A Novel Neuromorphic Tactile Sensor using Artificial Intelligence

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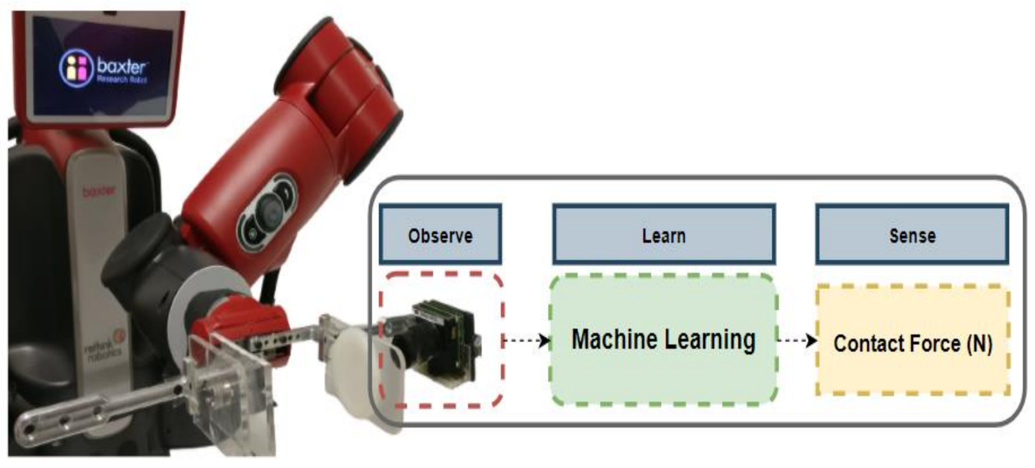
1. Neuromorphic Vision Sensors

- High **temporal resolution** of microseconds
- Low **power consumption** (14mW)
- High **dynamic range** (log intensity)
- Low **memory requirements**

Subtract current intensity from previous intensity of each pixel: if + fires a positive event
if − fires a negative event

2. Vision-based Tactile Sensor



3. Sensor Prototype

The proposed sensor includes a silicone membrane and a Dynamic Vision Sensor (DVS) to monitor the object contact area and uses AI to acquire tactile information.

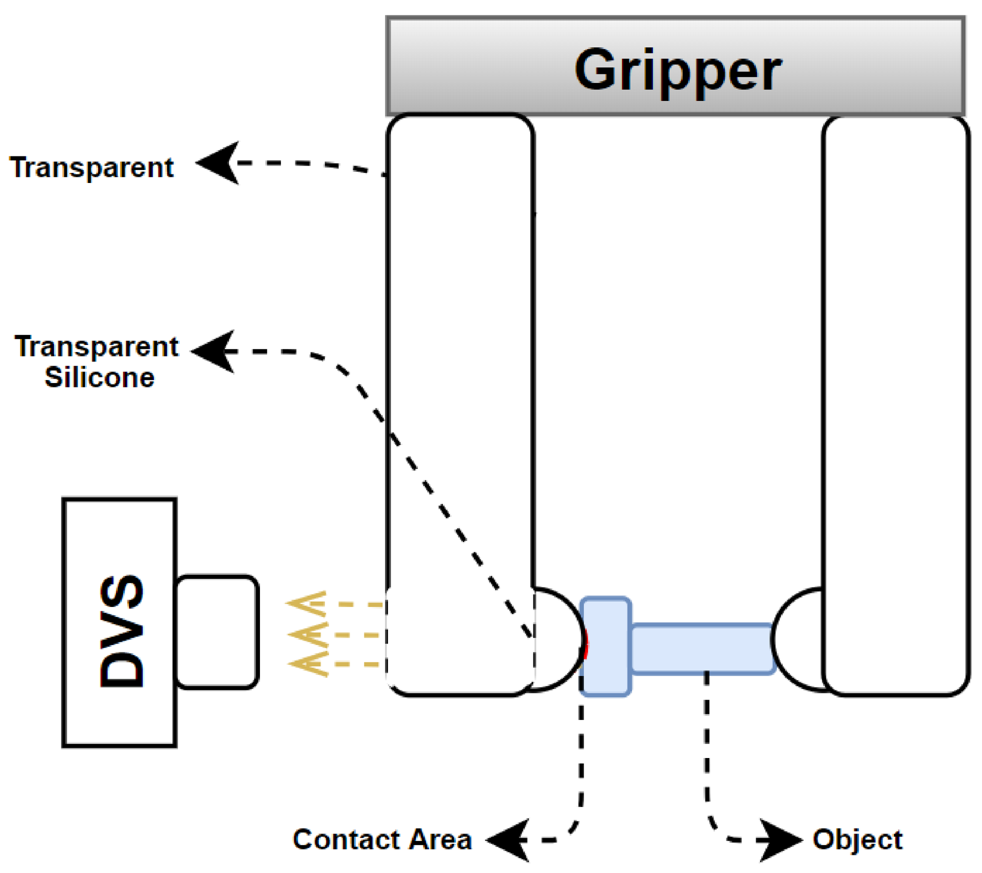


Figure 1. Prototype of the event-driven tactile sensor.

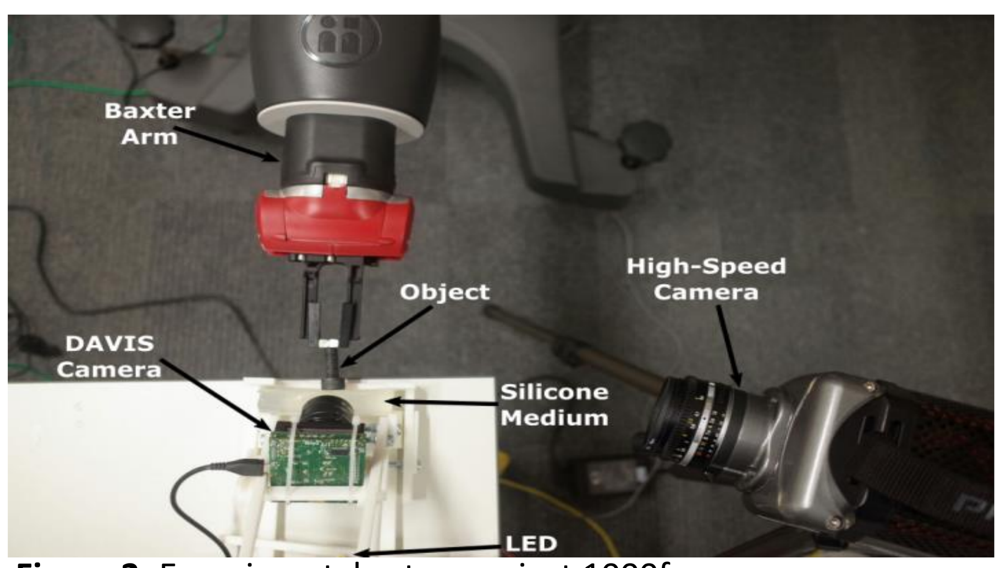


Figure 2. Experimental setup against 1000fps camera.

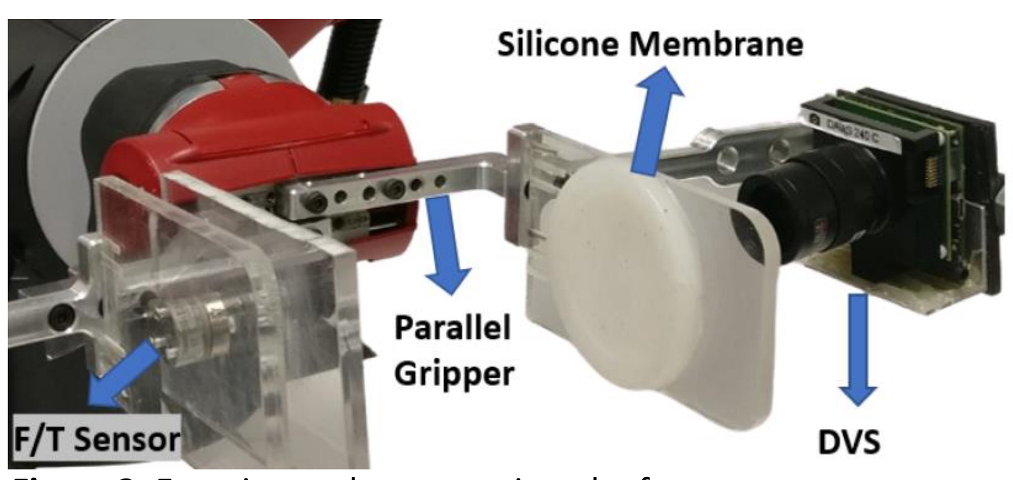


Figure 3. Experimental setup against the force sensor

4. Methods

4A. Physical Concept of The Events

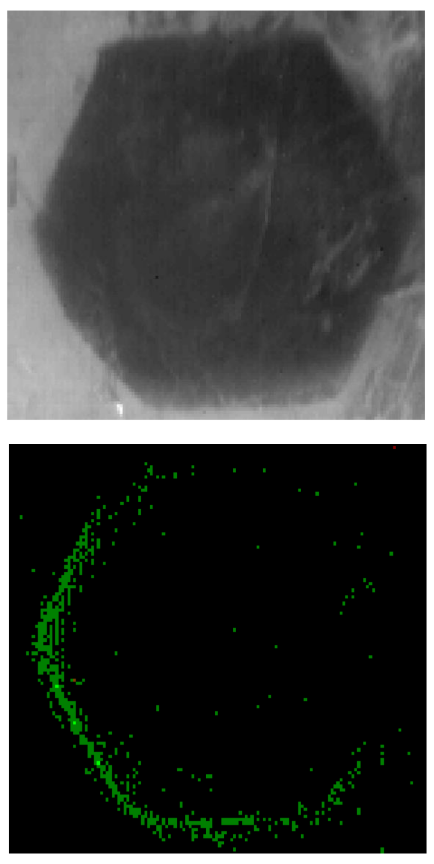


Figure 4. Decrease of the contact force (brighter contact area)

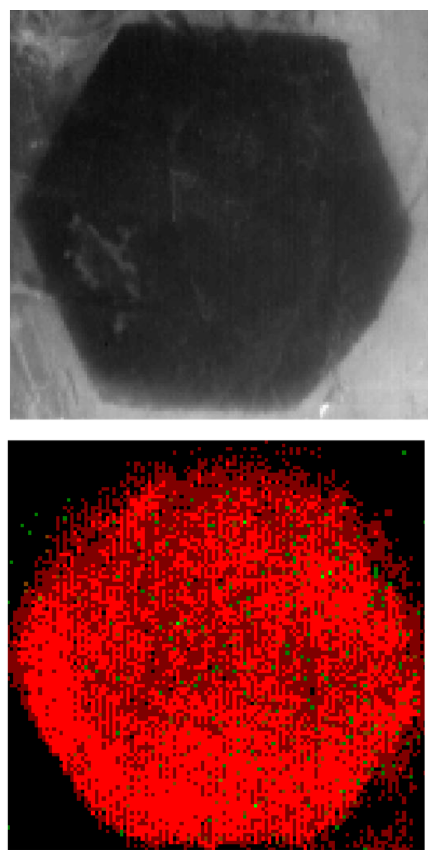


Figure 5. Increase of the contact force (darker contact area)

4B. Slip Detection

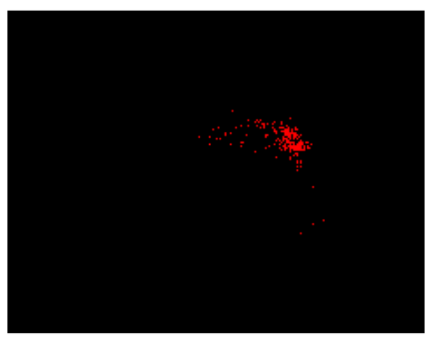


Figure 6. Accumulation of red events over 7ms

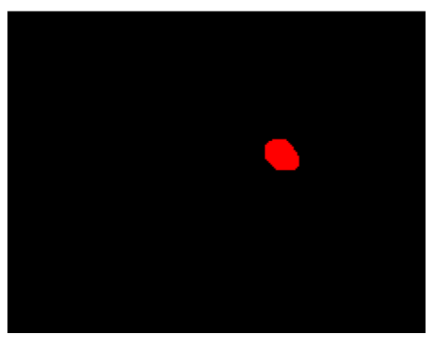


Figure 7. Morphological opening and closing to filter the noise

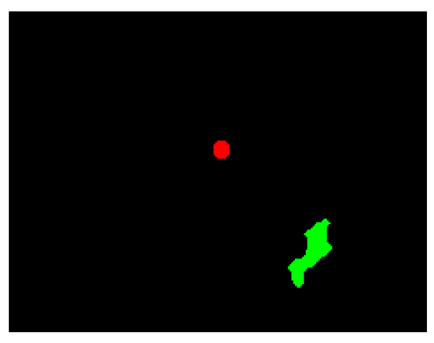


Figure 8. Object is losing the contact area (slip)

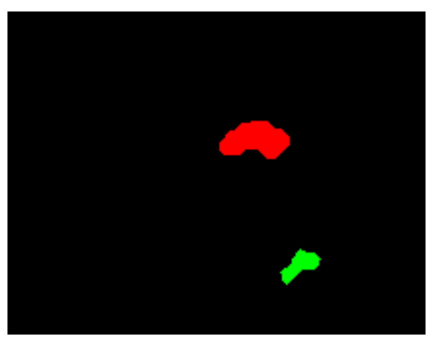


Figure 9. Vibration of the object (gaining contact area)

4C. Force Estimation

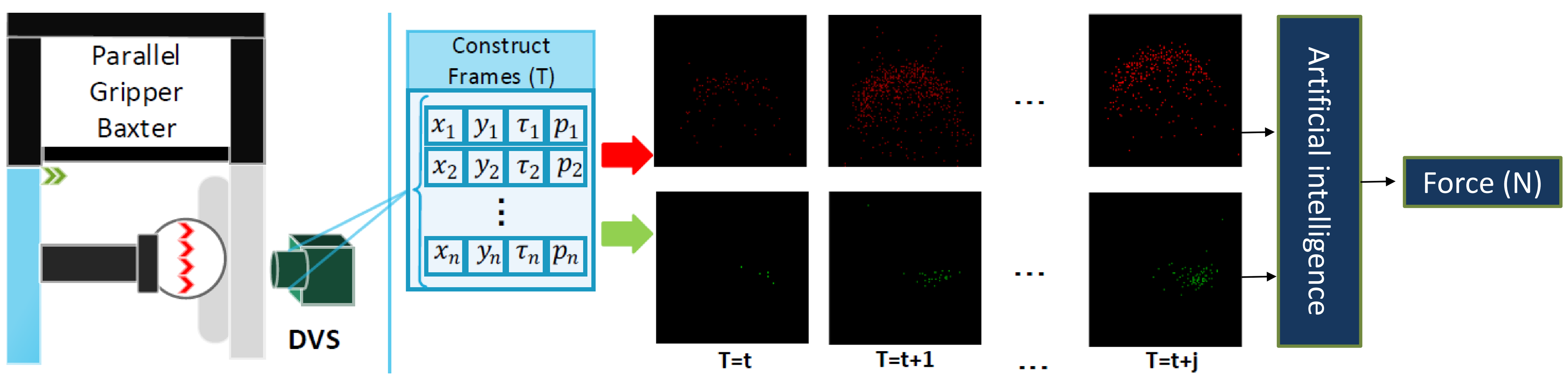


Figure 10. Overview of end-to-end pipeline for the contact force measurements

4D. Object Classification

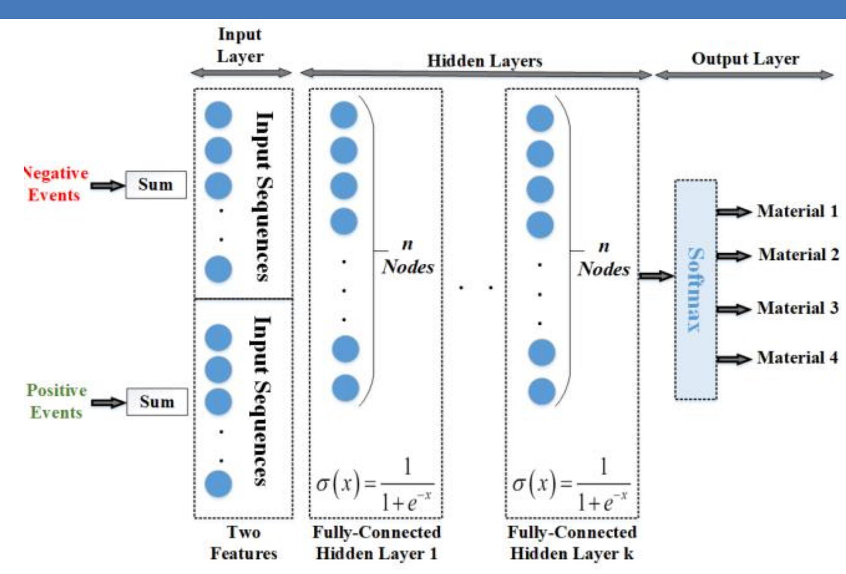


Figure 11. Object classification model

4E. Pressure Mapping

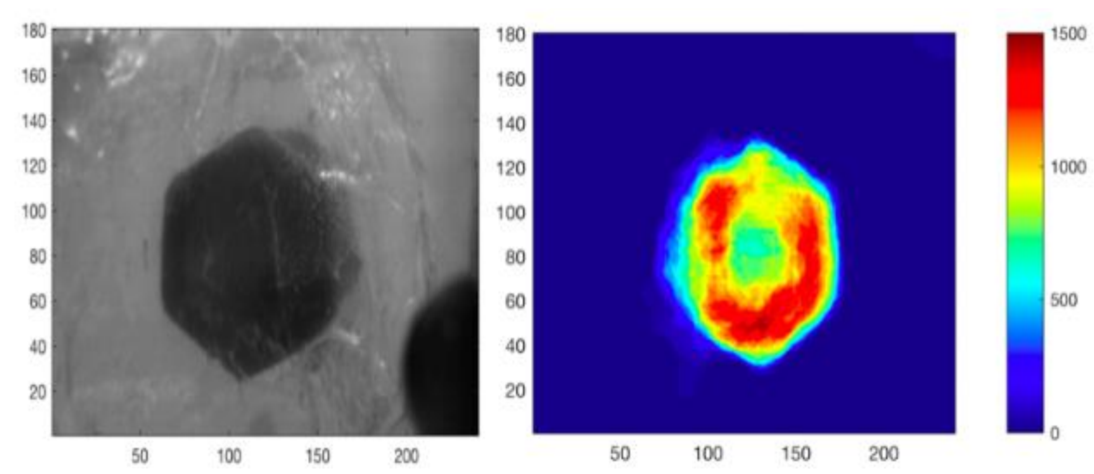


Figure 12. Image of the contact area through the silicone membrane

5. Validation and Results

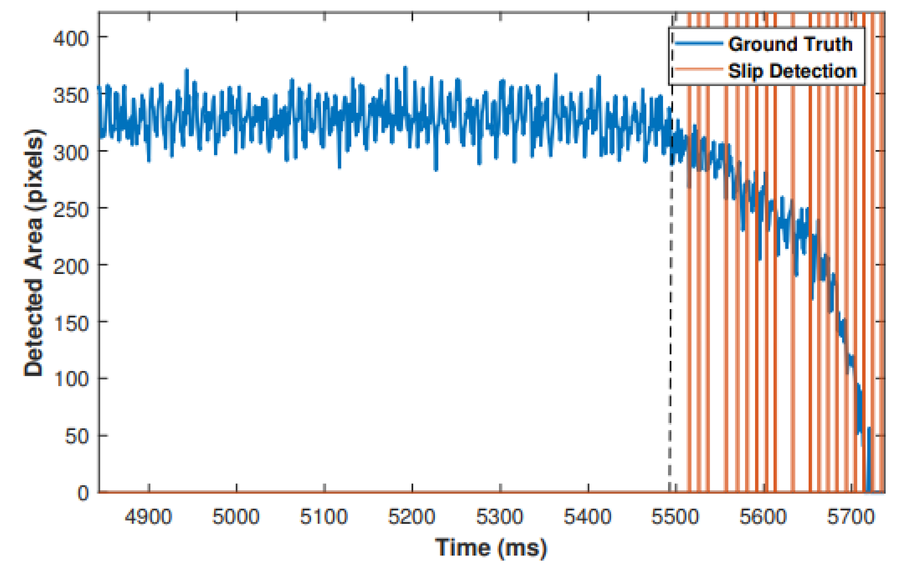


Figure 13. Slip detection based on pixel-area

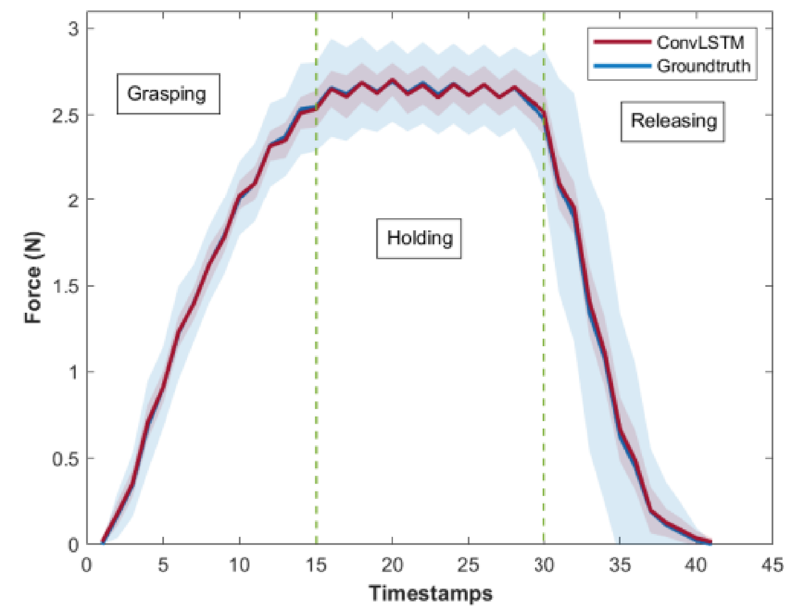


Diagram 3. Estimated contact force (ConvLSTM) against the force sensor

Output Class \ Target Class	Foam	Rubber	Silicone	Steel
Foam	63.6% 7	11.1% 1	21.4% 3	7.1% 1
Rubber	18.2% 2	77.8% 7	0.0% 0	0.0% 0
Silicone	18.2% 2	11.1% 1	78.6% 11	0.0% 0
Steel	0.0% 0	0.0% 0	0.0% 0	92.9% 13

Diagram 3. Material classification in a single grasp (confusion matrix)

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6. Conclusion

In this research, the first event-driven tactile sensor is proposed using a Dynamic Vision Sensor. It is demonstrated that the sensor can estimate the contact force, detect object slippage, classify different materials and provide the pressure map. For future work, we will consider to use temporal data augmentation techniques to reduce data collection and generalise our solution for unknown objects.

Journal Publications

[1] A. Rigi, **F. Baghaei Naeini**, D. Makris, and Y. Zweiri, "A Novel Event-Based Incipient Slip Detection Using Dynamic Active-Pixel Vision Sensor (DAVIS)," **Sensors**, vol. 18, no. 2, p. 333, Jan. 2018.

[2] **Naeini, F.B.**, AlAli, A.M., Al-Husari, R., Rigi, A., Al-Sharman, M.K., Makris, D. and Zweiri, Y., 2019. A novel dynamic-vision-based approach for tactile sensing applications. **IEEE Transactions on Instrumentation and Measurement**, 69(5), pp.1881-1893.

[3] **Baghaei Naeini, F.**, Makris, D., Gan, D. and Zweiri, Y., 2020. Dynamic-vision-based force measurements using convolutional recurrent neural networks. **Sensors**, 20(16), p.4469.