From Inconsistency to Unity: A Benchmarking Framework for Unsupervised RUL Domain Adaptation

-

Appendix

I. Dataset Details

Dataset		Training	Validation	Test
C-MAPSS	**1**	$\text{TRAIN}_1 - \text{TRAIN}_{80}$	$\text{TRAIN}_{81} - \text{TRAIN}_{100}$	$\text{TEST}_1 - \text{TEST}_{100}$
	2	$\text{TRAIN}_1 - \text{TRAIN}_{208}$	$\text{TRAIN}_{209} - \text{TRAIN}_{260}$	$\text{TEST}_1 - \text{TEST}_{259}$
	3	$\text{TRAIN}_1 - \text{TRAIN}_{80}$	$\text{TRAIN}_{81} - \text{TRAIN}_{100}$	$\text{TEST}_1 - \text{TEST}_{100}$
	4	$\text{TRAIN}_1 - \text{TRAIN}_{199}$	$\text{TRAIN}_{200} - \text{TRAIN}_{249}$	$\text{TEST}_1 - \text{TEST}_{248}$
FEMTO	**1**	$\text{BEARING}_1, \text{BEARING}_2$	BEARING_3	$\text{BEARING}_4 - \text{BEARING}_7$
	2			
	3	BEARING_1	BEARING_2	BEARING_3
XJTU-SY	**1**	$\text{BEARING}_1, \text{BEARING}_2$	BEARING_3	$\text{BEARING}_4, \text{BEARING}_5$
	2			
	3			

TABLE I

Split Assignments per Dataset: TRAIN_i denotes the i^{th} entity from the original C-MAPSS training split and TEST_i the i^{th} entity from the original test split. BEARING_i denotes the i^{th} bearing of the respective condition in FEMTO and XJTU-SY respectively.

XJTU-SY	Cond1	Cond2	Cond3
Cond1	-	$1 \rightarrow 2$	$1 \rightarrow 3$
Cond2	$2 \rightarrow 1$	-	$2 \rightarrow 3$
Cond3	$3 \rightarrow 1$	$3 \rightarrow 2$	-

FEMTO	Cond1	Cond2	Cond3
Cond1	-	$1 \rightarrow 2$	$1 \rightarrow 3$
Cond2	$2 \rightarrow 1$	-	$2 \rightarrow 3$
Cond3	$3 \rightarrow 1$	$3 \rightarrow 2$	-

C-MAPSS	Cond1	Cond2	Cond3	Cond4
Cond1	-	$1 \rightarrow 2$	$1 \rightarrow 3$	$1 \rightarrow 4$
Cond2	$2 \rightarrow 1$	-	$2 \rightarrow 3$	$2 \rightarrow 4$
Cond3	$3 \rightarrow 1$	$3 \rightarrow 2$	-	$3 \rightarrow 4$
Cond4	$4 \rightarrow 1$	$4 \rightarrow 2$	$4 \rightarrow 3$	-

TABLE II

Investigated adaptation Tasks: Each row represents a labeled source dataset and each column an unlabeled target dataset.

Dataset		Bearing 1	2	3	4	5	6	7
FEMTO	**1**	407	544	521	840	2306	479	995
	2	819	192	257	248	252	213	163
	3	132	116	306	-	-	-	-
XJTU-SY	**1**	28	32	61	52	36	-	-
	2	238	65	128	4	121	-	-
	3	749	614	342	1418	74	-	-

TABLE III

First-time-to-predict for the bearings in FEMTO and XJTU-SY.

II. HYPERPARAMETER DETAILS

	Hyperparameter	Sampling	Boundaries
1D-CNN	Learning Rate	loguniform	$[10^{-5}, 10^{-2}]$
	# Layers	choice	$[1, 10]$
	p Dropout	uniform	$[0, 0.5]$
	# Feature Channels	choice	$\{16, 32, 34\}$
	Kernel Size	choice	$\{3, 5, 8\}$
	# FC Units	choice	$\{16, 32, 64, 128\}$
LSTM	Learning Rate	loguniform	$[10^{-5}, 10^{-2}]$
	# Layers	choice	$[1, 3]$
	p Dropout	uniform	$[0, 0.5]$
	Hidden Size	choice	$\{16, 32, 34\}$
	# FC Units	choice	$\{16, 32, 64, 128\}$

TABLE IV
THE HYPERPARAMETER SEARCH SPACE FOR THE BACKBONE NETWORKS.

	Hyperparameter	Sampling	Boundaries
DANN	Learning Rate	loguniform	$[10^{-5}, 10^{-2}]$
	# Layers Domain Disc	choice	$[1, 3]$
	DANN Factor	loguniform	$[0.1, 10.0]$
MMD	Learning Rate	loguniform	$[10^{-5}, 10^{-2}]$
	# Kernels	choice	$[1, 5]$
	MMD Factor	loguniform	$[0.1, 10.0]$
Consistency	Learning Rate	loguniform	$[10^{-5}, 10^{-2}]$
	# Layers Domain Disc	choice	$[1, 3]$
	Consistency Factor	loguniform	$[0.1, 1.0]$
Conditional DANN	Learning Rate	loguniform	$[10^{-5}, 10^{-2}]$
	# Layers Domain Disc	choice	$[1, 3]$
	DANN Factor	loguniform	$[0.1, 10.0]$
	Dynamic Adaptive Factor	uniform	$[0.1, 0.9]$
Conditional MMD	Learning Rate	loguniform	$[10^{-5}, 10^{-2}]$
	# Kernels	choice	$[1, 5]$
	MMD Factor	loguniform	$[0.1, 10.0]$
	Dynamic Adaptive Factor	uniform	$[0.1, 0.9]$
Latent Alignment	Learning Rate	loguniform	$[10^{-5}, 10^{-2}]$
	α_h, $\alpha_{d,d}$, $\alpha_{d,l}$, $\alpha_{d,f}$	loguniform	$[0.1, 10.0]$
AdaRUL	Learning Rate	loguniform	$[10^{-5}, 10^{-2}]$
	# Generator Updates	choice	$[1, 10]$
	# Discriminator Updates	choice	$[5, 50]$
	# Layers Domain Disc	choice	$[1, 3]$
Pseudo Labels	Learning Rate	loguniform	$[10^{-5}, 10^{-2}]$

TABLE V
THE HYPERPARAMETER SEARCH SPACE FOR THE APPROACHES.

	Hyperparameter	C-MAPSS	FEMTO	XJTU-SY
1D-CNN	Learning Rate	0.00146	0.00048	0.00005
	# Layers	2	5	2
	p Dropout	0.1	0.2	0.2
	# Feature Channels	32	64	64
	Kernel Size	3	7	7
	# FC Units	32	64	64
LSTM	Learning Rate	0.00046	-	-
	# Layers	1	-	-
	p Dropout	0.2	-	-
	Hidden Size	16	-	-
	# FC Units	16	-	-

TABLE VI
THE HYPERPARAMETERS FOR THE BACKBONE NETWORKS.

	Hyperparameter	C-MAPSS	FEMTO	XJTU-SY
DANN	Learning Rate	0.00002	0.00052	0.00024
	# Layers Domain Disc	3	3	1
	DANN Factor	8.0	5.7	0.1
MMD	Learning Rate	0.00198	0.00657	0.00003
	# Kernels	3	1	4
	MMD Factor	1.1	4.9	0.2
Consistency	Learning Rate	0.0081	0.00224	0.00136
	# Layers Domain Disc	2	1	3
	Consistency Factor	0.5	1.0	0.7
Conditional DANN	Learning Rate	0.00001	0.00015	0.00023
	# Layers Domain Disc	3	2	3
	DANN Factor	5.7	0.3	1.1
	Dynamic Adaptive Factor	0.3	0.2	0.5
Conditional MMD	Learning Rate	0.00042	0.00087	0.00012
	# Kernels	2	4	1
	MMD Factor	0.4	0.1	0.1
	Dynamic Adaptive Factor	0.3	0.7	0.2
Latent Alignment	Learning Rate	0.000234	0.00546	0.00025
	α_h, $\alpha_{d,d}$, $\alpha_{d,l}$, $\alpha_{d,f}$	1.1	3.2	0.1
AdaRUL	Learning Rate	0.00014	0.00012	0.00001
	# Generator Updates	7	9	5
	# Discriminator Updates	20	10	25
	# Layers Domain Disc	3	2	2
Pseudo Labels	Learning Rate	0.00085	0.00584	0.0002

TABLE VII
THE HYPERPARAMETERS FOR THE APPROACHES.

III. FIRST-TIME-TO-PREDICT CALCULATION

$$h(\mathbf{a}_{ij}) = \textsc{Kurtosis}(||\mathbf{a}_{ijk}||_2, \forall k), \quad \mathbf{a}_{ijk} \in \mathbb{R}^2 \tag{1}$$

$$t^{\text{EARLY}} = \frac{1}{5|\mathcal{X}^{\text{TR}}|} \sum_{x \in \mathcal{X}^{\text{TR}}} |x| \tag{2}$$

$$t_i^{\text{EARLY}} = \begin{cases} t^{\text{EARLY}}, & t^{\text{EARLY}} \leq 0.5|x_i| \\ 0.1|x_i|, & t^{\text{EARLY}} > 0.5|x_i| \end{cases} \tag{3}$$

$$h_i^* = 2\sigma\left(h(\mathbf{a}_{ij}),\, j < t_i^{\text{EARLY}}\right) \tag{4}$$

$$\bar{h}_i = \mu\left(h(\mathbf{a}_{ij}),\, j < t_i^{\text{EARLY}}\right) \tag{5}$$

$$h'(\mathbf{a}_{ij}) = |h(\mathbf{a}_{ij}) - \bar{h}_i| \tag{6}$$

$$\text{FTTP}_i = \min t, \text{ subject to } h'(\mathbf{a}_{it}) > h_i^* \wedge h'(\mathbf{a}_{i(t-1)}) > h_i^* \tag{7}$$