

# Industrial Ergonomics Assisted by AI

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# Plan

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# Internship Context

## Importance and Objectives :

- Health and safety : essential priorities for companies.
- Need to assess risks on muscles and joints in order to reduce injuries. (Yazdanirad et al. (1), Schaub et al. (2))
- Ensure a safe working environment for employees.
- Implement modern ergonomic techniques (**RULA** and **REBA**) to automatically analyze postures and prevent risks.

### REBA Employee Assessment Worksheet

Based on Technical note: Rapid Upper Limb Assessment (RULA), Adapted, Hignett, Applied Ergonomics 31 (2000) 203-208

**A. Neck, Trunk and Leg Analysis**

**Step 1: Locate Neck Position**

Step 1a: Adjust...  
If neck is twisted: +1  
If trunk is side heading: -1

**Step 2: Locate Trunk Position**

Step 2a: Adjust...  
If trunk is twisted: +1  
If trunk is side heading: +1

**Step 3: Legs**

Adjust: 30-60°

**Step 4: Look-up Posture Score in Table A**  
Using values from steps 1-3 above, locate score in Table A.

**Step 5: Add Force/Load Score**  
If load = 22 lbs: +0  
If load = 11 to 22 lbs: +1  
If load = 22 lbs: +2  
Adjust: If hands or rapid build up of force: add +1

**Step 6: Score A. Find Row in Table C**  
Add values from steps 4 & 5 to obtain Score A. Find Row in Table C.

**Scoring:**  
1 = negligible risk  
2 or 3 = low risk, change may be needed  
4 to 7 = medium risk, further investigation, change soon  
8 to 10 = high risk, investigate and implement change  
11+ = very high risk, implement change

**B. Arm and Wrist Analysis**

**Step 7: Locate Upper Arm Position**

Step 7a: Adjust...  
If shoulder is raised: +1  
If upper arm is abducted: +1  
If arm is supported or person is leaning: -1

**Step 8: Locate Lower Arm Position**

**Step 9: Locate Wrist Position**

Step 9a: Adjust...  
If wrist is bent from midline or twisted: Add +1

**Step 10: Look-up Posture Score in Table B**  
Using values from steps 7-9 above, locate score in Table B.

**Step 11: Add Coupling Score**  
Wrist flexion, flexion and mid range power grip: good: +0  
Acceptable but not ideal hand hold or coupling acceptable with standard body part: Adjust: -1  
Hand hold not acceptable for possible power: Adjust: +2  
No handles, awkward, unsafe with any body part: Unacceptable: +3

**Step 12: Score B. Find Column in Table C**  
Add values from steps 10 & 11 to obtain Score B. Find column in Table C and search with Score A in row from step 6 to obtain Table C Score.

**Step 13: Activity Score**  
+1 = 1 or more body parts are held for longer than 1 minute (static)  
+1 = repeated small range motions (score times 4e per minute)  
+1 = Actions causes rapid large range changes in postures or unstable base

**Table A: Neck**

	1	2	3
Neck	1	2	3
Trunk Posture Score	1	2	3

**Table B: Lower Arm**

	1	2
Upper Arm Score	1	2
Wrist Score	1	2
Upper Arm Score	1	2
Wrist Score	1	2
Upper Arm Score	1	2
Wrist Score	1	2

**Table C: Score A, pairs in table - coupling score**

Score A	1	2	3	4	5	6	7	8	9	10	11	12
1	1	2	3	4	5	6	7	8	9	10	11	12
2	1	2	3	4	5	6	7	8	9	10	11	12
3	1	2	3	4	5	6	7	8	9	10	11	12
4	1	2	3	4	5	6	7	8	9	10	11	12
5	1	2	3	4	5	6	7	8	9	10	11	12
6	1	2	3	4	5	6	7	8	9	10	11	12
7	1	2	3	4	5	6	7	8	9	10	11	12
8	1	2	3	4	5	6	7	8	9	10	11	12
9	1	2	3	4	5	6	7	8	9	10	11	12
10	1	2	3	4	5	6	7	8	9	10	11	12
11	1	2	3	4	5	6	7	8	9	10	11	12
12	1	2	3	4	5	6	7	8	9	10	11	12

Final REBA Score = Table C Score + Activity Score

Figure 1 : REBA Worksheet . Hignett and

McAtamney (3)

# Literature Review

## Article by Jiao et al. (4)

Automatic computation of REBA scores.

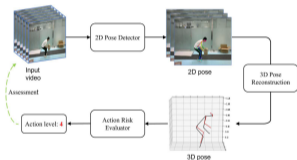


Figure 2 : Pipeline with 3D reconstruction.

## Article by Bortolini et al. (5)

Obtaining a human skeleton without occlusions.

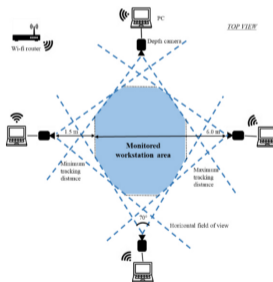


Figure 3 : Multi-camera architecture.

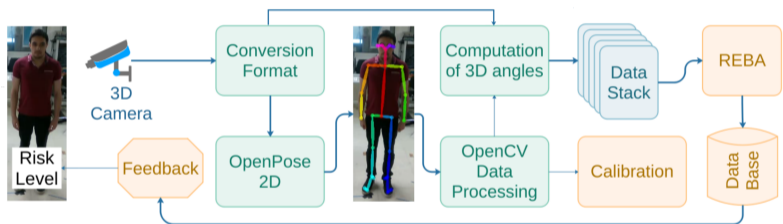
## Article by Sancho et al. (6)

Low-cost method to extract a 3D skeleton.



Figure 4 : Postural analysis with Kinect.

# Posture Estimation

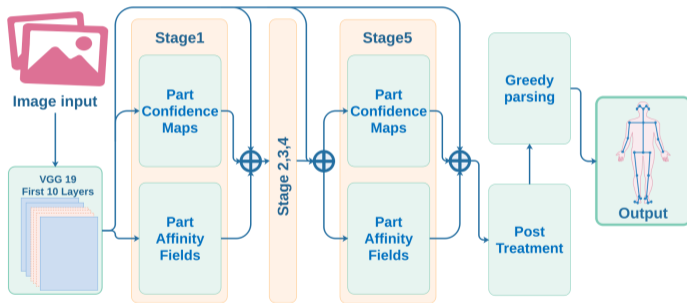


**Figure 5 :** Postural analysis pipeline with 3D camera

## Scientific Challenges :

- Data fusion.
- Occlusions.
- Real-time implementation.

# Description of OpenPose



**Figure 7** : Multi-stage architecture of OpenPose by Cao et al. (7)



(a)



(b)

**Figure 8** : (a) PCM and (b) PAF

# 2D → 3D Coordinate Conversion

## 2D → 3D Coordinate Conversion

- OpenPose provides  $(x, y)$  in pixels.
- Depth  $Z$  aligned in meters.
- Projection transformation according to Wikipédia (8) to obtain  $(X, Y, Z)$  in meters :

$$\begin{cases} X = (x - c_x) \times \frac{Z}{f_x} \\ Y = (y - c_y) \times \frac{Z}{f_y} \\ Z = \text{depth}(x, y) \end{cases}$$

- $(c_x, c_y)$  : optical center of the camera.
- $f_x, f_y$  : focal lengths (in pixels).

# Construction of an Orthonormal Frame and Rotation along 3 Axes

Transformation from frame B to frame A :

$${}^A R_B = R(z_A, \gamma) \cdot R(y_A, \beta) \cdot R(x_A, a)$$

$${}^A R_B = \begin{bmatrix} X_A \cdot X_B & X_A \cdot Y_B & X_A \cdot Z_B \\ Y_A \cdot X_B & Y_A \cdot Y_B & Y_A \cdot Z_B \\ Z_A \cdot X_B & Z_A \cdot Y_B & Z_A \cdot Z_B \end{bmatrix}$$

Extraction of nautical angles by identification :

$$\beta = -\arcsin(R_{3,1}),$$

$$a = \operatorname{atan2}\left(\frac{R_{3,2}}{\cos \beta}, \frac{R_{3,3}}{\cos \beta}\right),$$

$$\gamma = \operatorname{atan2}\left(\frac{R_{2,1}}{\cos \beta}, \frac{R_{1,1}}{\cos \beta}\right)$$

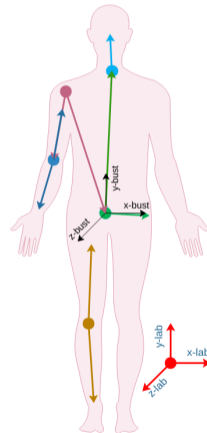


Figure 8 : Vectors and reference frame

# Angle Calculation & Data Processing

## Angle calculation using the dot product :

- Example : angle of the **right elbow** ( $\vartheta$ ).
- Definition of vectors :
  - $\vec{CE}$  = elbow-shoulder vector
  - $\vec{CP}$  = elbow-wrist vector

$$\vartheta = \arccos\left(\frac{\vec{CE} \cdot \vec{CP}}{\|\vec{CE}\| \|\vec{CP}\|}\right)$$

## Calibration with respect to neutral posture :

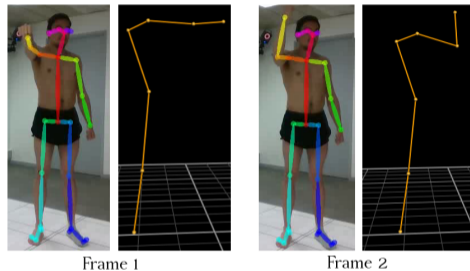
$$|\vartheta_{\text{dyn}} - \vartheta_{\text{calib}}| = \vartheta_{\text{REBA}}$$

## Chosen smoothing method :

- **Polynomial regression** :
  - Fits a polynomial of order  $p$  to the data :

$$\hat{y}(x) = a_0 + a_1x + \dots + a_px^p$$

# Comparison OpenPose vs VICON

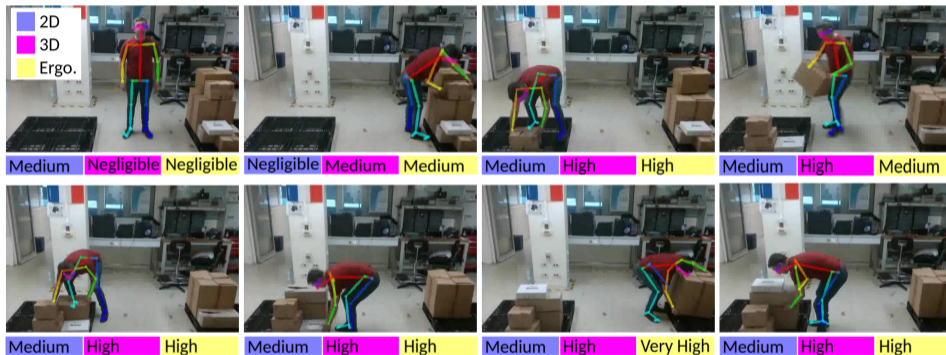


**Figure 9** : Comparison of joint angle estimations : OpenPose vs. VICON

**Table 1** : Comparison of joint angle measurements between VICON and OpenPose (2D vs. 3D).

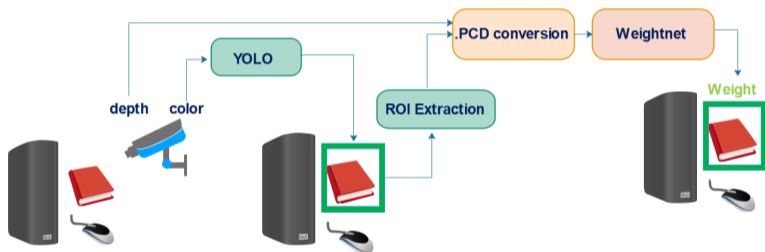
ID	Segment	VICON (°)	2D Mean (°)	3D Mean (°)	2D SD (°)	3D SD (°)	Diff 2D / 3D (°)
1	Right elbow (rest)	157.58	161.96	160.45	1.31	1.16	+4.38 / +2.87
1 and 2	Right knee (rest)	174.61	175.53	175.13	0.84	0.53	+0.92 / +0.52
2	Right elbow (action)	79.47	63.48	70.16	5.03	0.85	-15.99 / -9.31

# Comparison OpenPose vs Ergonomist



**Figure 10** : REBA risk scores with 2D, 3D angles calculation, and manual annotation by an ergonomist

# Mass Estimation



**Figure 14** : Mass estimation pipeline with WeightNet

## Scientific Challenges :

- Noise and missing data.
- 3D point cloud processing.
- Non-uniqueness of shape-mass.

# Dataset Creation

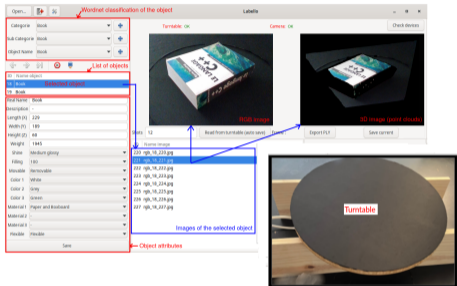


Figure 15 : Data acquisition

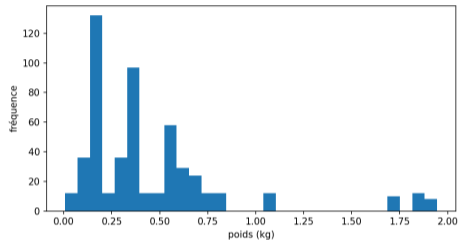


Figure 16 : Dataset histogram after post-processing

# WeightNet Based on PointNet++

## Hierarchical point set feature learning

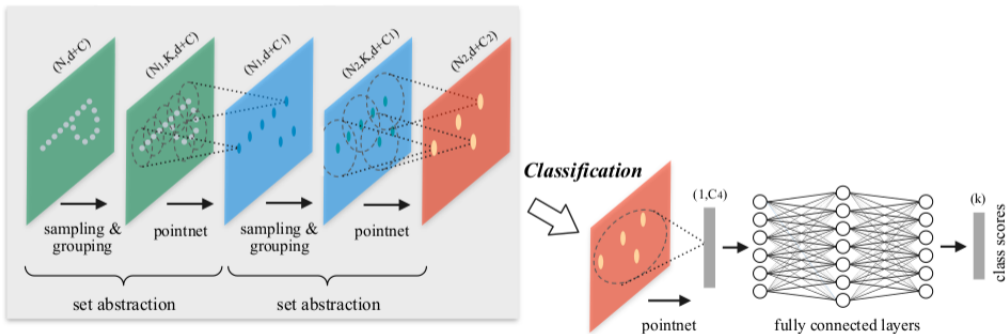


Figure 17 : PointNet++ architecture from Qi et al. (9)

# Regression Metrics

## Loss function (regression) : Smooth L1

$$\mathcal{L}_{\text{SmoothL1}}(y, \hat{y}) = \begin{cases} \frac{1}{2}(y - \hat{y})^2 & \text{if } |y - \hat{y}| < 1 \\ |y - \hat{y}| - \frac{1}{2} & \text{otherwise} \end{cases}$$

## Evaluation metrics :

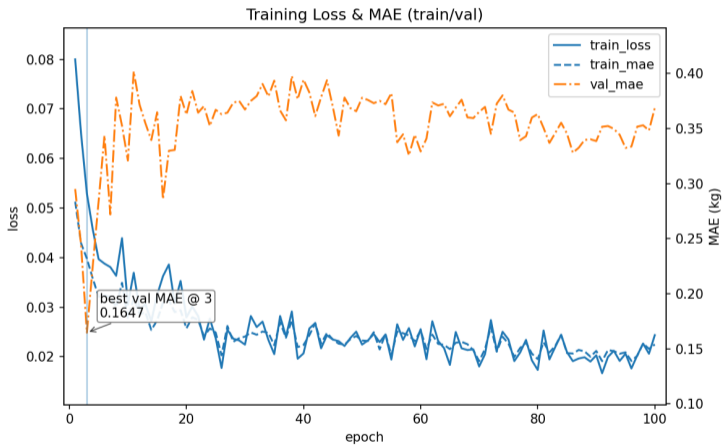
- Mean Absolute Error (MAE)

$$\text{MAE} = \frac{1}{N} \sum_{i=1}^N |y_i - \hat{y}_i|$$

- Root Mean Squared Error (RMSE)

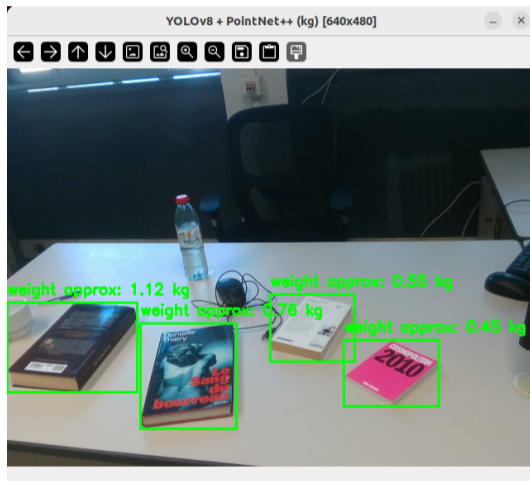
$$\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^N (y_i - \hat{y}_i)^2}$$

# Training and Validation Results



**Figure 18** : Best configuration in validation and testing, comparison of MAE

# Results in Real Conditions



**Figure 19** : Online test with several books detected simultaneously.

# Conclusion

## Opportunities :

- Presentations at TUT F'SATI
- PhD defense simulation before a doctoral school jury
- Submission of an article to the journal *IEEE Transactions on Human-Machine Systems*
- JJCR Conference : presentation of the work carried out

## Perspectives :

- Real-time REBA implementation
- Improvement of WeightNet
- Writing of a second scientific article
- Integration of WeightNet together with REBA

# References

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- (6) Miguel Pérez Sancho, Daysi Baño Morales, José María Baydal-Bertomeu, Iván Zambrano, and Ricardo Soto. Ergonomic risk analysis inherent in neonate bathing activity performed by nurses using the reba methodology through kinect depth sensors. *Periodicals of Engineering and Natural Sciences (PEN)*, 9(4) :864–876, 2021.
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- (9) Charles Ruizhongtai Qi, Li Yi, Hao Su, and Leonidas J. Guibas. Pointnet++ : Deep hierarchical feature learning on point sets in a metric space. In *Advances in Neural Information Processing Systems 30 (NeurIPS 2017)*, pages 5099–5108, 2017.

## Fine tuning results Table

Table – Results of different checkpoint and hyperparameter configurations on the test dataset.

Strategy	Main Hyperparameters	MAE (kg)	RMSE (kg)
Head reuse	lr_head = 0.001, freeze = all	<b>0.189</b>	<b>0.274</b>
Head reuse	lr_head = 0.001, lr_backbone = 0.001, freeze = none	0.246	0.357
Same but slow learning	lr_head = 5e-05, freeze = all	0.300	0.476
Same but slow learning	lr_head = 1e-05, lr_backbone = 0.0001, freeze = none	0.315	0.446
Without head reuse	lr_head = 0.001, freeze = all	0.514	0.590
3-layer MLP	lr = 1e-05	0.490	0.584
10-layer MLP	lr = 5e-04	0.396	0.577