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From sensor-based mobility to quality-of-life assessment: a linguistic fuzzy approach

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Abstract. Quality-of-life assessment in ambient assisted living environments currently relies on psychometric questionnaires that are discrete in time and dependent on self-report, while human activity recognition systems produce continuous outputs that are opaque and poorly communicable to clinicians. This work in progress proposes a formal mapping between the two: a linguistic Mamdani fuzzy inference system that translates sensor-derived behavioural aggregates into a continuous level on the ordinal EQ-5D-5L scale, focused on the Mobility dimension. Two operational antecedents (daily time outside the home and nightly sleep duration) feed a consequent aligned with the five ordinal levels of the instrument. A pilot on the Mi4A-HomeData dataset (two co-residing patients, fourteen days, multi-resident ambient assisted living setting) shows that the inferences reproduce the expected behavioural hierarchy without hard thresholds and offer explicit traceability down to the activated rules.

Keywords: Fuzzy logic · Human activity recognition · Explainable AI · Health-related quality of life · Ambient assisted living · Smart home.

1 Introduction and motivation

The continuous measurement of quality of life (QoL) in ambient assisted living (AAL) remains an open methodological challenge. Validated instruments such as the EuroQol 5-Dimension 5-Level questionnaire (EQ-5D-5L) [3] provide clinical anchoring, but they must be administered individually by care staff (which does not scale to continuous monitoring), depend on self-report, and are discrete in time, missing sub-clinical change. A sensor-based human activity recognition (HAR) system could estimate the same construct continuously and objectively from observed behaviour; HAR has reached technical maturity and enables continuous, non-invasive observation [2], but its outputs are classes or probabilities poorly communicable to clinicians and lacking anchoring in any psychometric construct.

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Post-hoc explainability methods (SHAP, LIME, Grad-CAM for 1D signals) add an external interpretive layer to opaque models. Linguistic fuzzy logic [6] instead embeds interpretability natively: each inference combines IF–THEN rules in the expert's vocabulary, and the result is traceable to the membership grade of each antecedent. To the best of our knowledge, no proposal explicitly translates HAR output into an EQ-5D-5L level through fuzzy inference.

This work in progress reports a first step in that direction, restricted to the Mobility dimension. Its contribution is threefold: (i) an explicit conceptual mapping between the questionnaire item and sensor-derived observable variables; (ii) a Mamdani type-1 fuzzy inference system (FIS) that materialises that translation as a continuous scalar on the ordinal range $[1, 5]$; and (iii) a feasibility demonstration on a multi-resident AAL dataset with explicit traceability and behaviourally coherent results.

The EQ-5D-5L questionnaire [3] structures self-perceived health along five orthogonal ordinal dimensions, which makes partial estimation legitimate; we therefore confine ourselves to Mobility.

EQ-5D-5L provides descriptive labels but no quantitative criteria, and no validated mapping exists between them and continuous behavioural variables — the gap this work addresses. Consistent with the digital-biomarker and behavioural-phenotyping literature, we hypothesise that both vocabularies describe the same underlying construct: observed behaviour manifests the functional capacity that the questionnaire estimates subjectively [1].

Hard thresholds would not capture this imprecision, which the Mamdani formulation [6] accommodates natively, yielding a continuous, auditable inference on the ordinal $[1, 5]$ scale.

2 Fuzzy inference system for the EQ-5D-5L Mobility dimension

The implemented system is a Mamdani type-1 FIS with two operational antecedents and a single consequent aligned with the Mobility dimension. Time outside the home (daily minutes spent outside the dwelling) is an observable correlate of ambulatory capacity, consistent with life-space mobility [1]; nightly sleep duration spans insufficient, adequate and excessive ranges, following adult rest recommendations [4]. In the absence of validated quantitative thresholds for the EQ-5D-5L labels, the antecedent breakpoints are expert priors amenable to data-driven calibration in future work. Both antecedents use three trapezoidal labels; the consequent is defined over $[1, 5]$ with five triangular labels centred at integers 1–5, respecting the ordinal nature of EQ-5D-5L in which each level is a point rather than a band. Figure 1 depicts the complete partitions.

The rule base comprises nine IF–THEN rules; for instance, IF time outside is high AND sleep is adequate THEN Mobility is no problems. Inference uses the minimum t-norm for antecedent conjunction and the maximum t-conorm for rule aggregation, with centroid defuzzification over the resulting area. The system is continuous and bounded by construction.

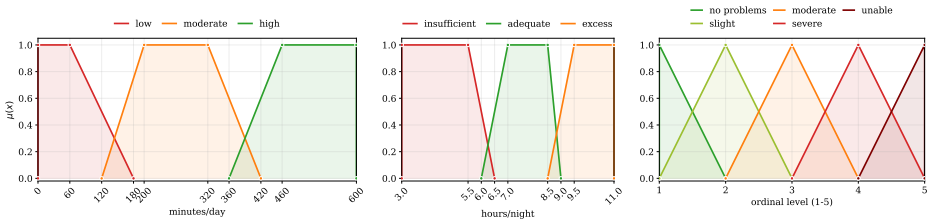


Fig. 1. Fuzzy partitions: two trapezoidal antecedents and a triangular consequent on the ordinal EQ-5D-5L scale.

3 Pilot case and preliminary results

The system was evaluated on the Mi4A-HomeData (MicroChip4Age) dataset [5], a multi-resident AAL scenario with two patients co-habiting an instrumented dwelling with Bluetooth Low Energy (BLE) anchors and manual activity annotation over fourteen consecutive days. From the six annotated activities we use the traces of leaving the home and sleep, aggregated as daily minutes outside the dwelling and hours of the main nightly sleep episode per patient and day. After discarding one partial initial day, twenty-five valid days remain across both patients.

Figure 2 shows the daily trajectory of the inferred Mobility level. Both patients remain predominantly between no problems and moderate, compatible with preserved functional autonomy, with Patient 1 showing a better median than Patient 2; day-to-day oscillations capture specific days of domiciliary confinement as a transient degradation that recovers once the usual pattern resumes.

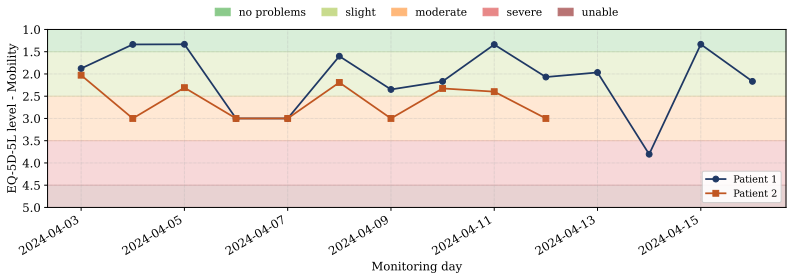


Fig. 2. Daily trajectory of the ordinal EQ-5D-5L Mobility level inferred by the FIS for the two patients of Mi4A-HomeData. The y-axis is inverted so that upward values represent better mobility. Coloured bands associate ranges of the inferred scalar with the linguistic levels of the instrument.

Table 1 reports four representative days. Three readings emerge. (i) The operational range spans the scale from no problems to severe without saturating

Table 1. Best and worst day per patient; in parentheses, the closest ordinal label.

Patient and case	Date	Time outside (min)	Sleep (h)	Level (FIS)
P1 · best day	2024-04-05	474	7.3	1.33 (no problems)
P1 · worst day	2024-04-14	60	9.8	3.80 (severe)
P2 · best day	2024-04-08	296	6.8	2.19 (slight)
P2 · worst day	2024-04-04	0	8.2	3.00 (moderate)

it. (ii) The output is continuous between adjacent days with small antecedent variations, a property hard-threshold rules cannot deliver. (iii) Each inference is traceable: Patient 1's worst day (60 min outside, sleep in the excess band) is explained by naming the two activated linguistic labels and the resulting consequent, with no external explainability technique required.

Ongoing extensions. Priorities are validation on substantially larger cohorts and extension to the remaining sensor-observable EQ-5D-5L dimensions and to fully automatic activity recognition, within the broader Fuzzy-QoL-AAL programme.

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