

¹ EMGFlow: A Python package for pre-processing and ² feature extraction of electromyographic signals

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⁵ Summary

⁶ Surface electromyography (sEMG) is increasingly used to study human physiology and behaviour,
⁷ spurred by advances in deep learning and wearable sensors. Here, we introduce *EMGFlow*, an
⁸ open-source Python package that streamlines preprocessing and feature extraction for sEMG
⁹ signals. Tailored for batch processing, *EMGFlow* handles large datasets typical in machine
¹⁰ learning, extracting a comprehensive set of 33 statistical features across time and frequency
¹¹ domains. The package supports flexible file selection with regular expressions and uses Pandas
¹² DataFrames end-to-end to facilitate interoperability. An interactive dashboard visualises signals
¹³ at each preprocessing stage to aid user decisions. *EMGFlow* is distributed under the GNU
¹⁴ General Public License v3.0 (GPL-3.0) and is available on PyPI. Documentation with guides,
¹⁵ API references, and runnable examples is available at <https://willson.github.io/EMGFlow-Python-Package/>.

Statement of Need

¹⁸ Although several packages process physiological and neurological signals, support for sEMG
¹⁹ has remained limited. Many lack a comprehensive feature set for sEMG, forcing researchers to
²⁰ use a patchwork of tools. Others focus on event detection with GUI-centric workflows that suit
²¹ continuous recordings of a single participant, but complicate batch feature extraction common
²² in machine learning (Abadi et al., 2015; Chen et al., 2022; Koelstra et al., 2012; Schmidt et
²³ al., 2018; Sharma et al., 2019; Zhang et al., 2016).

²⁴ *EMGFlow*, a portmanteau of EMG and Workflow, fills this gap by providing a flexible pipeline
²⁵ for extracting a wide range of sEMG features, with a scalable design suited for large datasets.
²⁶ An overview of package metadata is presented in Table 1.

| Metadata | Description |
|-------------------|---|
| License | GPLv3 |
| Implementation | Python >= 3.9 |
| Code repository | https://github.com/Willson/EMGFlow-Python-Package |
| Documentation | https://willson.github.io/EMGFlow-Python-Package |
| PyPI installation | <code>pip install EMGFlow</code> |

²⁷ Table 1: *EMGFlow* package metadata.

²⁸ Comparison to Other Packages

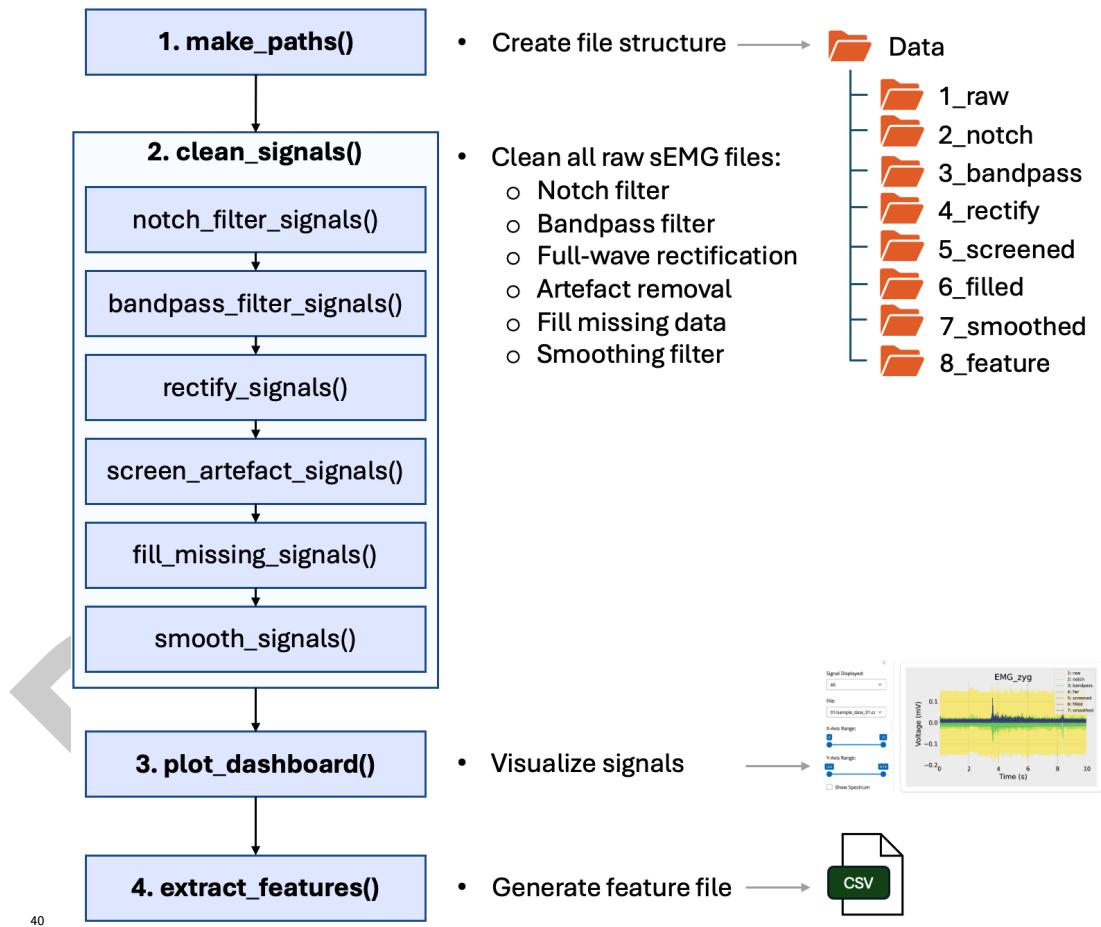
²⁹ Compared to existing toolkits, *EMGFlow* provides a broader, sEMG-specific library of 33
³⁰ features (Bizzego et al., 2019; Bota et al., 2024; Makowski et al., 2021; Sjak-Shie, n.d.);

³¹ Soleymani et al., 2017). Its dashboard visualises batch-processed files rather than single
³² recordings, enabling inspection of preprocessing effects across datasets (Gabrieli et al., 2020).
³³ Adjustable filters and smoothing support international mains standards (50 vs 60 Hz), a subtle
³⁴ detail some packages omit.

³⁵ Features

³⁶ A Simplified Workflow

³⁷ Extracting features from large datasets is fundamental in machine learning and quantitative
³⁸ analysis. *EMGFlow* supports batch-processing, enabling fully or semi-automated treatment of
³⁹ sEMG recordings. Figure 1 outlines the pipeline.



⁴¹ **Figure 1:** An overview of the processing pipeline.

⁴² Example 1 demonstrates end-to-end preprocessing and feature extraction. We create project
⁴³ paths with `make_paths()` and load bundled sample data with `make_sample_data()` (adapted
⁴⁴ from PeakAffectDS (Greene et al., 2022)). Next, we run automated preprocessing via
⁴⁵ `clean_signals()` using sensible, literature-based defaults, and then write a plaintext CSV of
⁴⁶ 33 features per file with `extract_features()`.

```
# %% Example 1: Quick start (full pipeline)
import EMGFlow
```

```
# Create project paths
path_names = EMGFlow.make_paths()
```

```

# Load sample data
EMGFlow.make_sample_data(path_names)

# Preprocess signals
EMGFlow.clean_signals(path_names, sampling_rate=2000, notch_f0=50)

# Extract features to disk "Features.csv"
EMGFlow.extract_features(path_names, sampling_rate=2000)

```

47 Tailored Preprocessing

48 Example 2 shows how advanced users can tailor low-level preprocessing. After setup, Step 1
 49 applies a notch filter to remove AC mains interference. Most functions use common sense
 50 defaults, which can be modified task-wide or for select cases. For instance, the sample data
 51 were recorded in New Zealand (200-240 VAC 50Hz), so we set the notch frequency and quality
 52 factor accordingly.

```

# %% Example 2: Tailored preprocessing
import EMGFlow

# Setup workspace
path_names = EMGFlow.make_paths()
EMGFlow.make_sample_data(path_names)

# Data sampling rate
sampling_rate = 2000

# Notch filter for mains hum (Hz, Q-score)
notch_main = [(50, 5)]

# Columns names containing sEMG (Zygomaticus major, Corrugator supercilii)
muscles = ['EMG_zyg', 'EMG_cor']

# Step 1. Apply notch filter to all files in 1_raw, writing output to 2_notch
EMGFlow.notch_filter_signals(path_names['raw'], path_names['notch'],
                             muscles, sampling_rate, notch_main)

# EMGFlow preserves the raw directory structure and mirrors it at each pipeline stage. All
# preprocessing functions accept an optional regular expression to target specific files. In Step 1b,
# we apply an additional notch filter at 150 Hz (the 3rd harmonic) only to files in subfolder /01.

# Custom notch settings
notch_custom = [(150, 25)]
path_pattern = '^01/'

# Step 1b. Apply custom notch filter all to files in subfolder "/01"
EMGFlow.notch_filter_signals(path_names['notch'], path_names['notch'],
                             muscles, sampling_rate, notch_custom,
                             expression=path_pattern)

```

56 Interference Attenuation

57 Surface EMG is susceptible to multiple sources of interference that affect the signal with
 58 distinct spectral signatures (Boyer et al., 2023). Band-pass filtering is typically performed
 59 in Step 2 to isolate the frequency spectrum of human muscle activity. Common passbands
 60 are 10-500 Hz (Livingstone et al., 2016; McManus et al., 2020; Sato et al., 2021; Tamietto
 61 et al., 2009), though precise edges vary by domain (Abadi et al., 2015). Step 3 performs

```

62 full-wave rectification, converting negative values to positive (Dakin et al., 2014; Rutkowska et
63 al., 2024).

# Passband edges (low, high)
passband_edges = [20, 450]

# Step 2. Apply band-pass filter
EMGFlow.bandpass_filter_signals(path_names['notch'], path_names['bandpass'],
                                 muscles, sampling_rate, passband_edges)

# Step 3. Apply full-wave rectifier
EMGFlow.rectify_signals(path_names['bandpass'], path_names['fwr'], muscles)

64 Signal artefacts are another source of contamination and span a diverse range of phenomenon
65 including thermal noise, eyeblinks, and random noise bursts (Boyer et al., 2023). These can
66 be mitigated with screen_artefacts(), which applies a Hampel filter (default), or Wiener
67 filter, both reported as robust denoisers (Allen, 2009; Bhowmik et al., 2017; Jarrah et al.,
68 2022). Because artefact profiles vary across projects, we recommend visual inspectection
69 with the interactive dashboard to tune n_sigma (Hampel) and window_ms (Bhowmik et al.,
70 2017; Pearson et al., 2016). In Step 4 we target /02/sample_data_04.csv which contains an
71 artificial, band-limited noise pulse, and copy other files forward untouched.

screen_pattern = r'^02/sample_data_04\.csv$'

# Step 4. Apply Hampel artefact filter to 02/sample_data_04.csv
EMGFlow.screen_artefact_signals(path_names['fwr'], path_names['screened'],
                                 muscles, sampling_rate,
                                 expression=screen_pattern, copy_unmatched=True)

72 Missing data consisting of brief gaps or NaNs can be filled with fill_missing_signals(),
73 which defaults to Piecewise Cubic Hermite Interpolating Polynomial (method=pchip). PCHIP
74 is shape-preserving, monotonicity-respecting, and avoids overshoot - properites desirable for
75 sEMG (SciPy Community, 2025). Cubic spline is also available (Shin et al., 2021). In Step 5,
76 we address artificially injected gaps with PCHIP.

77 In Step 6, optional smoothing removes residual high-frequency noise before feature extraction.
78 The default smoother RMS, equal to the square root of the total power, estimates signal
79 amplitude and is commonly used in sEMG (McManus et al., 2020). Boxcar, Gaussian, and
80 LOESS alternatives are also provided.

# Step 5. Fill missing data
EMGFlow.fill_missing_signals(path_names['screened'], path_names['filled'],
                             muscles, sampling_rate)

# Step 6. Apply smoothing filter
EMGFlow.smooth_signals(path_names['filled'], path_names['smooth'],
                       muscles, sampling_rate)

```

81 An Interactive Dashboard

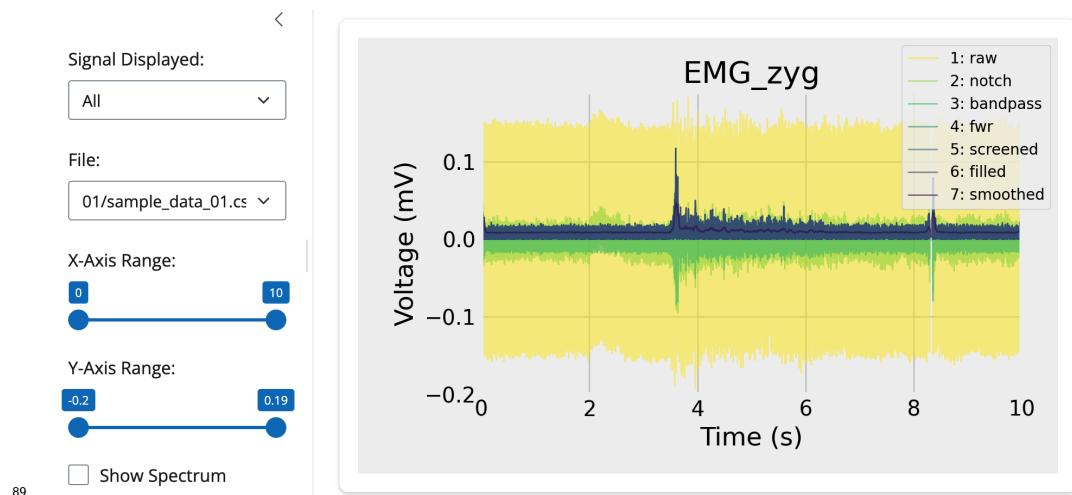
82 *EMGFlow* includes a Shiny dashboard for visualising preprocessing effects. Pipeline steps can
83 be overlaid or shown individually, and files are selected from a drop-down menu. A checkbox
84 toggles between a time-domain amplitude view and a spectral view that displays the Power
85 Spectral Density (PSD). The amplitude view exposes transients and drift, guiding selection of
86 passband edges and confirming that filtering preserves waveform shape. The PSD highlights
87 mains peaks and harmonics, guiding the choice of notch parameters (f_0 , Q). Below we generate
88 a dashboard for the *Zygomaticus major* channel.

```

# Column and measurement units to plot
show_muscle = 'EMG_zyg'
units = 'mV'

# Plot data for the "EMG_zyg" column
EMGFlow.plot_dashboard(path_names, show_muscle, units)

```



90 **Figure 2:** *EMGFlow*'s interactive dashboard visualizing effects of different preprocessing steps
91 on batch processed files.

92 An Extensive Feature Library

93 After preprocessing, files are ready for feature extraction. Surface EMG records voltage
94 differences at the skin arising from the summed motor-unit action potentials (Fridlund &
95 Cacioppo, 1986), yielding an interference signal whose amplitude (time domain) and spectrum
96 (frequency domain) reflect motor-unit recruitment, discharge rates, and muscle-fiber conduction
97 velocity (De Luca, 2008; McManus et al., 2020). *EMGFlow* extracts 33 features across time
98 and frequency domains, as listed in Table 2.

| Domain | Feature |
|----------|--|
| Temporal | minV, maxV, meanV, stdV, skewV, kurtosisV, maxF, IEMG, MAV, MMAV1, MMAV2, SSI, VAR, VOrder, RMS, WL, WAMP, LOG |
| Spectral | MFL, AP, SpecFlux, MDF, MNF, TwitchRatio, TwitchIndex, TwitchSlope, SC, SF, SS, SDec, SEntropy, SRoll, SBW |

99 **Table 2:** Features extracted from sEMG signals.

100 We conclude Example 2 by extracting features and previewing the first rows.

```

# Step 7. Extract features and save results in "Features.csv"
df = EMGFlow.extract_features(path_names, muscles, sampling_rate)

# Inspect features
df.round(4).head()

...
   File_Path  EMG_zyg_Min ...  EMG_cor_SB  EMG_cor_Spectral_PCT_Missing
0  01/sample_data_01.csv      0.0031  ...      543.1803           0.0050

```

```

1 01/sample_data_02.csv      0.0050 ... 346.9988 0.0002
2 02/sample_data_03.csv      0.0001 ... 2183.3999 0.0153
3 02/sample_data_04.csv      0.0024 ... 1051.9444 0.0000

```

[4 rows x 71 columns]

'''

101 Temporal Feature Extraction

102 The set of 18 time-domain features include statistical moments (mean, variance, skew, kurtosis)
 103 and sEMG-specific measures. Examples include Willison amplitude, a proxy for motor unit
 104 firing that counts threshold crossings, and log-detector, an estimator of muscle force (Tkach
 105 et al., 2010). Time-domain features can be computed after the first three preprocessing steps
 106 (notch, band-pass, rectify); Steps 4-6 are optional.

107 Spectral Feature Extraction

108 The 15 frequency-domain features characterise power-spectrum shape and distribution. Median
 109 frequency (Phinyomark et al., 2009) tracks changes in conduction velocity and is used in
 110 muscle fatigue assessments (Boxtel et al., 1983; Lindstrom et al., 1977; McManus et al., 2020).
 111 Standard measures include spectral centroid, flatness, entropy, and roll-off. We also introduce
 112 Twitch Ratio, adapted from speech analysis (Eyben et al., 2016), defined as the ratio of upper-
 113 to lower-band energy with a 60 Hz boundary between slow- and fast-twitch muscles fibres
 114 (Hegedus et al., 2020).

115 Spectral features are computed by converting the Step 2 band-limited signal into a PSD. To
 116 avoid discarding otherwise valid Welch frames due to isolated dropouts, we perform constrained
 117 interpolation for micro-gaps <5 samples (2.5–5 ms at 1–2 kHz) and leave longer gaps as
 118 NaN so affected frames are rejected (Jas et al., 2017). This limits interpolation bias, which
 119 increases with gap size and density (Clifford & Tarassenko, 2005; Munteanu et al., 2016). We
 120 do not apply Steps 3–6 before PSD: rectification is non-linear and distorts spectra (Farina et
 121 al., 2013; McClelland et al., 2014; Neto & Christou, 2010); artefact-replacement filters can
 122 violate stationarity assumptions for FFT-based PSD; and smoothing suppresses high-frequency
 123 content. We estimate PSD with Welch’s method using Hann windows, 50% overlap, and
 124 rejection of segments with remaining invalid samples, and mean averaging of retained spectra
 125 to form a long-term spectrum (Welch, 1967).

126 Missing Data Reporting

127 EMGFlow reports the percentage of missing data in the final temporal and spectral series
 128 as _Temporal_PCT_Missing and _Spectral_PCT_Missing in the extracted feature DataFrame,
 129 enabling downstream exclusion criteria where appropriate.

130 Documentation and Testing

131 The documentation site (<https://wiiison.github.io/EMGFlow-Python-Package>) is built with
 132 VitePress. It provides a Quick-Start, an example gallery from minimal to advanced pipelines,
 133 an API reference with executable snippets, and a detailed catalogue of all mathematical feature
 134 definitions. Mermaid diagrams give a high-level view of the module structure.

135 Code reliability is enforced via an automated *unittest* suite run on every commit via GitHub
 136 Actions. The same tests can be executed locally; instructions and examples are provided on
 137 the documentation site. This ensures that changes remain reliable across platforms.

138 Community Guidelines

139 Contributions are welcome via issues or pull requests. Suggestions for features, usage tips, and
140 questions can also be raised through GitHub Discussions.

141 AI Usage Disclosure

- 142 ▪ Source code: All EMGFlow source code and test cases were written manually by the
143 authors.
- 144 ▪ Manuscript: The authors used GPT-5 to edit a final draft of the manuscript for flow,
145 tone, and grammatical correctness. The authors reviewed and edited the content as
146 needed and take full responsibility for the content of the publication.
- 147 ▪ Documentation: The documentation website was created manually by the authors. The
148 authors used GPT-5 to edit the “About electromyography” page. The authors reviewed
149 and edited the content of this page and take full responsibility for the content of the
150 page. All remaining documentation content was written manually by the authors.

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154 Author contributions

155 S.R.L. conceptualised the project. W.L.C. and S.R.L. designed the toolbox functionality. W.L.C.
156 wrote the toolbox code and maintains the GitHub repository. W.L.C. and S.R.L. maintain the
157 documentation website. S.R.L prepared manuscript figures; W.L.C. prepared repository and
158 documentation figures. S.R.L and W.L.C. prepared the manuscript and approved the final
159 version.

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