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Appendix A

For calculating the exact bounds $[c_l, c_r]$ of the centroid of the interval type-2 fuzzy set

$$\tilde{A} = \left\{\left(x, \left(1, \left[\underline{u}_{f_i}(x), \overline{u}_{f_i}(x)\right]\right)\right), x \in X, \left[\underline{u}_{f_i}(x), \overline{u}_{f_i}(x)\right] \subseteq [0,1]\right\} = \left\{\left(x, \tilde{\mu}_{f_i}(x)\right), x \in X\right\}$$

Karnik and Mendel have proposed an iterative algorithm (KM Algorithm) [20]. Moreover, Mendel and Wu have proved that the end points of the centroid of an interval type-2 fuzzy set are bounded and have driven formulas for calculating c_l and c_r [21], that is

$$\underline{c_l} \le c_l \le \overline{c_l}$$
$$\underline{c_r} \le c_r \le \overline{c_r}$$

Toward the aim, since FOU is fully characterized by two type-1 fuzzy set, named *Upper Membership Function* (*UMF*) and *Lower membership Function* (*LMF*), and their centroid is defined to be

$$C_{LMF(\tilde{A})} = \frac{\sum_{i=1}^{N} x_i \underline{u}(x_i)}{\sum_{i=1}^{N} \underline{u}(x_i)}$$

$$C_{UMF(\tilde{A})} = \frac{\sum_{i=1}^{N} x_i \overline{u}(x_i)}{\sum_{i=1}^{N} \overline{u}(x_i)}$$

So the bounds would be calculated as

$$\overline{c_l} = min\{C_{LMF(\tilde{A})}, C_{UMF(\tilde{A})}\}$$
$$\underline{c_r} = max\{C_{LMF(\tilde{A})}, C_{UMF(\tilde{A})}\}$$

$$\underline{c_l} = \overline{c_l} - \frac{\sum_{i=1}^{N}\left(\overline{u}(x_i) - \underline{u}(x_i)\right)}{\sum_{i=1}^{N}\overline{u}(x_i)\sum_{i=1}^{N}\underline{u}(x_i)} \times \frac{\sum_{i=1}^{N}\underline{u}(x_i)(x_i - x_1)\ \sum_{i=1}^{N}\overline{u}(x_i)(x_N - x_i)}{\sum_{i=1}^{N}\underline{u}(x_i)(x_i - x_1) + \sum_{i=1}^{N}\overline{u}(x_i)(x_N - x_i)}$$

$$\overline{c_r} = \underline{c_r} + \frac{\sum_{i=1}^{N}\left(\overline{u}(x_i) - \underline{u}(x_i)\right)}{\sum_{i=1}^{N}\overline{u}(x_i)\sum_{i=1}^{N}\underline{u}(x_i)} \times \frac{\sum_{i=1}^{N}\overline{u}(x_i)(x_i - x_1)\ \sum_{i=1}^{N}\underline{u}(x_i)(x_N - x_i)}{\sum_{i=1}^{N}\overline{u}(x_i)(x_i - x_1) + \sum_{i=1}^{N}\underline{u}(x_i)(x_N - x_i)}$$