delta\lambda_{\text{ft}}$	Decrease of balance parameter
$T_{\text{d,down}}$	Balance parameter decrease starting time

A.3 Detection hyperparameters

The detection hyperparameters are described in Table 4. We use two-stage detection technique. The landmark-wise, stage-wise hyperparameter configuration are detailed in Table 5 (COFW) and Table 6 (300W).

A.4 Pseudocode

Algorithm 1 summarizes the overall procedure of the two-stage detection process for landmark c.

Table 5: Landmark-wise, stage-wise hyperparameter confiugration on COFW.

	1	2	3	4	5	6	7	8
$\theta_{\mathrm{d,min}}$	0.009 / 0.002	0.003 / 0.001	0.006 / 0.002	0.010 / 0.004	0.006 / 0.002	0.006 / 0.002	0.004 / 0.002	0.008 / 0.003
$\Delta\theta_{\mathrm{d}}$	0.004 / 0.002	0.003 / 0.002	0.003 / 0.001	0.003 / 0.001	0.003 / 0.001	0.003 / 0.001	0.004 / 0.001	0.003 / 0.001
$T_{\mathrm{d,up}}$	7 / 1	1 / 2	1 / 2	9 / 1	1 / 2	1 / 2	1 / 3	4 / 3
$\lambda_{\mathrm{ft,max}}$	0.89 / 0.90	0.99 / 0.99	0.79 / 0.81	0.78 / 0.82	0.79 / 0.81	0.79 / 0.81	0.73 / 0.90	0.91 / 0.97
$\Delta\lambda_{\mathrm{ft}}$	0.18 / 0.08	0.16 / 0.09	0.18 / 0.10	0.19 / 0.07	0.18 / 0.10	0.18 / 0.10	0.18 / 0.08	0.15 / 0.09
$T_{\mathrm{d,down}}$	6 / 6	9 / 7	5 / 5	9 / 9	5 / 5	5 / 5	9 / 10	7 / 8
	9	10	11	12	13	14	15	16
$\theta_{\mathrm{d,min}}$	0.006 / 0.002	0.009 / 0.003	0.006 / 0.002	0.005 / 0.002	0.010 / 0.003	0.006 / 0.002	0.008 / 0.002	0.009 / 0.002
$\Delta\theta_{\mathrm{d}}$	0.003 / 0.001	0.004 / 0.001	0.003 / 0.001	0.005 / 0.001	0.004 / 0.002	0.003 / 0.001	0.004 / 0.001	0.004 / 0.001
$T_{\mathrm{d,up}}$	1 / 2	1 / 3	1 / 2	3 / 3	2 / 1	1 / 2	5 / 4	4 / 3
$\lambda_{\mathrm{ft,max}}$	0.79 / 0.81	0.94 / 0.98	0.79 / 0.81	0.78 / 0.84	0.83 / 0.84	0.79 / 0.81	0.93 / 0.99	0.89 / 0.98
$\Delta\lambda_{\mathrm{ft}}$	0.18 / 0.10	0.19 / 0.09	0.18 / 0.10	0.16 / 0.07	0.14 / 0.08	0.18 / 0.10	0.12 / 0.08	0.19 / 0.09
$T_{\mathrm{d,down}}$	5 / 5	9 / 5	5 / 5	7 / 7	8 / 7	5 / 5	9 / 5	8 / 5
	17	18	19	20	21	22	23	24
$\theta_{\mathrm{d,min}}$	0.006 / 0.002	0.005 / 0.002	0.008 / 0.003	0.009 / 0.004	0.007 / 0.003	0.010 / 0.003	0.009 / 0.002	0.008 / 0.003
$\Delta\theta_{\mathrm{d}}$	0.003 / 0.001	0.005 / 0.001	0.004 / 0.002	0.004 / 0.002	0.002 / 0.001	0.003 / 0.001	0.004 / 0.002	0.003 / 0.001
$T_{\mathrm{d,up}}$	1 / 2	3 / 3	6 / 1	8 / 1	1 / 1	5 / 1	2 / 2	3 / 2
$\lambda_{\mathrm{ft,max}}$	0.79 / 0.81	0.78 / 0.84	0.74 / 0.76	0.73 / 0.74	0.77 / 0.91	0.96 / 0.99	0.76 / 0.99	0.94 / 0.96
$\Delta\lambda_{\mathrm{ft}}$	0.18 / 0.10	0.16 / 0.07	0.16 / 0.07	0.11 / 0.06	0.16 / 0.09	0.14 / 0.10	0.18 / 0.06	0.13 / 0.10
$T_{\mathrm{d,down}}$	5 / 5	7 / 7	8 / 7	6 / 8	8 / 7	7 / 7	7 / 6	5 / 9
	25	26	27	28	29			
$\theta_{\mathrm{d,min}}$	0.008 / 0.003	0.010 / 0.003	0.006 / 0.002	0.010 / 0.003	0.009 / 0.003			
$\Delta\theta_{\mathrm{d}}$	0.004 / 0.002	0.003 / 0.001	0.004 / 0.002	0.003 / 0.001	0.004 / 0.002			
$T_{\mathrm{d,up}}$	4 / 2	5 / 1	3 / 2	5 / 1	3 / 4			
$\lambda_{\mathrm{ft,max}}$	0.77 / 0.93	0.96 / 0.99	0.90 / 0.96	0.96 / 0.99	0.87 / 0.91			
$\Delta\lambda_{\mathrm{ft}}$	0.15 / 0.08	0.14 / 0.10	0.14 / 0.07	0.14 / 0.10	0.14 / 0.07			
$T_{\mathrm{d,down}}$	6 / 7	7 / 7	9 / 5	7 / 7	6 / 6			

A.5 Landmark-wise performance

The landmark-wise detection performance is detailed in Table 7 (COFW) and Table 8 (300W).

Table 6: Landmark-wise, stage-wise hyperparameter confiugration on 300W.

	1	2	3	4	5	6	7	8
$\theta_{\text{d,min}}$	0.005 / 0.002	0.008 / 0.008	0.005 / 0.002	0.009 / 0.005	0.006 / 0.001	0.004 / 0.002	0.003 / 0.001	0.010 / 0.002
$\Delta\theta_{\text{d}}$	0.005 / 0.002	0.005 / 0.005	0.005 / 0.002	0.005 / 0.002	0.004 / 0.002	0.004 / 0.002	0.005 / 0.001	0.004 / 0.002
$T_{\text{d,up}}$	4 / 6	1 / 1	1 / 1	1 / 4	5 / 3	5 / 2	3 / 1	5 / 1
$\lambda_{\text{ft,max}}$	0.78 / 0.99	0.80 / 0.80	0.85 / 0.97	0.79 / 0.91	0.95 / 0.96	0.95 / 0.95	0.97 / 0.99	0.88 / 0.97
$\Delta\lambda_{\text{ft}}$	0.11 / 0.10	0.11 / 0.11	0.10 / 0.07	0.10 / 0.10	0.18 / 0.10	0.11 / 0.07	0.15 / 0.07	0.14 / 0.06
$T_{\text{d,down}}$	5 / 9	8 / 8	10 / 7	10 / 9	6 / 5	10 / 8	10 / 8	6 / 10
	9	10	11	12	13	14	15	16
$\theta_{\text{d,min}}$	0.005 / 0.002	0.004 / 0.004	0.005 / 0.002	0.003 / 0.001	0.003 / 0.001	0.010 / 0.004	0.010 / 0.004	0.010 / 0.005
$\Delta\theta_{\text{d}}$	0.003 / 0.001	0.003 / 0.003	0.004 / 0.002	0.005 / 0.001	0.004 / 0.002	0.002 / 0.001	0.004 / 0.002	0.005 / 0.002
$T_{\text{d,up}}$	3 / 2	4 / 4	4 / 2	1 / 1	1 / 2	5 / 1	9 / 1	1 / 3
$\lambda_{\text{ft,max}}$	0.83 / 0.98	0.86 / 0.86	0.94 / 0.99	0.95 / 0.98	0.90 / 0.91	0.94 / 0.95	0.78 / 0.88	0.73 / 0.80
$\Delta\lambda_{\text{ft}}$	0.12 / 0.06	0.18 / 0.18	0.17 / 0.07	0.15 / 0.10	0.16 / 0.08	0.14 / 0.07	0.13 / 0.07	0.18 / 0.09
$T_{\text{d,down}}$	6 / 9	7 / 7	8 / 7	5 / 7	7 / 6	7 / 5	8 / 8	10 / 6
	17	18	19	20	21	22	23	24
$\theta_{\text{d,min}}$	0.003 / 0.001	0.009 / 0.009	0.006 / 0.001	0.009 / 0.003	0.003 / 0.001	0.005 / 0.001	0.010 / 0.001	0.010 / 0.001
$\Delta\theta_{\text{d}}$	0.005 / 0.002	0.003 / 0.003	0.005 / 0.002	0.004 / 0.002	0.004 / 0.002	0.004 / 0.002	0.002 / 0.001	0.002 / 0.001
$T_{\text{d,up}}$	5 / 1	8 / 8	1 / 5	2 / 2	3 / 7	1 / 5	5 / 5	5 / 5
$\lambda_{\text{ft,max}}$	0.91 / 0.92	0.99 / 0.99	1.00 / 1.00	0.93 / 1.00	0.99 / 0.99	0.88 / 1.00	0.90 / 1.00	0.90 / 1.00
$\Delta\lambda_{\text{ft}}$	0.14 / 0.07	0.20 / 0.20	0.12 / 0.07	0.11 / 0.06	0.14 / 0.08	0.13 / 0.06	0.20 / 0.05	0.20 / 0.05
$T_{\text{d,down}}$	5 / 9	7 / 7	6 / 5	10 / 7	7 / 6	5 / 6	10 / 10	10 / 10
	25	26	27	28	29	30	31	32
$\theta_{\text{d,min}}$	0.009 / 0.004	0.005 / 0.005	0.009 / 0.003	0.010 / 0.001	0.010 / 0.001	0.009 / 0.002	0.010 / 0.001	0.010 / 0.001
$\Delta\theta_{\text{d}}$	0.004 / 0.001	0.005 / 0.005	0.003 / 0.001	0.002 / 0.001	0.002 / 0.001	0.004 / 0.002	0.002 / 0.001	0.002 / 0.001
$T_{\text{d,up}}$	5 / 8	4 / 4	6 / 3	5 / 5	5 / 5	1 / 2	5 / 5	5 / 5
$\lambda_{\text{ft,max}}$	0.86 / 0.97	0.95 / 0.95	0.97 / 0.98	0.90 / 1.00	0.90 / 1.00	0.98 / 0.99	0.90 / 1.00	0.90 / 1.00
$\Delta\lambda_{\text{ft}}$	0.11 / 0.08	0.12 / 0.12	0.16 / 0.09	0.20 / 0.05	0.20 / 0.05	0.14 / 0.09	0.20 / 0.05	0.20 / 0.05
$T_{\text{d,down}}$	9 / 7	6 / 6	10 / 9	10 / 10	10 / 10	5 / 8	10 / 10	10 / 10
	33	34	35	36	37	38	39	40
$\theta_{\text{d,min}}$	0.010 / 0.001	0.010 / 0.010	0.010 / 0.001	0.010 / 0.001	0.003 / 0.001	0.009 / 0.002	0.009 / 0.002	0.009 / 0.002
$\Delta\theta_{\text{d}}$	0.002 / 0.001	0.002 / 0.002	0.002 / 0.001	0.002 / 0.001	0.002 / 0.001	0.003 / 0.001	0.003 / 0.001	0.003 / 0.001
$T_{\text{d,up}}$	5 / 5	5 / 5	5 / 5	5 / 5	5 / 2	8 / 1	8 / 1	8 / 1
$\lambda_{\text{ft,max}}$	0.90 / 1.00	0.90 / 0.90	0.90 / 1.00	0.90 / 1.00	0.85 / 0.99	0.99 / 1.00	0.99 / 1.00	0.90 / 0.99
$\Delta\lambda_{\text{ft}}$	0.20 / 0.05	0.20 / 0.20	0.20 / 0.05	0.20 / 0.05	0.20 / 0.07	0.20 / 0.08	0.20 / 0.08	0.20 / 0.08
$T_{\text{d,down}}$	10 / 10	10 / 10	10 / 10	10 / 10	10 / 6	7 / 6	7 / 6	7 / 6
	41	42	43	44	45	46	47	48
$\theta_{\text{d,min}}$	0.006 / 0.003	0.003 / 0.003	0.010 / 0.001	0.005 / 0.002	0.007 / 0.002	0.010 / 0.004	0.007 / 0.003	0.010 / 0.001
$\Delta\theta_{\text{d}}$	0.004 / 0.002	0.002 / 0.002	0.002 / 0.001	0.003 / 0.001	0.004 / 0.001	0.002 / 0.001	0.005 / 0.001	0.002 / 0.001
$T_{\text{d,up}}$	1 / 10	6 / 6	5 / 5	1 / 3	2 / 2	2 / 5	4 / 3	5 / 5
$\lambda_{\text{ft,max}}$	0.91 / 1.00	1.00 / 1.00	0.90 / 1.00	0.99 / 0.99	0.92 / 0.95	0.91 / 0.96	0.96 / 0.99	0.90 / 1.00
$\Delta\lambda_{\text{ft}}$	0.15 / 0.05	0.19 / 0.19	0.20 / 0.05	0.16 / 0.06	0.12 / 0.08	0.13 / 0.06	0.19 / 0.08	0.20 / 0.05
$T_{\text{d,down}}$	10 / 6	7 / 7	10 / 10	6 / 8	8 / 7	6 / 6	6 / 6	10 / 10
	49	50	51	52	53	54	55	56
$\theta_{\text{d,min}}$	0.001 / 0.001	0.004 / 0.004	0.007 / 0.003	0.010 / 0.001	0.010 / 0.003	0.009 / 0.004	0.007 / 0.003	0.007 / 0.003
$\Delta\theta_{\text{d}}$	0.004 / 0.002	0.004 / 0.004	0.003 / 0.001	0.002 / 0.001	0.003 / 0.001	0.004 / 0.001	0.002 / 0.001	0.004 / 0.002
$T_{\text{d,up}}$	1 / 3	1 / 1	10 / 2	5 / 5	10 / 2	8 / 6	1 / 1	4 / 2
$\lambda_{\text{ft,max}}$	0.95 / 0.98	0.91 / 0.91	0.98 / 0.99	0.90 / 1.00	0.99 / 1.00	0.99 / 1.00	0.99 / 0.99	0.93 / 0.95
$\Delta\lambda_{\text{ft}}$	0.14 / 0.06	0.15 / 0.15	0.11 / 0.08	0.20 / 0.05	0.15 / 0.05	0.18 / 0.09	0.19 / 0.08	0.12 / 0.09
$T_{\text{d,down}}$	7 / 7	9 / 9	6 / 6	10 / 10	8 / 10	6 / 9	6 / 10	7 / 8
	57	58	59	60	61	62	63	64
$\theta_{\text{d,min}}$	0.004 / 0.002	0.009 / 0.009	0.009 / 0.004	0.005 / 0.002	0.008 / 0.004	0.007 / 0.002	0.002 / 0.001	0.003 / 0.001
$\Delta\theta_{\text{d}}$	0.004 / 0.001	0.005 / 0.005	0.004 / 0.001	0.003 / 0.001	0.004 / 0.002	0.003 / 0.002	0.003 / 0.001	0.004 / 0.002
$T_{\text{d,up}}$	1 / 3	2 / 2	1 / 3	5 / 3	7 / 2	3 / 3	1 / 2	6 / 2
$\lambda_{\text{ft,max}}$	0.93 / 1.00	0.98 / 0.98	0.96 / 0.98	0.98 / 0.99	0.99 / 0.99	1.00 / 1.00	0.96 / 1.00	0.99 / 1.00
$\Delta\lambda_{\text{ft}}$	0.11 / 0.10	0.13 / 0.13	0.17 / 0.06	0.15 / 0.09	0.15 / 0.09	0.16 / 0.06	0.12 / 0.05	0.12 / 0.07
$T_{\text{d,down}}$	9 / 7	9 / 9	9 / 7	10 / 9	7 / 5	5 / 8	8 / 9	10 / 6
	65	66	67	68				
$\theta_{\text{d,min}}$	0.009 / 0.004	0.010 / 0.010	0.010 / 0.001	0.007 / 0.002				
$\Delta\theta_{\text{d}}$	0.003 / 0.002	0.003 / 0.003	0.002 / 0.001	0.004 / 0.001				
$T_{\text{d,up}}$	9 / 2	7 / 7	5 / 5	10 / 1				
$\lambda_{\text{ft,max}}$	0.97 / 0.98	1.00 / 1.00	0.90 / 1.00	0.98 / 1.00				
$\Delta\lambda_{\text{ft}}$	0.13 / 0.07	0.17 / 0.17	0.20 / 0.05	0.14 / 0.08				
$T_{\text{d,down}}$	9 / 10	9 / 9	10 / 10	5 / 10				

Table 7: Landmark-wise detection performance on COFW.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
NME	10.42	9.37	8.24	8.34	8.70	8.40	9.10	8.45	8.26	7.34	6.53	6.49	7.70	6.81
T_{d}	6.98	7.15	10.96	8.30	11.21	10.99	10.42	8.90	11.26	8.46	11.85	11.74	7.89	9.33
	15	16	17	18	19	20	21	22	23	24	25	26	27	28
NME	6.18	6.06	7.29	6.07	8.04	7.09	8.42	7.80	10.26	9.66	8.67	8.62	9.47	10.45
T_{d}	9.95	8.54	11.43	12.43	10.45	10.50	8.91	9.44	10.40	11.93	10.11	11.63	12.04	10.15
	29	**mean**												
NME	12.02	**8.28**												
T_{d}	18.36	**10.42**												

Algorithm 1 Operation of proposed agent.

Input: c, Image, $\boldsymbol{x}$, t_{max} $\boldsymbol{\theta}_{\text{d,min}} \in \mathbb{R}^2$, $\Delta\boldsymbol{\theta}_{\text{d}} \in \mathbb{R}^2$, $\boldsymbol{T}_{\text{d,up}} \in \mathbb{R}^2$, $\boldsymbol{\lambda}_{\text{ft,max}} \in \mathbb{R}^2$, $\Delta\boldsymbol{\lambda}_{\text{ft}} \in \mathbb{R}^2$, $\boldsymbol{T}_{\text{d,down}} \in \mathbb{R}^2$
Output: $\hat{\boldsymbol{x}}_c$

$z^*_{\text{c,ft}}, z^*_{\text{c,cd}} \leftarrow$ Prior knowledge modeling(c)
$\hat{\boldsymbol{x}}_c \leftarrow$ NULL
for stage $= 0$ to 1 **do**
  $\theta_{\text{d}} \leftarrow \boldsymbol{\theta}_{\text{d,min}}$[stage]
  $\Delta\theta_{\text{d}} \leftarrow \Delta\boldsymbol{\theta}_{\text{d}}$[stage]
  $T_{\text{d,up}} \leftarrow \boldsymbol{T}_{\text{d,up}}$[stage]
  $\lambda_{\text{ft}} \leftarrow \boldsymbol{\lambda}_{\text{ft,max}}$[stage]
  $\lambda_{\text{cd}} \leftarrow 1 - \lambda_{\text{ft}}$
  $\Delta\lambda_{\text{ft}} \leftarrow \Delta\boldsymbol{\lambda}_{\text{ft}}$[stage]
  $T_{\text{d,down}} \leftarrow \boldsymbol{T}_{\text{d,down}}$[stage]
  $\hat{\boldsymbol{\Lambda}} \leftarrow \{\lambda_{\text{ft}}[t] | \forall t \in [0, t_{\text{max}}]\}$
  for $t = 0$ to t_{max} **do**
    $\boldsymbol{o} \leftarrow$ Observation by agent(Image, $\boldsymbol{x}$)
    $z_{\text{ft}}, z_{\text{cd}}, \hat{\boldsymbol{x}} \leftarrow$ Data extraction$(\boldsymbol{o})$
    $D_{\text{ft}}, D_{\text{cd}}, D \leftarrow$ DistComp$(z_{(\cdot)}, z^*_{\text{c},(\cdot)}, \lambda_{(\cdot)})$, where $(\cdot) \in$ {ft,cd}
    $\hat{\boldsymbol{x}}_c \leftarrow$ Delayed decision$(\hat{\boldsymbol{\Lambda}}, D_{\text{ft}}, D_{\text{cd}}, \theta_{\text{d}}, \lambda_{\text{ft}}, \hat{\boldsymbol{x}})$
    if $\hat{\boldsymbol{x}}_c \neq$ NULL **then**
      $\boldsymbol{x} \leftarrow \hat{\boldsymbol{x}}_c$
      Terminate.
    end if
    if $t \geq T_{\text{d,up}}$ **then**
      $\theta_{\text{d}} \leftarrow \theta_{\text{d}} + \Delta\theta_{\text{d}}$
    end if
    if $t \geq T_{\text{d,down}}$ and $t - T_{\text{d,down}} =$ even **then**
      $\lambda_{\text{ft}} \leftarrow \lambda_{\text{ft}} - \Delta\lambda_{\text{ft}}$
    end if
    $s \cdot \boldsymbol{u}^* \leftarrow$ Hopping policy$(D, z_{(\cdot)}, z^*_{\text{c},(\cdot)}, \lambda_{(\cdot)})$, where $(\cdot) \in$ {ft,cd}
    $\boldsymbol{x} \leftarrow \boldsymbol{x} + s \cdot \boldsymbol{u}^*$
  end for
end for

Table 8: Landmark-wise detection performance on 300W.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
NME	13.68	12.68	13.01	14.51	13.38	13.03	11.97	10.73	9.74	10.28	11.00	12.07	13.56	13.07
T_{d}	23.80	18.83	19.67	17.83	19.50	16.92	14.56	11.92	13.67	15.09	14.54	16.09	18.78	26.02
	15	16	17	18	19	20	21	22	23	24	25	26	27	28
NME	12.83	12.13	14.06	10.62	9.49	10.33	9.87	10.70	9.44	9.49	9.97	9.49	10.67	8.25
T_{d}	24.22	17.37	21.61	8.57	10.11	6.50	13.94	10.13	11.92	13.07	10.88	11.47	9.63	14.60
	29	30	31	32	33	34	35	36	37	38	39	40	41	42
NME	9.53	13.00	15.99	11.52	10.85	10.92	10.96	11.00	6.43	6.11	6.31	8.02	6.69	6.61
T_{d}	12.26	6.81	14.23	20.55	19.95	19.24	19.66	21.35	13.48	8.53	9.19	10.61	7.35	9.39
	43	44	45	46	47	48	49	50	51	52	53	54	55	56
NME	7.08	5.85	6.13	6.11	5.93	6.10	8.25	7.14	7.54	7.41	7.72	6.81	8.61	7.28
T_{d}	11.79	7.19	8.88	10.97	7.51	10.56	9.70	8.64	8.98	14.70	7.92	8.48	7.51	9.77
	57	58	59	60	61	62	63	64	65	66	67	68	**mean**	
NME	7.41	6.55	7.09	7.29	7.62	6.71	6.45	7.00	7.67	7.26	6.80	7.26	**9.36**	
T_{d}	9.22	6.97	7.14	12.01	7.28	8.08	9.13	11.54	7.45	8.92	13.94	10.31	**12.77**	