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Automatic evaluation of blind fasteners installation

Mariluz Penalva

Tecnalia Industry & Mobility

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To be the agents of change in **companies and society**, adapting them to the challenges of a constantly evolving future.

We work with companies and institutions to increase their **competitiveness, quality of life** of people and achieve **sustainable growth**.

We are committed to **results**, always thinking about our clients and facilitating their activity with a close and useful service.

Smart Manufacturing:

In a changing global scenario, we pursue an aim shared with manufacturing companies from all sectors, making a positive impact on their productivity while increasing the competitiveness of their businesses. To do so, **we are committed to smart, flexible and sustainable manufacturing through digitalisation, automation and eco-efficiency** as drivers of the change that transforms materials and manufacturing processes.

Further information

What can we do for you?

- Industry 4.0
- Advanced machines, **automation** and robotics
- Decarbonisation of industry and the circular economy
- New materials and **manufacturing processes**
- Additive manufacturing

The drivers

- Assembly by mechanical joining is a relevant operation in the overall aircraft manufacturing cycle though heavily manual due to high flexibility requirements
- The need for automated assembly has increased over the last years
  - Lower cost, shorter cycle times, higher precision, limited accessibility, people augmentation…
- The control of the quality of the joints is a major request in an automated environment
- Blind fasteners are originally conceived for closed structures and are installed just by accessing the front side of the assembly, leading to easier and cheaper automation solutions for any type of structure

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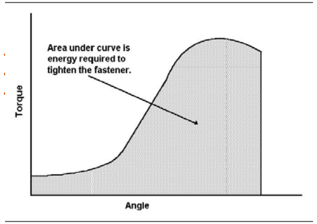
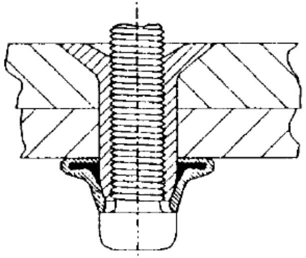


Using AI to control blind fastening

- Achieving proper control of a tightening process is possible by understanding the relationship between torque and turn in the development of tension, aka installation diagram

- Blind fastening is dominated by
  - Stochastic variables: complex mechanical system, batch variability
  - Continuously varying conditions: material, thickness, fastener dash&grip



By combining **domain knowledge** and several **AI approaches** Tecnalia has been working in the development of an automated evaluation of the quality of blind fasteners installations through several **collaborations with industry**

- Private contracts with Airbus Es
- Clean Sky 2 BLINDFAST project (ref. 686827) with Airbus De as Topic Manager
- On-going discussions with end-users, tiers-1 and OEMs

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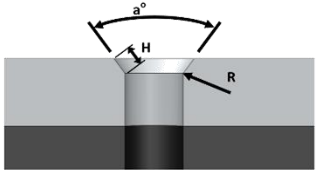
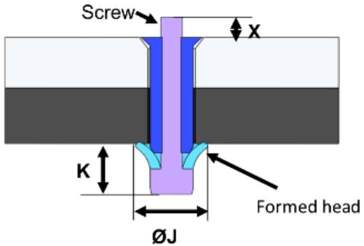
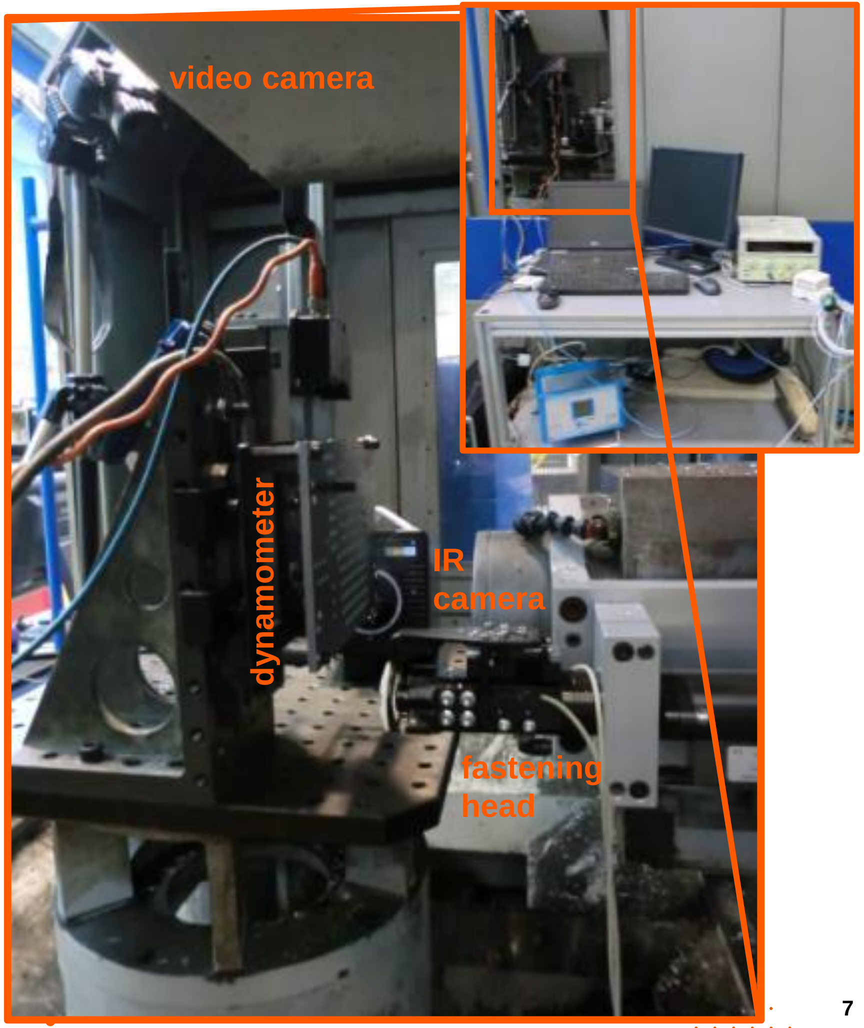
Materials and tests

- In-house holemaking & fastening tests
- Monogram Composilok-II fasteners
- Aritex-Loxin fastening head to provide the torque-rev installation diagram
- NI platform for signals acquisition (1000Hz)
- IR and video (286fps) images
- Holes & fasteners quality checks according to specifications







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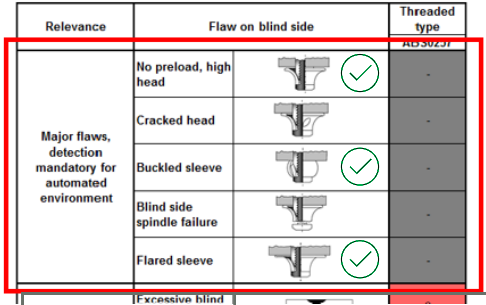
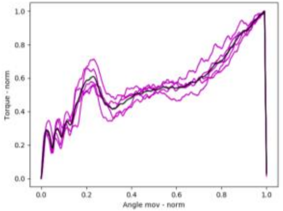
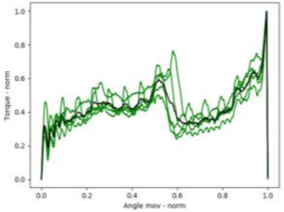


Relevance	Flaw on blind side		Threaded type
Major flaws, detection mandatory for automated environment	No preload, high head		-
	Cracked head		-
	Buckled sleeve		-
	Blind side spindle failure		-
	Flared sleeve		-
	Excessive blind		

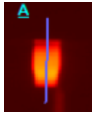
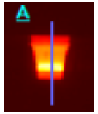
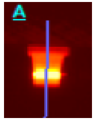
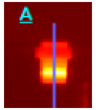


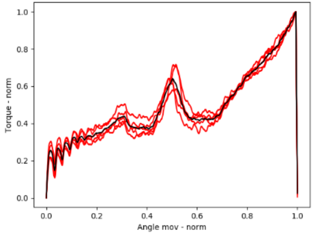


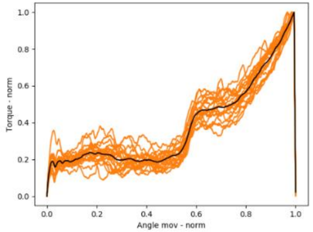
RCA

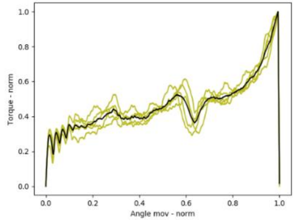
Aim. (1) Identify the conditions leading to different defect installations, (2) Gain any other domain knowledge

Main conclusion. How important are grip conditions (thickness, code) on the installation and diagram produced, either OK/NOK

Thickness (mm)	Camera picture	IR picture	J (mm)	K (mm)	Type of error
Too low ~8,5			NOK ~6,16	NOK ~9,6	High head Can be quantified
Lower limit ~11,4			OK 7,71-7,86	OK 7,56-7,89	Correct installation Can be quantified
Upper limit ~12,6			OK 8,34-8,39	OK 6,59-7,00	Flared head Cannot be quantified
Too high ~15,1			NOK 7,24-7,48	OK 6,43-6,86	Buckled head Can be quantified







CL-II-6-500 /Grip range [11,43; 12,7mm] | Formed head limits (Jmin 7,62mm; Kmax 8,89mm)

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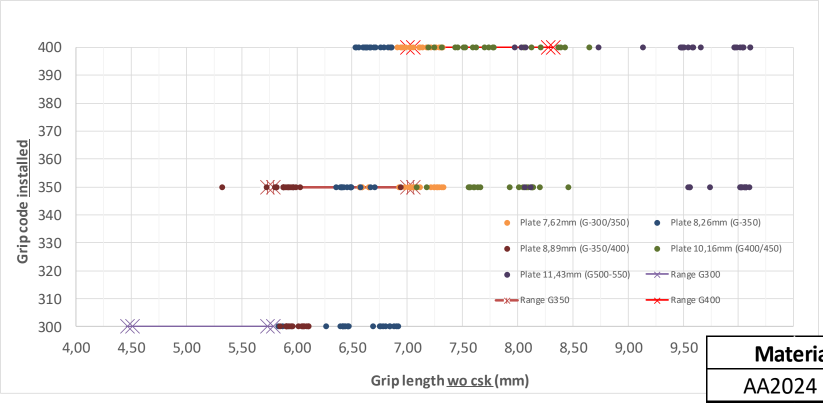
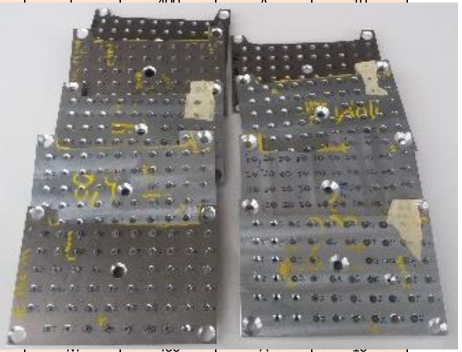
Test program

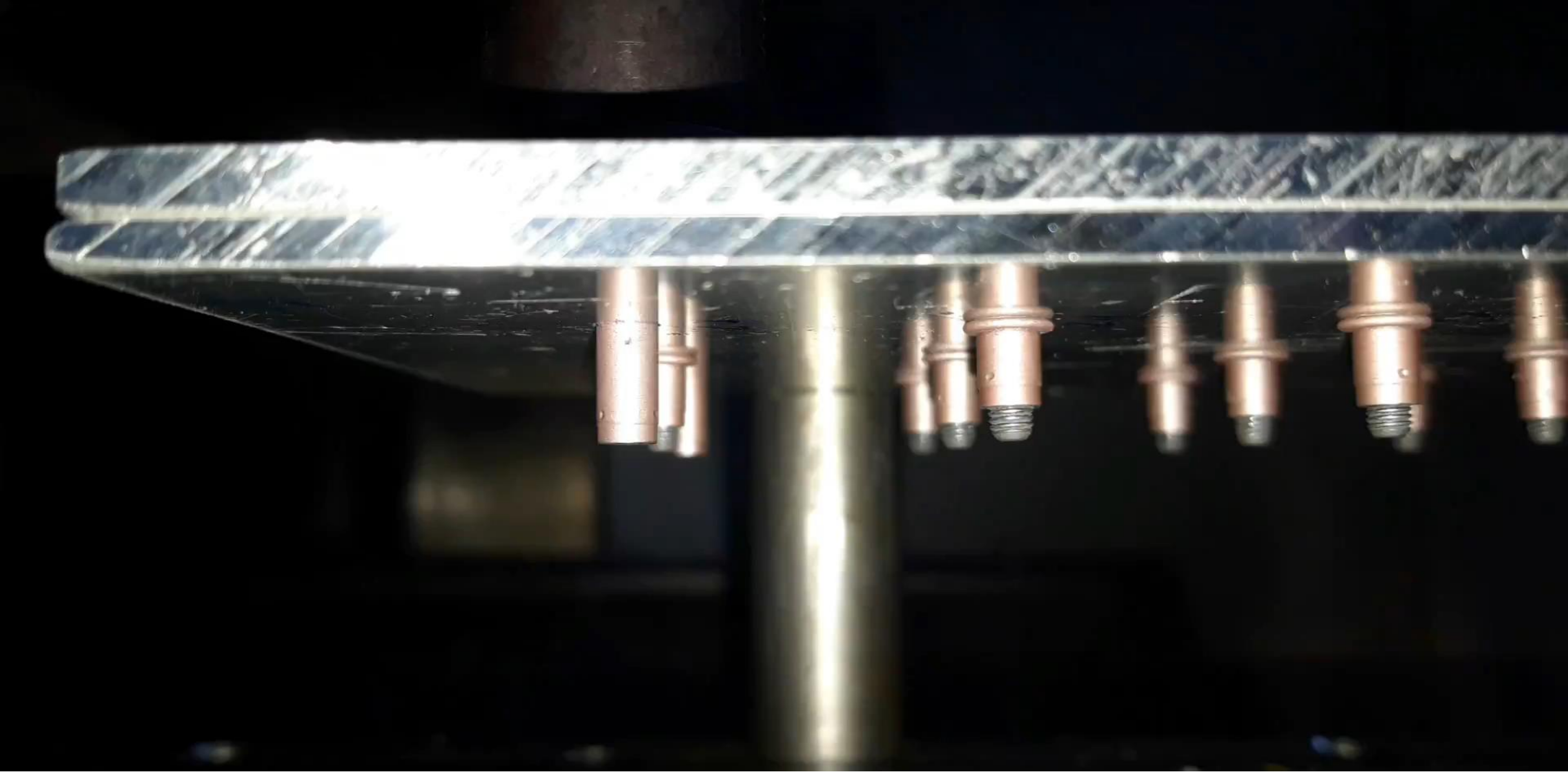
- Both OK/NOK installations generated under different grip conditions
- Monogram Composilok-II, dash 5
- Iterations and batch effect included
- Over 400 installations



Nr	Plate thickness	Ref.	Grip code -for plate thickness	Grip range	Grip code - installed	Batch	Iterations
1	0	G0R0G300A	0	R0	300	A	10
2	0	G0R0G300B	0	R0	300	B	10
3	0	G0R0G350A	0	R0	350	A	10
4	0	G0R0G350B	0	R0	350	B	10
5	0	G0R0G400A	0	R0	350	A	10
6	0	G0R0G400B	0	R0	350	B	10
7	2,3	G100LG300A	100	L	300	A	10
8	2,3	G100LG300B	100	L	300	B	10
9	2,3	G100LG350A	100	L	350	A	10
10	2,3	G100LG350B	100	L	350	B	10
11	7,62	G350SG300A	350	S	300	A	10
12	7,62	G350SG300B	350	S	300	B	10
13	7,62	G350SG350A	350	S	350	A	10
14	7,62	G350SG350B	350	S	350	B	10
15	8,26	G350MG300A	350	M	300	A	10
16	8,26	G350MG300B	350	M	300	B	10
17	8,26	G350MG350A	350	M	350	A	10
18	8,26	G350MG350B	350	M	350	B	10
19	8,26	G350MG400A	350	M	400	A	10
20	8,26	G350MG400B	350	M	400	B	10
21	8,89	G350LG350A	350	L	350	A	10
22	8,89	G350LG350B	350	L	350	B	10
23	8,89	G350LG400A	350	L	400	A	10
24	8,89	G350LG400B	350	[illegible]	[illegible]	[illegible]	[illegible]
25	10,16	G400LG350A	400	[illegible]	[illegible]	[illegible]	[illegible]
26	10,16	G400LG350B	400	[illegible]	[illegible]	[illegible]	[illegible]
27	10,16	G400LG400A	400	[illegible]	[illegible]	[illegible]	[illegible]
28	10,16	G400LG400B	400	[illegible]	[illegible]	[illegible]	[illegible]
29	11,43	G450LG350A	450	[illegible]	[illegible]	[illegible]	[illegible]
30	11,43	G450LG350B	450	[illegible]	[illegible]	[illegible]	[illegible]
31	11,43	G450LG400A	450	[illegible]	[illegible]	[illegible]	[illegible]
32	11,43	G450LG400B	450	[illegible]	[illegible]	[illegible]	[illegible]
33	3,2	G150MG300A	150	[illegible]	[illegible]	[illegible]	[illegible]
34	3,2	G150MG300B	150	[illegible]	[illegible]	[illegible]	[illegible]
35	3,2	G150MG350A	150	[illegible]	[illegible]	[illegible]	[illegible]
36	3,2	G150MG350B	150	[illegible]	[illegible]	[illegible]	[illegible]
37	2,3	G100LG400A	100	[illegible]	[illegible]	[illegible]	[illegible]
38	2,3	G100LG400B	100	[illegible]	[illegible]	[illegible]	[illegible]
39	3,2	G150MG400A	150	M	400	A	10
40	3,2	G150MG400B	150	M	400	B	10



Material	Fastener	Dash	Grip code	Batch	Grip range
AA2024 T3	CL-II	5	300/**350**/400	A,B	0/S/M/L



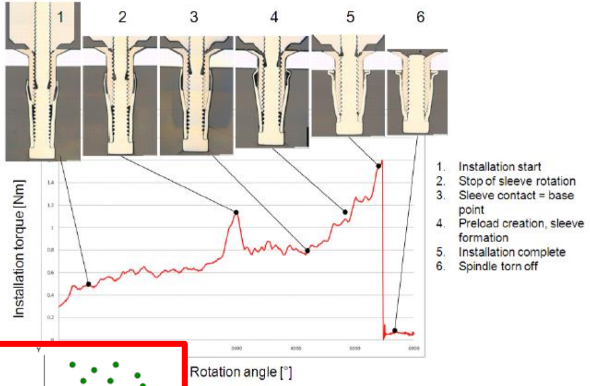
Sol#1

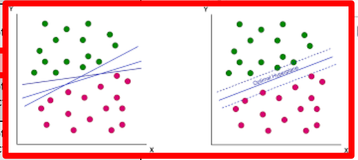
“Classify different OK/NOK grip condition groups through time, ~~frequency~~ domain descriptors of the installation diagram evolution and different ML algorithms”

+ Good overall scores in classifying the groups with different algorithms

- Uncontrolled NOK group that cannot be replicated (highly unbalanced class)

	Free parameter	Classification scenario	Test score	Remarks
Logistic regression	C=1.21	In-air vs OK selected (40)	0.75	Descriptors from points of interest
Random forests	#estimators=1		0.75	
CSVM	Gamma=0.04		1.0	
Logistic regression	C=2.81	In-air, OK selected, NOK selected (60)	0.541	Descriptors from points of interest
Random forests	#estimators=10		0.792	
CSVM	Gamma=0.06		1.0	
Logistic regression	C=1.37	In-air, OK selected, NOK selected (160)	0.79	Descriptors from points of interest
Random forests	#estimators=11		0.94	
CSVM	N/A		N/A	
Logistic regression	C=8.31	In-air vs OK (273)	0.946	Descriptors from 5 equal length sections
Random forest	#estimators=8	In-air vs OK (273)	0.955	
CSVM	Gamma=0.1	In-air vs OK (273)	1.0	
LSTM-FCNN	network architecture	In-air vs OK (273)	1.0	No descriptors needed but deep black-box solution
Logistic regression	C=8.71	All groups (400)	0.769	Descript
Random forest	#estimators=29	All groups (400)	0.819	
CSVM	Gamma=10.1	All groups (400)	1.0	
Logistic regression	C=2.61	All groups (400)	0.5626	Descript sec
Random forest	#estimators=41	All groups (400)	0.7625	
Logistic regression	C=0.01	All groups (400)	0.6125	Descript sec
Random forest	#estimators=33	All groups (400)	0.7626	





#GROUP	SELECTION-INSTALLATION	# SAMPLES
1	AIR-NO INSTALLED	60
2	LARGE SELECTED-OK INSTALLED	0
3	LARGE SELECTED-NOK INSTALLED	120
4	NOK SELECTED-OK INSTALLED	53
5	NOK SELECTED-NOK INSTALLED	47
6	OK SELECTED-OK INSTALLED	96
7	OK SELECTED-NOK INSTALLED	4
8	SMALL SELECTED-OK INSTALLED	0
9	SMALL SELECTED-NOK INSTALLED	20

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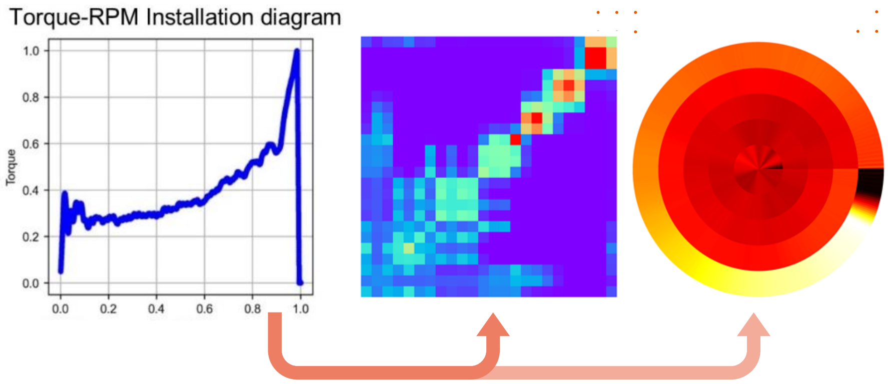
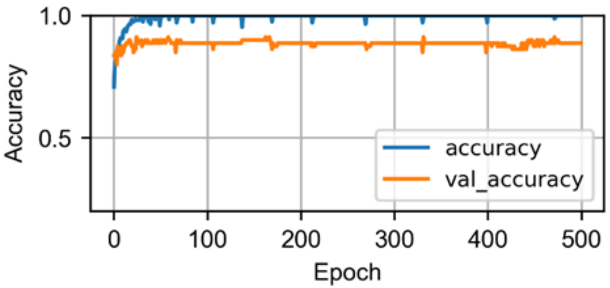
Sol#2

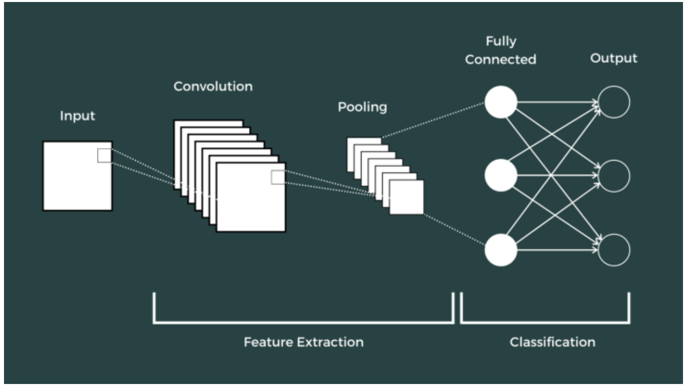
“OK/NOK classification by coding the installation diagrams into images (MTF, polar coordinates transformations) and DL (CNN)”

+ Use of robust classification algorithms

- Small volume of data (400 installations), overfitting highly likely





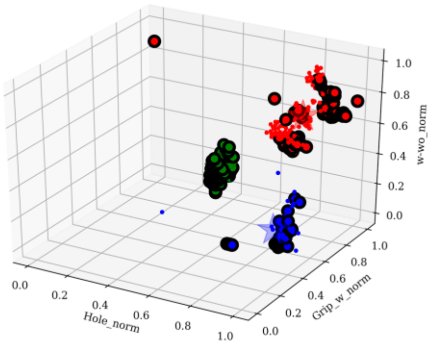


TP	TN	FP	FN	Precision	Accuracy
8	11	1	0	0.89	0.95

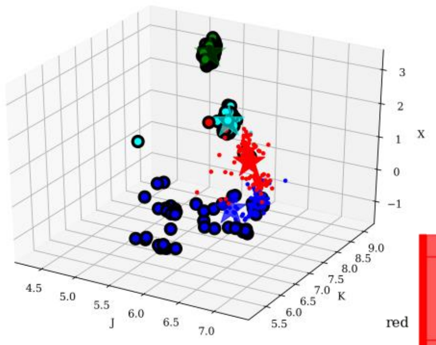
Sol#3

“Analyze the process chain by clustering using the holes/fasteners quality checks and visualize possible relationships between them, namely defect transmission paths”

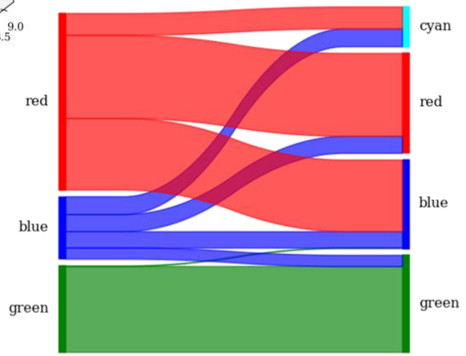
- No conclusive results so far

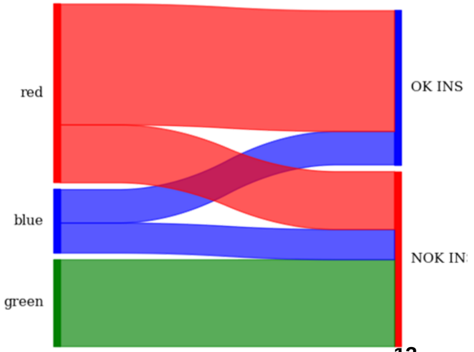


Holemaking



Fastening





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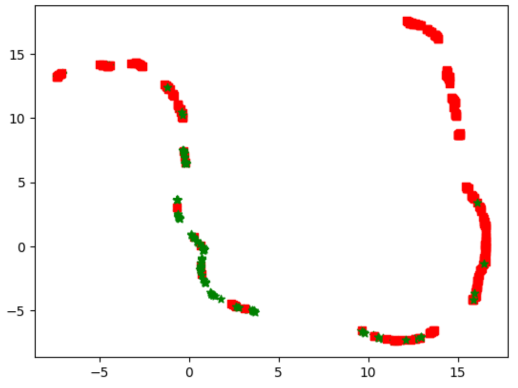
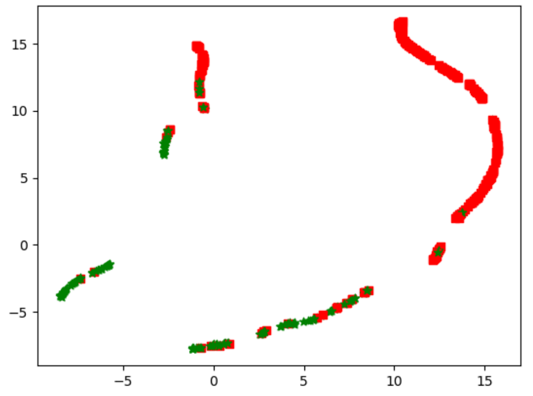
Sol#4

"Unsupervised classification of OK/NOK installations using time-domain descriptors to skip time-consuming, and eventually unrealistic data labelling"

+/- Some good predictions results though not high as with labelled data





VARIABLES	10 DESCRIPTORES CORRELACIONADOS CON EL RESULTADO OK/NOK [a,c,d,e,f,g,h,i,j,k]	6 DESCRIPTORES CORRELACIONADOS CON EL RESULTADO OK/NOK [a,d,e,f,i,k]	[a,d,e,i]	ANCHO DE SEÑAL CON UNA SUPERPOSICIÓN DEL 10%. (a1,a2,a3,a4,a5)	RES CORRELACIONADOS y 5 ÁREAS [a,c,d,e,f,g,h,i,j,k,a1,a2,a3,a4,a5]	[a2,a3,a4,a5]	[a,e,i,k,a2,a3,a4,a5]	[a,e,i,k,a3,a4,a5]	[a,e,i,k,a4,a5]	TODOS LOS DESCRIPTORES DE LA TABLA RESUMEN					
REDUCIÓN DIMENSIONAL	UMAP									NO					
CLUSTERING	DBSCAN									Gaussian Mixture	K-means	Agglomerative			
PARAMETROS	eps=1, min_samples=5									n_clusters=2	n_clusters=2	n_clusters=2, lincage=complete	n_clusters=2, lincage=average	n_clusters=2, lincage=single	n_clusters=2, lincage=ward
Accuracy	0.8575	0.6275	0.6275	0.6475	0.8575	0.6475	0.69	0.6699	0.85	0.6275	0.6275	0.6275	0.6275	0.6275	0.6275
Precision OK	0.8456	0	0	0.06711	0.8456	0.0671	0.5234	0.46308	0.6845	0	0	0	0	0	0
Precision NOK	0.8645	1	1	0.9920	0.8645	0.9920	0.7888	0.7928	0.9482	1	1	1	1	1	1
GRUPOS	11 (4 OK)	2 (0 OK)	2 (0 OK)	3 (1 OK)	12 (4 OK)	2 (1 OK)	3 (2 OK)	2 (1 OK)	13 (4 OK)	2 (0 OK)	2 (0 OK)	2 (0 OK)	2 (0 OK)	2 (0 OK)	2 (0 OK)
REDUCIÓN DIMENSIONAL	UMAP La última variable ha quedado sin normalizar, UN ERROR QUE HA MEJORADO LOS RESULTADOS									UMAP					
CLUSTERING	DBSCAN									Gaussian Mixture	K-means	Agglomerative			
PARAMETROS	eps=1, min_samples=5									n_clusters=2	n_clusters=2	n_clusters=2, lincage=complete	n_clusters=2, lincage=average	n_clusters=2, lincage=single	n_clusters=2, lincage=ward
Accuracy	0.8575	0.85	0.7425	0.884999	0.835	0.895	0.885	0.885	0.895	0.6275	0.6275	0.6275	0.6275	0.6275	0.6275
Precision OK	0.8456	0.6845	0.9194	0.8993	0.7248	0.8993	0.8993	0.8993	0.8993	0	0	0	0	0	0
Precision NOK	0.8645	0.9482	0.6374	0.8764	0.90039	0.8924	0.8764	0.87649	0.8924	1	1	1	1	1	1
GRUPOS	13 (4 OK)	11 (4 OK)	2 (1 OK)	10 (5 OK)	7 (2 OK)	9 (5 OK)	10 (5 OK)	9 (4 OK)	8 (4 OK)	2 (0 OK)	2 (0 OK)	2 (0 OK)	2 (0 OK)	2 (0 OK)	2 (0 OK)

Summary, conclusions and outlook

- Automatic evaluation of mechanical joints is an important step towards assembly automation in the aerospace industry
- Blind fastening is particularly suitable for automated assembly
- The fastener torque-rev diagram is a simple but powerful source of information for installations evaluation
- Aerospace fastening is a complex operation dominated by varying conditions and random variables where uncontrolled defects can appear
- Tecnalia is working in industry oriented solutions that combine domain knowledge with AI techniques such as ML, DL and unsupervised clustering
  - Challenges include uncontrolled defects, constraints in data labelling, unbalanced data
  - Foreseen steps forward address data augmentation, real time execution

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Thank you!

Questions are welcome

mariluz.penalva@tecnalia.com