Fine-Grained Activity Detection in the Kitchen with UWB

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3.1 System Tuning Review

The Pozyx Creator Kit comes with anchors and several tags. Anchors are mounted on the walls and are used to position the tags. Multiple tags may be positioned at the same time. The Pozyx Creator kit uses ultrawideband (UWB) signals with the two-way ranging protocol to localize the tag. The tag is mounted on custom 3D printed wearables which the participant can wear as a wrist-watch or a necklace. Through trial-and-error and consultation with the Pozyx Creator Documentation [80, 81] it was determined that the accuracy of the system depends on factors listed below:

- Number of anchors
- Position of anchors

These variables were modified to achieve satisfactory actual position error and standard deviation below the expected error of 30 cm for UWB systems. The protocol for obtaining data and evaluating the actual position error and standard deviation is described in the next section.

3.2 Methodology

This protocol tests the X, Y, and Z positional accuracy of the Pozyx Creator system in the Independent Living Suite (ILS) at the Glenrose Rehabilitation Hospital by having a participant stand at a specific location in each room. Permanent appliances or furniture such as the stove or dining table were used as much as possible to ensure that the experiment is repeatable.

3.2.1 Setup

Masking tape was used to mark the locations where the participant should place their feet. The following procedure was followed to place the tape:

1. Using a measuring tape, measure 1 meter out from the middle of the appliance or furniture and place a 20 cm piece of tape centered on, perpendicular to and underneath the measuring tape (the tips of the participant's toes should be 1 meter away from the appliance).

2. Place parallel tape on the sides of the tape placed in Step 1 to constrain the feet to a box. (The participant should have their toes on the tape perpendicular to the measuring tape and usually facing the appliance or furniture). Figure 3.1 outlines some examples of tape placements.

Figure 3.1: Box tape placement at the stove, fridge, and dining table. Participant's toes and sides of feet should touch the tape.

Following the tape placement guidelines outlined at the beginning of this section, tape was placed at or near the following locations. Refer to the AUTOCAD floor plan for the location of the rooms (Figure 3.2):

- The Hallway between Living Room and Kitchen facing the Dining Table.
- The Living Room facing the Desk.
- The Bedroom facing the bed.
- The Hallway between the bedroom and the bathroom, facing away from the wall.

- Bathroom facing the toilet.
- Kitchen facing the stove.

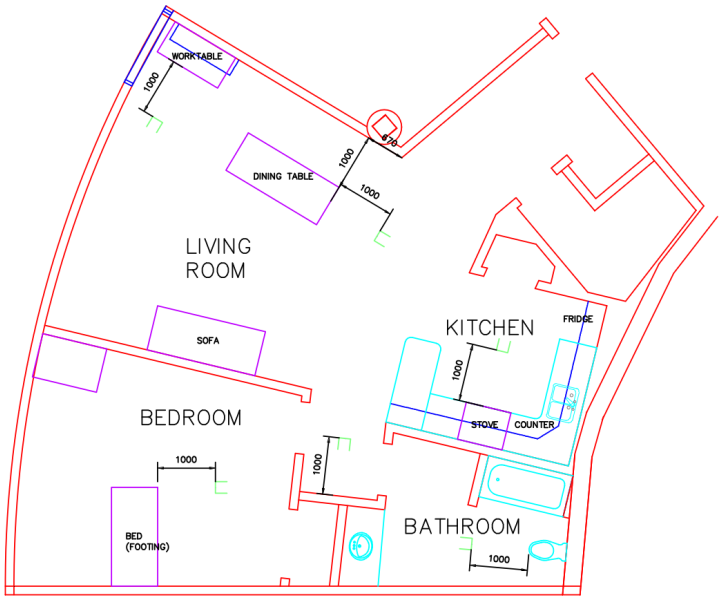


Figure 3.2: Floor plan of the ILS. Positions where the participant stood 1 meter from appliances or furniture are marked in the green "open" box on the floorplan.

3.2.2 Protocol

A stopwatch python script was created with predetermined labels and used as the ground truth for positions. A single participant wore the tag on a 3D printed necklace mount (Figure 3.3). The measuring tape was used to measure the height from the ground and height when squatting. For this participant, the standing height was **144cm** and the squatting height was **68.5cm**.

Figure 3.3: The Pozyx tag mounted in a custom 3D printed necklace mount.

The protocol had the following steps:

1. At the first location (Hallway Between Living Room and Kitchen) stand still for 10 seconds
2. Squatt still for 10 seconds.

3. Move to next position.

4. Repeat steps 1-3 until all of the positions have been reached.

5. Finally return to the first position (Hallway Between Living Room and Kitchen)

There were 3 trials for each configuration. Following the guidelines from the Pozyx Creator Setup [81] anchors were staggered at heights of 1.4m and 2.4m (ceiling height) for 4, 5, 6, 8, and 10 anchors. A configuration where anchors were all low (10cm) were tested for 8 anchors and configurations where anchors were all high (2.4m) were tested for 8 and 9 anchors.

3.3 Results

Trials for each configuration were aggregated, transition periods were removed, data of interest was time normalized and the error and standard deviation of each location while standing and squatting were calculated. An as-built AUTOCAD file of the ILS was used to obtain the real position and used in the calculation of the error between measured versus the actual position. The results of the experiment are summarized in the heatmap tables (Figures 3.4, 3.5 and 3.6) with a minimum darkness set at 30cm and a maximum darkness set at 60cm.

X Position Error at Each Location (cm)

	POS_X_A4	POS_X_A5	POS_X_A6	POS_X_A8	POS_X_A10	POS_X_A8H	POS_X_A8L	POS_X_A9H
Go Hallway between kitchen and living	40.1	41.5	42.2	47.9	33.0	11.8	3.5	28.0
Go Hallway between kitchen and living(sit)	18.6	11.7	7.4	44.2	20.6	29.2	21.9	41.4
Living Room	50.4	57.8	48.3	7.7	34.5	20.0	31.3	41.8
Living Room(sit)	44.6	30.2	20.0	28.8	23.7	5.2	6.5	11.0
bathroom	49.1	39.8	33.0	65.3	15.4	111.9	120.6	52.0
bathroom(sit)	29.2	19.6	22.9	23.2	39.0	64.5	24.6	61.1
bedroom	24.1	2.5	39.4	58.3	55.8	99.8	78.3	49.2
bedroom(sit)	26.9	12.8	4.1	103.8	45.9	53.5	27.0	37.5
hallway between bedroom and bathroom	2.7	14.9	5.3	5.4	7.6	6.6	3.7	36.1
hallway between bedroom and bathroom(sit)	2.8	13.9	26.5	0.1	3.4	1.7	51.3	22.2
kitchen	23.7	26.8	18.5	30.1	31.5	37.3	29.1	7.7
kitchen(sit)	8.2	22.2	8.8	41.9	31.2	43.7	44.1	28.0

(a)

X Standard Deviation at Each Location (cm)

	POS_X_A4	POS_X_A5	POS_X_A6	POS_X_A8	POS_X_A10	POS_X_A8H	POS_X_A8L	POS_X_A9H
Go Hallway between kitchen and living	105.9	56.5	62.1	39.2	42.2	43.8	29.1	28.2
Go Hallway between kitchen and living(sit)	9.8	19.2	12.7	24.5	13.7	12.3	20.0	15.6
Living Room	5.4	7.9	6.4	18.7	19.1	17.3	12.0	12.9
Living Room(sit)	11.6	24.9	19.2	18.0	20.2	17.4	16.2	13.2
bathroom	44.4	27.3	19.6	82.5	43.4	65.3	90.6	39.1
bathroom(sit)	13.8	12.6	9.7	68.0	39.7	44.5	80.2	23.1
bedroom	17.7	17.3	17.6	21.0	21.6	36.3	30.5	24.7
bedroom(sit)	7.9	20.7	28.1	28.3	14.6	29.5	29.1	14.4
hallway between bedroom and bathroom	10.2	12.5	6.9	24.6	18.1	16.0	13.6	19.3
hallway between bedroom and bathroom(sit)	14.6	4.8	10.8	13.0	13.4	10.1	12.3	12.9
kitchen	16.7	7.8	10.3	5.1	5.0	7.9	7.9	7.8
kitchen(sit)	20.7	6.6	16.4	14.4	9.6	8.5	9.7	5.1

(b)

Figure 3.4: The positional error in X (a) and the standard deviation in X (b) at each location and body position

Y Position Error at Each Location (cm)

	POS_Y_A4	POS_Y_A5	POS_Y_A6	POS_Y_A8	POS_Y_A10	POS_Y_A8H	POS_Y_A8L	POS_Y_A9H
Go Hallway between kitchen and living	20.5	28.7	38.8	95.4	62.3	58.2	8.6	28.5
Go Hallway between kitchen and living(sit)	46.5	58.2	57.9	65.5	49.5	63.4	31.7	42.7
Living Room	11.6	6.2	3.2	62.3	63.5	47.1	37.4	38.0
Living Room(sit)	7.8	0.7	3.7	47.8	35.6	25.8	32.7	15.1
bathroom	27.9	0.4	7.8	44.4	56.1	47.3	10.3	38.2
bathroom(sit)	54.7	39.2	37.7	53.7	29.7	5.1	15.1	1.0
bedroom	22.8	14.5	9.2	39.5	16.1	71.7	58.4	5.7
bedroom(sit)	20.2	5.3	33.9	60.9	5.0	34.6	1.8	8.7
hallway between bedroom and bathroom	4.6	7.8	24.8	7.1	9.4	23.5	2.0	19.4
hallway between bedroom and bathroom(sit)	56.2	67.0	44.4	31.0	7.7	28.3	8.8	13.8
kitchen	16.8	2.8	10.8	28.5	33.7	39.0	38.0	31.3
kitchen(sit)	17.5	4.0	9.0	21.9	31.1	15.5	28.6	22.2

(a)

Y Standard Deviation at Each Location (cm)

	POS_Y_A4	POS_Y_A5	POS_Y_A6	POS_Y_A8	POS_Y_A10	POS_Y_A8H	POS_Y_A8L	POS_Y_A9H
Go Hallway between kitchen and living	103.7	53.5	62.1	115.5	79.0	137.9	25.8	24.7
Go Hallway between kitchen and living(sit)	10.3	13.7	10.7	23.6	17.8	21.1	27.6	16.0
Living Room	5.7	8.3	4.8	13.7	16.1	17.4	20.8	14.2
Living Room(sit)	11.1	14.7	11.0	21.3	12.2	16.3	13.1	7.5
bathroom	35.1	25.1	21.9	50.8	24.8	36.2	39.8	23.4
bathroom(sit)	29.8	42.1	29.3	19.1	23.4	20.3	38.9	17.8
bedroom	15.6	17.7	14.2	18.9	12.2	18.4	23.7	9.5
bedroom(sit)	9.5	12.4	14.3	24.9	14.9	16.8	17.5	6.2
hallway between bedroom and bathroom	15.2	9.0	12.2	23.0	13.6	13.4	9.5	13.0
hallway between bedroom and bathroom(sit)	12.7	10.5	16.7	8.0	12.9	12.3	12.1	8.2
kitchen	17.6	9.1	6.2	9.9	7.1	14.0	9.0	9.8
kitchen(sit)	24.4	16.0	17.2	15.3	11.0	12.7	16.1	5.9

(b)

Figure 3.5: The positional error in Y (a) and the standard deviation in Y (b) at each location and body position

Z Position Error at Each Location (cm)

	POS_Z_A4	POS_Z_A5	POS_Z_A6	POS_Z_A8	POS_Z_A10	POS_Z_A8H	POS_Z_A8L	POS_Z_A9H
Go Hallway between kitchen and living	132.3	56.9	47.9	180.1	87.6	7.5	58.2	3.2
Go Hallway between kitchen and living(sit)	137.0	207.8	184.0	232.3	104.7	7.6	22.8	16.0
Living Room	121.5	36.7	41.7	99.4	88.5	58.1	54.8	57.0
Living Room(sit)	79.1	177.1	197.1	224.9	16.7	30.8	97.0	17.2
bathroom	84.0	66.7	114.7	64.2	27.3	43.6	147.6	80.3
bathroom(sit)	43.2	10.2	11.2	211.1	66.4	26.3	4.6	66.2
bedroom	57.5	65.8	121.6	192.9	233.5	155.3	234.6	37.1
bedroom(sit)	39.7	1.3	54.8	305.5	3.5	80.9	142.5	20.6
hallway between bedroom and bathroom	74.0	103.4	4.1	208.3	48.6	30.8	72.3	71.7
hallway between bedroom and bathroom(sit)	33.4	26.2	59.1	84.2	2.8	61.1	54.4	65.2
kitchen	70.5	117.0	40.5	0.1	38.7	33.5	73.8	31.5
kitchen(sit)	119.0	3.9	25.9	216.1	70.6	38.5	139.6	20.5

(a)

Z Standard Deviation at Each Location (cm)

	POS_Z_A4	POS_Z_A5	POS_Z_A6	POS_Z_A8	POS_Z_A10	POS_Z_A8H	POS_Z_A8L	POS_Z_A9H
Go Hallway between kitchen and living	93.9	80.0	89.6	68.1	69.9	58.7	110.3	33.8
Go Hallway between kitchen and living(sit)	84.8	110.0	123.2	151.2	108.1	21.0	77.3	9.0
Living Room	46.7	36.1	23.5	92.1	25.6	20.0	144.2	17.1
Living Room(sit)	53.1	118.1	112.8	107.5	106.7	13.2	87.2	22.0
bathroom	89.9	105.2	69.6	99.9	77.3	79.4	151.9	40.7
bathroom(sit)	107.7	18.3	35.4	90.0	115.6	119.0	93.6	63.7
bedroom	65.4	109.7	67.8	142.2	58.5	24.2	246.9	20.0
bedroom(sit)	15.1	28.4	66.1	154.6	130.0	25.6	144.2	12.1
hallway between bedroom and bathroom	37.2	50.0	21.1	51.5	98.9	31.1	150.1	30.2
hallway between bedroom and bathroom(sit)	104.2	13.2	24.7	176.0	112.5	14.1	57.9	15.7
kitchen	75.2	62.0	64.5	61.8	13.2	24.4	26.3	17.0
kitchen(sit)	149.3	46.5	95.5	172.8	119.5	15.9	42.7	7.2

(b)

Figure 3.6: The positional error in Z (a) and the standard deviation in Z (b) at each location and body position

3.4 Discussion

3.4.1 X Position

Visually, the heatmap of error in the X position shows different spots where the system struggled to obtain the location based on the AUTOCAD as-builts depending on the configuration selected. For 4, 5 and 6 anchors, the errors seemed to be larger in the living room and the hallway between the kitchen and the living room. 8, 10, 8 (L)ow, 8 (H)igh, and 9H anchors seemed to struggle most around the bathroom and bedroom area. The standard deviation in X position seems to follow a similar pattern where 4, 5 and 6 anchors have higher standard deviation in hallway between the kitchen and living area and 8, 10, 8 (L)ow, 8 (H)igh, and 9H seems to struggle the most in the bathroom. Out of all of the configurations the 9H configuration has the most locations where the standard deviation is acceptable.

3.4.2 Y Position

For 4, 5, and 6 anchors, the error seems to increase in the seated position meaning that there may be some dependence on the Z position. This occurs in the hallway between the kitchen and the living room, the bathroom and the hallway between the bedroom and bathroom. There seems to be a large struggle for 8, 10 and 8H anchors to pinpoint the Y position in the hallway between the kitchen and the living, the living room and the bathroom. The 8L anchor configuration struggled when the in the bedroom, but was overall within or near the acceptable threshold of 30cm. 9H anchors overall seemed to be the best at determining the Y position with mild errors at the hallway between the kitchen and the living room, the living room and the bathroom.

In terms of standard deviation, anchor configurations 4, 5, 6, 8, 8H, and 10 had trouble at a height of 144cm, but otherwise had low standard deviation. 8L had minor issues regarding standard deviation in the bathroom but was otherwise low. The 9H configuration seemed to yield the lowest standard deviations in the Y Position.

3.4.3 Z Position

The Z position at many of the locations and all configurations seem to deviate from the measured heights and have high error. Only the 8H and 9H

configurations have acceptable standard deviations for most of the rooms (there is still some struggle in the bathroom). Considering the inaccuracies in the Z positioning, it is recommended that the Z not be used as a absolute source of truth for height. Rather Z position should be used relative to another reference tag with the 9H configuration. For example, a necklace tag may be combined a wrist tag. When standing, the position of the wrist may be compared with the position of the necklace to determine if the wrist is above, below or at chest height.

3.4.4 Overall

The 9H configuration seems to provide the most reliable data when observing the standard deviations of the X, Y, and Z positions. With this configuration, each room had around 4 anchors surrounding it Figure 3.7

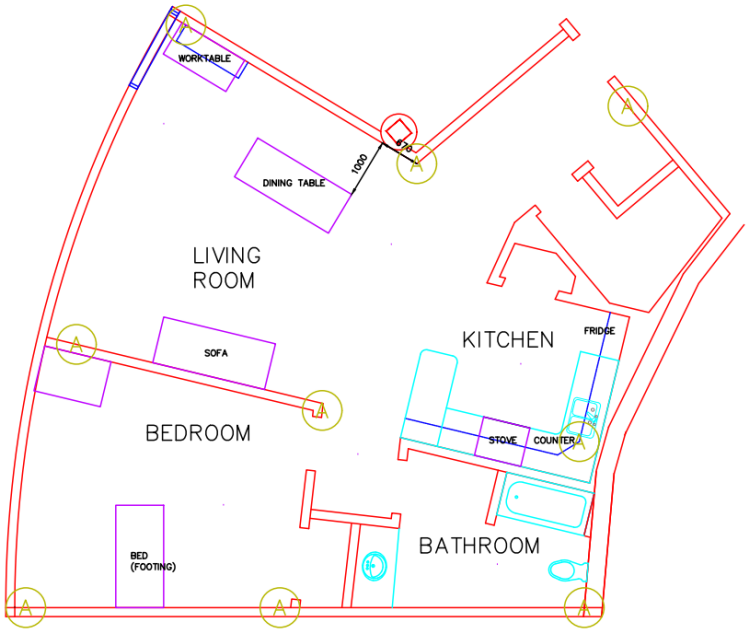


Figure 3.7: ILS Floorplan with the 9 anchors all high.

Though the inaccuracies in the hallway, living room, bathroom and bedroom may prevent the 9H configuration from using heuristics for classification

at these locations, the inherent repeatability evident in the low standard deviation in each axes of the position can make the position data from the 9H configuration a candidate for machine-learning based classification.

Chapter 4

Classification of Time Series Data

Chapter 5

Pilot Testing of Detecting Activities to make a Sandwich

Chapter 6

Data Collection for Fine-grained Activities

6.1 Selecting Cooking Tasks

To employ some of the time-series classification methods discussed in Chapter 4, a dataset of the proposed positional + IMU system is required. Chapter 2's section on the traditional assessments of ADLs will serve as a basis for the selection of tasks to perform and collect data from. Of the assessments discussed, Table 6.1 summarizes the assessments with cooking tasks mentioned in its procedure.

Table 6.1: Cooking tasks in the Assessment tools for the IADLs.

Tool	**Tasks**
PASS	making soup with water/milk
	making muffins in the oven
	cutting up fruit
Self-Assessment PD Disability Scale	making a cup of tea
	inserting electrical plug
	pouring milk from bottle
	opening tins
	washing
Melbourne Low-vision ADL Index	preparing meals
Lawton Instrumental ADL Scale	plans, prepares and serves adequate meals independently
Frenchay Activities Index	preparing main meals
Texas Functional Living Scale	Describe how to make peanut butter and jelly sandwich

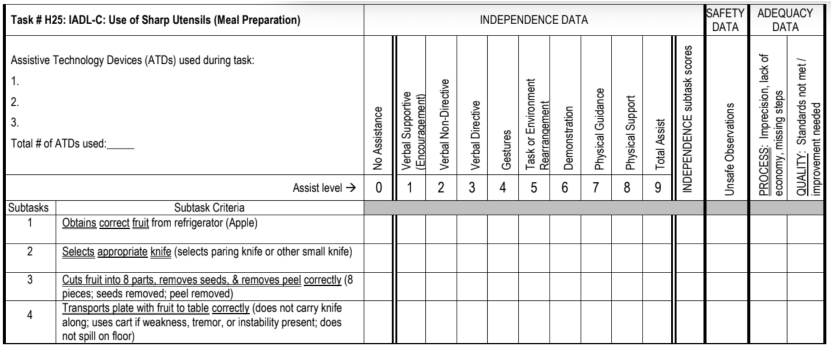
Of the assessments in Table 6.1, the cooking task(s) in the Melbourne Low-vision ADL Index, Lawton Instrumental ADL Scale, Frenchay Activities Index, and Self-Assessment PD Disability Scale are all questionnaires and as a result do not have concrete steps on how the task should be performed.

Futhermore, the Melbourne Low-vision ADL Index, Lawnton Instrumental ADL Scale and the Frenchay Activities Index only have general requirements for the cooking task such as the ability to "prepare meals," and "plans, prepares and serves adequate meals independently." These general cooking tasks may be useful in the evaluation of ADL ability in a questionnaire format by requesting the older adult to holistically consider their ability to cook, but may not be the best candidates when looking for fine-grained actions to extract.

The remaining 2 assessment tools, the Texas Functional Living Scale and Performance Assessment of Self-Care Skills (PASS), mention cooking task(s) that requires a clinician to evaluate. Upon closer inspection of the Texas Functional Living Scale, however, the individual is only required to describe the task and not actually perform it. The only candidate that has clear cooking tasks broken down into their fine-grained actions is the PASS and will be used as a reference for the experiment protocol and extraction of fine-grained tasks. 3 Cooking Scenarios are presented in the PASS: making soup with water/milk, making muffins in the oven, and cutting up fruit. The 3 cooking scenarios are shown in Figures 6.1-6.3.

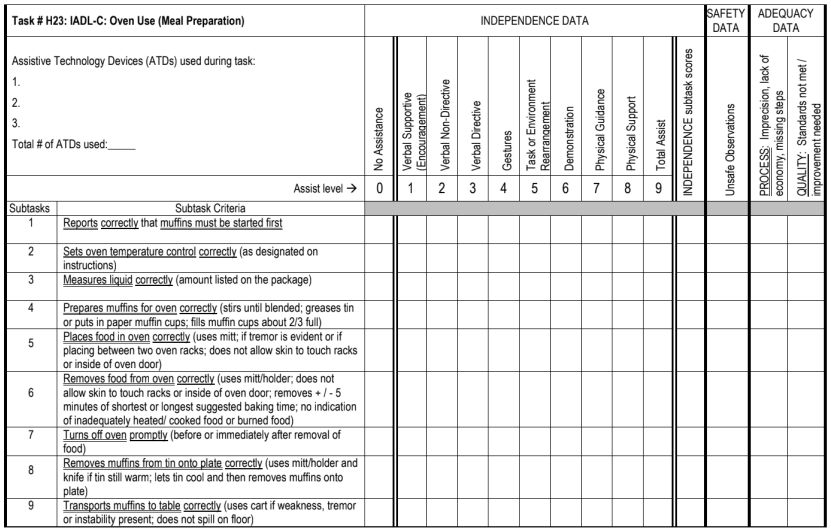
Task # H24: IADL-C: Stovetop Use (Meal Preparation)		INDEPENDENCE DATA											SAFETY DATA	ADEQUACY DATA	
Assistive Technology Devices (ATDs) used during task: 1. 2. 3. Total # of ATDs used:_____		No Assistance	Verbal Supportive (Encouragement)	Verbal Non-Directive	Verbal Directive	Gestures	Task or Environment Rearrangement	Demonstration	Physical Guidance	Physical Support	Total Assist	INDEPENDENCE subtask scores	Unsafe Observations	PROCESS: Imprecision, lack of economy, missing steps	QUALITY: Standards not met / improvement needed
Assist level →		0	1	2	3	4	5	6	7	8	9				
Subtasks	Subtask Criteria														
1	Opens soup can correctly (cut is even, entire top is off or <1/2" is retained in one place)														
2	Removes/handles soup can lid correctly (lifts lid with knife; punches lid into can; does not cut finger)														
3	Pours/spoons soup into pan without spilling (no soup on Ct, counter, or floor)														
4	Adds liquid correctly (adds 1 can of water/milk; does not spill on self, floor)														
5	Places pan on correct stove burner (burner closest to pan size)														
6	Turns burner on correctly (manipulates knob for burner that soup is on or is placed onto later; sets control on medium to high)														
7	Monitors soup adequately (stirs; alters heat as necessary, soup does not stick on pan, checks to make sure soup temperature is hot rather than lukewarm to touch or taste or that soup boils/bubbles)														
8	Removes pan from burner when soup is still hot (steam can be seen rising from pan; checks to make sure soup temperature is hot rather than lukewarm to touch or taste)														
9	Turns burner off promptly (+/- 1 minute of removing soup from burner)														
10	Transports & pours soup into bowls correctly (uses mitt under pan or slides pan across counter for stability if weakness or tremor present; does not spill on floor; only minor drips on counter)														
11	Transports bowls to table correctly (uses mitt under bowl or uses cart if weakness, tremors, or instability present; uses bowl rim to carry: does not spill on floor)														

Figure 6.1: PASS Soup Task [47]



Task # H25: IADL-C: Use of Sharp Utensils (Meal Preparation)		INDEPENDENCE DATA											SAFETY DATA	ADEQUACY DATA	
Assistive Technology Devices (ATDs) used during task: 1. 2. 3. Total # of ATDs used:_____		No Assistance	Verbal Supportive (Encouragement)	Verbal Non-Directive	Verbal Directive	Gestures	Task or Environment Rearrangement	Demonstration	Physical Guidance	Physical Support	Total Assist	INDEPENDENCE subtask scores	Unsafe Observations	PROCESS: Imprecision, lack of economy, missing steps	QUALITY: Standards not met / improvement needed
Assist level →		0	1	2	3	4	5	6	7	8	9				
Subtasks	Subtask Criteria														
1	Obtains correct fruit from refrigerator (Apple)														
2	Selects appropriate knife (selects paring knife or other small knife)														
3	Cuts fruit into 8 parts, removes seeds, & removes peel correctly (8 pieces; seeds removed; peel removed)														
4	Transports plate with fruit to table correctly (does not carry knife along; uses cart if weakness, tremor, or instability present; does not spill on floor)														

Figure 6.2: PASS Fruit Task [47]



Task # H23: IADL-C: Oven Use (Meal Preparation)		INDEPENDENCE DATA											SAFETY DATA	ADEQUACY DATA	
Assistive Technology Devices (ATDs) used during task: 1. 2. 3. Total # of ATDs used:_____		No Assistance	Verbal Supportive (Encouragement)	Verbal Non-Directive	Verbal Directive	Gestures	Task or Environment Rearrangement	Demonstration	Physical Guidance	Physical Support	Total Assist	INDEPENDENCE subtask scores	Unsafe Observations	PROCESS: Imprecision, lack of economy, missing steps	QUALITY: Standards not met / improvement needed
Assist level →		0	1	2	3	4	5	6	7	8	9				
Subtasks	Subtask Criteria														
1	Reports correctly that muffins must be started first														
2	Sets oven temperature control correctly (as designated on instructions)														
3	Measures liquid correctly (amount listed on the package)														
4	Prepares muffins for oven correctly (stirs until blended; greases tin or puts in paper muffin cups; fills muffin cups about 2/3 full)														
5	Places food in oven correctly (uses mitt; if tremor is evident or if placing between two oven racks; does not allow skin to touch racks or inside of oven door)														
6	Removes food from oven correctly (uses mitt/holder; does not allow skin to touch racks or inside of oven door; removes + / - 5 minutes of shortest or longest suggested baking time; no indication of inadequately heated/ cooked food or burned food)														
7	Turns off oven promptly (before or immediately after removal of food)														
8	Removes muffins from tin onto plate correctly (uses mitt/holder and knife if tin still warm; lets tin cool and then removes muffins onto plate)														
9	Transports muffins to table correctly (uses cart if weakness, tremor or instability present; does not spill on floor)														

Figure 6.3: PASS Muffin Task [47]

6.2 Fine-grained Task Extraction

The detail in which tasks can be broken down varies in literature. Human actions may be decomposed all the way into action primitives which is a body part + some motion (eg. right/left hand forward/backward) [118]. Fine-grained actions can be thought as being one level "coarser" than these action primitives and may combine action primitives to perform a small task (eg. cutting fruit, stir-frying, washing a fruit) [76]. A "coarser" level above fine-grained actions are coarse-grained actions and describe the activity that encompasses all of the fine-grained actions (eg. cooking, working). Although action primitives may be useful to consider when breaking down a task, the focus of the thesis is the evaluation of function and ability to perform tasks toward some goal. The detection of coarse-grained actions or activities have been successful in literature previously [68], but these coarse-grained actions are too general and do not provide insight into the functional quality of the cooking task. Thus, the focus of the task extraction will be at the "fine-grained" level.

For each cooking activity in the PASS, an experimental protocol will be developed based on the subtasks outlined in the task document. Although the PASS presents general steps to complete the task, there may sometimes be other actions, or "side-actions" involved in the task. For example, for the Cutting Fruit task in Figure 6.2, obtaining the fruit from the refrigerator would require the individual to perform OPEN-FRIDGE, GRAB-FRIDGE, and CLOSE-FRIDGE. The experimental protocol will be more detailed with steps detailing the actions in the PASS as well as any side-actions that occur. Then, from the steps in the experimental protocol, the fine-grained actions can be extracted.

6.3 Experimental Protocol

This section will detail the experimental protocol for each of the 3 pass tasks. The steps presented in the original PASS document (Figures 6.2-6.3) are used as reference and adapted to the environment where the experiments will take place: the Independent Living Suite. Location of items that were interacted with in the ILS that are not standard in every kitchen are labelled in Figure 6.4.

Figure 6.4: Independent Living Suite locations.

6.3.1 Initial Setup

The initial setup prior to conducting the experiments involved the following steps:

Data Recording

1. Referencing the 9H configuration the resulted in the best accuracy and repeatability determined in Chapter 3, the anchors are set up in the locations indicated by Figure 3.7.

2. Based on the documentation for the Pozyx [81], the settings for the fastest possible sample rate (16 Hz) without a large effect on the communication range was a bitrate of 850 kbit/s and a preamble length of 128. Both the anchors and the tags were set to communicate at these settings.

3. Setup a camera with a countdown timer so that segments of the data can be manually labelled at a later time.

4. Wear the Pozyx tag on the dominant hand.

Home Conditions

The home conditions per the PASS Meal Preparation Tasks are listed as the following [47]:

1. Kitchen area and Electric or gas stove with oven

2. Sink, "as is"

3. Usual meal preparation utensils and supplies (e.g., spoons, spatula, bowls, oven mitt/pot holder, etc.)

4. Apple placed in refrigerator, within easy view when door is opened

5. Muffin tin for 6 muffins and muffin mix requiring only the addition of water/milk

6. Can of soup requiring the addition of water/milk

7. Cookie sheet on kitchen counter nearest stove, with items 5-6 stacked on it

Note that for the following experiments, whenever possible, the dominant hand should be used to perform the actions.

6.3.2 Protocol: Cutting Fruit

Based on Figure 6.2, this task involves getting a piece of fruit from the refrigerator, choosing a knife, peeling the fruit, cutting it into 8 pieces, plating and serving it. The detailed steps for the protocol are shown in Table 6.2 with the fruit being an apple. Figure 6.5 shows a part of the setup for the PASS fruit cutting task. Prior to performing the task, the items that the participant interacts with are placed in their original location:

- apples - refrigerator
- knife - cutlery drawer

- plate - tableware cabinet
- chopping board - chopping board holder
- towel - on oven handle

Figure 6.5: PASS: Fruit Cutting task setup.

Table 6.2: Protocol for the PASS cutting fruit task. Note that Quiet Standing (QS) refers to the position where the participant has their hands on the side of their thighs, being as still as possible.

Step	**Details**	**Fine-Grained Action**
1	Start the video with the countdown and just as the countdown finishes start data collection script	

Continued on next page

Table 6.2 – continued from previous page

Step	Details	Fine-Grained Action
2	Move to the position in front of the refrigerator and stand in a Quiet Standing (QS) position for 2-3 seconds. Quickly raise and lower the hand with the sensor (for sensor and video time synchronization) and return to QS	
3	Stay in QS for 5 seconds	QS
4	Walk to the sink	
5	Open the faucet and wash hands for 10 seconds, close the faucet	WASH
6	Walk to the position in front of the oven (where the drying towel is)	
7	Dry hands	DRY
8	Walk to the position in front of the refrigerator	
9	Open the refrigerator with the dominant hand	OPEN-FRIDGE
10	Reach into the fridge and grab an apple with the dominant hand	GRAB-FRIDGE
11	Close the fridge with the dominant hand	CLOSE-FRIDGE
12	Place the apple on the kitchen counter	
13	Walk to where the cutting board is	
14	Grab the cutting board with the dominant hand	GRAB-BOARD
15	Walk to the kitchen counter	
16	Place the cutting board on the kitchen counter (beside the apple)	
17	Move to the position in front of the drawer containing the knife	

Continued on next page

Table 6.2 – continued from previous page

Step	Details	Fine-Grained Action
18	Open the drawer with the knife with the dominant hand	OPEN-CUTLERY
19	Grab the parring knife with the dominant hand	GRAB-CUTLERY
20	Close the drawer with the dominant hand	CLOSE-CUTLERY
21	Place the knife on the counter	
22	Grab the apple and move to the position in front of the sink	
23	Wash the apple	WASH
24	Move back to the position in front of the counter	
25	Peel the apple using the parring knife	PEEL
26	Cut the apple into 8ths using the chopping board	CUT
27	Move to the position in front of the tableware cabinet	
28	Open the tableware cabinet door with the dominant hand	OPEN-TABLEWARE
29	Grab a plate and place it on the kitchen counter	GRAB-TABLEWARE
30	Close the tableware cabinet with the dominant hand	CLOSE-TABLEWARE
31	Move to the position in front of the kitchen counter	
32	Transfer the apple slices from the cutting board to the plate with the dominant hand	PLATING

Continued on next page

Table 6.2 – continued from previous page

Step	**Details**	**Fine-Grained Action**
33	Grab the plate with the apples and bring it to the dining table	SERVE
34	Return to the position in front of the refrigerator and stand in QS for 5 seconds	QS
35	End data collection and end the recording	

6.3.3 Protocol: Making Soup

Based on Figure 6.1, this task involves preparing soup from a soup can. The individual must locate the soup can in the pantry, open it and prepare it according to the instructions. The preparation of a soup can typically involves measuring and adding a liquid such as milk or water to the contents in the soup can and warming it up on the stove top. The detailed steps are documented in Table 6.3. Similar to the cutting fruit task, the items (shown in Figure 6.6) that the participant interacts with must be placed back in their original position:

- soup can - pantry
- towel - on oven handle
- can opener - cutlery cabinet
- spoon - cutlery drawer
- pot - cookware drawer
- bowl - tableware cabinet

Figure 6.6: Items used in the PASS make soup task. From the left: the can of soup, can opener, spoon and pot.

Table 6.3: Protocol for the PASS making soup task. Note that Quiet Standing (QS) refers to the position where the participant has their hands on the side of their thighs, being as still as possible.

Step	**Details**	**Fine-Grained Action**
1	Start the video with the countdown and just as the countdown finishes start data collection script	
2	Move to the position in front of the refrigerator and stand in a Quiet Standing (QS) position for 2-3 seconds. Quickly raise and lower the hand with the sensor (for sensor and video time synchronization) and return to QS	
3	Stay in QS for 5 seconds	QS
4	Walk to the sink	
5	Open the faucet and wash hands for 10 seconds, close the faucet	WASH
6	Walk to the position in front of the oven (where the drying towel is)	
7	Dry hands	DRY
8	Move to the position in front of the pantry cabinet	
9	Open the pantry cabinet with the dominant hand	OPEN-PANTRY
10	Grab the soup can inside the pantry cabinet with the dominant hand	GRAB-PANTRY
11	Close the pantry cabinet with the dominant hand	CLOSE-PANTRY
12	Bring the soup can to the kitchen counter and set it on the counter	

Continued on next page

Table 6.3 – continued from previous page

Step	Details	Fine-Grained Action
13	Move to the position in front of the cutlery drawer	
14	Open the cutlery drawer with the dominant hand	OPEN-CUTLERY
15	Grab the spoon and the can opener in the cutlery drawer and place them on the counter	GRAB-CUTLERY
16	Close the cutlery drawer with the dominant hand	CLOSE-CUTLERY
17	Move to the position in front of the cookware drawer	
18	Open the cookware drawer with the dominant hand	OPEN-COOKWARE
19	Grab the pot from the cookware drawer and place it on the counter	GRAB-COOKWARE
20	Close the cookware drawer with the dominant hand	CLOSE-COOKWARE
21	Move to the position in front of the kitchen counter	
22	Using the can opener, open the can of soup with the dominant hand	OPEN-CAN
23	Pour the contents into the pot with the dominant hand	POUR
24	While holding the empty can, move to the position in front of the sink	
25	Fill the soup can to the top with tap water with the dominant hand	FILL-WATER
26	Move back to the position in front of the kitchen counter	

Continued on next page

Table 6.3 – continued from previous page

Step	Details	Fine-Grained Action
27	Pour the water into the pot containing the concentrated soup with the dominant hand	POUR
28	Grab the pot and move to the position in front of the stove with the dominant hand	
29	Place the pot on one of the burners	
30	Turn the burner on with the dominant hand	BURNER-ON
31	Move back about a meter and stand in QS for about 10 seconds to mimic waiting for the soup to boil	QS
32	Grab the spoon on the counter and use it to stir the soup for about 10 seconds with the dominant hand	STIR
33	Turn the burner off	BURNER-OFF
34	Move to the position in front of the tableware cabinet	
35	Open the tableware cabinet door with the dominant hand	OPEN-TABLEWARE
36	Grab a bowl and place it on the kitchen counter	GRAB-TABLEWARE
37	Close the tableware cabinet with the dominant hand	CLOSE-TABLEWARE
38	Move to the position in front of the stove and grab the pot	
39	Move to the position in front of the cabinet with the pot	
40	Pour the soup in the pot into the bowl (being careful not to spill any) with the dominant hand	POUR

Continued on next page

Table 6.3 – continued from previous page

Step	**Details**	**Fine-Grained Action**
41	Grab the bowl of soup and bring it to the dining table	SERVE
42	Return to the position in front of the refrigerator and stand in QS for 5 seconds	QS
43	End data collection and end the recording	

6.3.4 Protocol: Making Muffins

From Figure 6.3, this PASS task evaluates the older adult's ability to use the oven through baking muffins. The muffin batter is made using pre-made muffin mix to minimize the number of steps required in gathering the ingredients per the PASS task instructions. The participant is required to make the muffin batter, pour the batter into the muffin tin for 6 muffins and place the muffin tin into the oven. To simulate a speed up in the baking process, a pre-baked 6 pack of muffin has been placed in the oven before hand and used as the finished product for plating and serving. Items used in this experiment are shown in Figure 6.7 Detailed steps are found in Table 6.4. Similar to the making soup task, the items (shown in Figure 6.7) that the participant interacts with must be placed back in their original position:

- muffin mix - pantry
- towel - on oven handle
- measuring cup - cutlery drawer
- tongs - cutlery drawer
- spoon - cutlery drawer
- mixing bowl - cookware drawer
- muffin tin - baking trays drawer
- water measuring cup - cups cabinet
- oven mitts - cookware drawer
- 6-pack pre-baked muffins - inside the oven, to one side

Figure 6.7: Items used in the Baking Muffin task. From the left: the muffin mix, the mixing bowl, the spoon, the muffin tin, the water measuring cup, the (green) measuring cup, and assorted oven mitts. The 6 pack of muffins and tongs are not shown in the image, but can be found at any local super market and kitchen supply store respectively.

Table 6.4: Protocol for the PASS making muffins task. Note that Quiet Standing (QS) refers to the position where the participant has their hands on the side of their thighs, being as still as possible.

Step	**Details**	**Fine-Grained Action**
1	Start the video with the countdown and just as the countdown finishes start data collection script	
2	Move to the position in front of the refrigerator and stand in a Quiet Standing (QS) position for 2-3 seconds. Quickly raise and lower the hand with the sensor (for sensor and video time synchronization) and return to QS	
3	Stay in QS for 5 seconds	QS
4	Walk to the sink	
5	Open the faucet and wash hands for 10 seconds, close the faucet	WASH
6	Walk to the position in front of the oven (where the drying towel is)	
7	Dry hands	DRY
8	Move to the position in front of the pantry cabinet	
9	Open the pantry cabinet with the dominant hand	OPEN-PANTRY
10	Grab the muffin mix in the pantry with the dominant hand	GRAB-PANTRY
11	Close the pantry cabinet with the dominant hand	CLOSE-PANTRY
12	Bring the muffin mix kitchen counter and set it on the counter	

Continued on next page

Table 6.4 – continued from previous page

Step	Details	Fine-Grained Action
13	Move to the position in front of the cutlery drawer	
14	Open the cutlery drawer with the dominant hand	OPEN-CUTLERY
15	Grab the spoon and the measuring cup in the cutlery drawer and place them on the counter	GRAB-CUTLERY
16	Close the cutlery drawer with the dominant hand	CLOSE-CUTLERY
17	Move to the position in front of the cups cabinet	
18	Open the cup cabinet with the dominant hand	OPEN-CUPS
19	Grab the water measuring cup with the dominant hand	GRAB-CUPS
20	Close the cup cabinet with the dominant hand	GRAB-CUPS
21	Move to the position in front of the cookware drawer	
22	Open the cookware drawer with the dominant hand	OPEN-COOKWARE
23	Grab the mixing bowl from the cookware drawer and place it on the counter	GRAB-COOKWARE
24	Close the cookware drawer with the dominant hand	CLOSE-COOKWARE
25	Move to the position in front of the kitchen counter	
26	Open the muffin mix and grab the measuring cup with the dominant hand	

Continued on next page

Table 6.4 – continued from previous page

Step	Details	Fine-Grained Action
27	Scoop the required amount of muffin mix into the mixing bowl	SCOOP
28	Put down the measuring cup and grab the water measuring cup with the dominant hand	
29	While holding the empty water measuring cup, move to the position in front of the sink	
30	Fill the water measuring cup can to the required level (per muffin mix directions) with tap water	FILL-WATER
31	Move back to the position in front of the kitchen counter	
32	Pour the water in the water measuring cup into the mixing bowl containing the muffin mix	POUR
33	Put down the water measuring cup and grab the spoon	
34	Mix the water and muffin mix together in the mixing bowl using a stirring motion	STIR
35	Put the spoon down and move to the position in front of the drawer for the baking trays	
36	Open the baking tray drawer with the dominant hand	OPEN-BAKING-TRAYS
37	Grab the muffin tin from the drawer with the dominant hand	GRAB-BAKING-TRAYS
38	Close the baking tray drawer with the dominant hand	CLOSE-BAKING-TRAYS
39	Bring the tray to the kitchen counter and set it close to the mixing bowl	

Continued on next page

Table 6.4 – continued from previous page

Step	Details	Fine-Grained Action
40	Grab the measuring cup with the dominant hand	
41	Scoop the muffin batter in the mixing bowl into the muffin tin	SCOOP
42	Move in front of the oven	
43	Simulate turning on the oven (do not actually turn it on) with the dominant hand	OVEN-POWER
44	Step backwards around 1 meter away from the oven and stand in QS for about 10 seconds to mimic waiting for the oven to preheat	QS
45	Once the oven has "pre-heated" move back to the position in front of the oven	
46	Open the oven using the dominant hand	OPEN-OVEN
47	Grab the muffin tin with the muffin batter and place it into one of the oven racks	GRAB-OVEN
48	Close the oven with the dominant hand	CLOSE-OVEN
49	Step backwards around 1 meter away from the oven and stand in QS for about 10 seconds to mimic waiting for the muffins to bake	QS
50	Move back in front of the oven	
51	Simulate turning off the oven with the dominant hand	OVEN-POWER
52	Move in front of the cookware drawer	
53	Open the cookware drawer with the dominant hand	OPEN-COOKWARE
54	Grab some oven mitts that are in the cookware drawer	GRAB-COOKWARE

Continued on next page

Table 6.4 – continued from previous page

Step	Details	Fine-Grained Action
55	Close the cookware drawer with the dominant hand	CLOSE-COOKWARE
56	Put on the oven mitts	
57	Move to the position in front of the oven	
58	Open the oven with the dominant hand	OPEN-OVEN
59	Reach in and grab the pre-made 6-pack of muffins with the dominant hand and place the muffins on the stovetop (because in a real baking scenario it should be hot)	GRAB-OVEN
60	Close the oven with the dominant hand	CLOSE-OVEN
61	Take the oven mitts off and move to the position in front of the cookware drawer	
62	Open the cookware drawer with the dominant hand	OPEN-COOKWARE
63	Place the oven mitts into the cookware drawer	GRAB-COOKWARE
64	Close the cookware drawer with the dominant hand	CLOSE-COOKWARE
65	Move to the position in front of the cutler drawer	
66	Open the cutlery drawer with the dominant hand	OPEN-CUTLERY
67	Grab the tongs from the cutlery drawer with the dominant hand	GRAB-CUTLERY
68	Close the cutlery drawer with the dominant hand	CLOSE-CUTLERY

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Table 6.4 – continued from previous page

Step	Details	Fine-Grained Action
69	Move to the position in front of the tableware cabinet	
70	Open the tableware cabinet door with the dominant hand	OPEN-TABLEWARE
71	Grab a plate and place it on the kitchen counter	GRAB-TABLEWARE
72	Close the tableware cabinet with the dominant hand	CLOSE-TABLEWARE
73	Move to the position in front of the kitchen counter	
74	Use the tongs to transfer 3 muffins from the "muffin tin" to the plate	PLATING
75	Put the tongs down	
76	Grab the plate with the muffins on it and bring it to the dining table	SERVE
77	Return to the position in front of the refrigerator and stand in QS for 5 seconds	QS
78	End data collection and end the recording	

6.4 Disability Simulation

To both further the amount of data collected as well as increase the variation in the data, 3 disability simulations will be used while following the experimental protocol described in Section 6.3. Figure 6.8 shows the items used to simulate the disabilities and the disability simulations are as follows:

1. Vision Impairment: Covering one eye
2. Mild Physical Impairment: Wearing Knitted Gloves
3. Severe Physical Impairment: Wearing Electrical Gloves

Figure 6.8: Items used to simulate disability.

6.5 The Dataset

8 trials for each task (cutting fruit, making soup, making muffins) and each type of disability + able-bodied (one-eyed: OE, knitted gloves: KG, electrical gloves: EG, able-bodied: AB) were recorded resulting in a total 8 * 3 * 4 = 96 trials lasting a duration of 6 hours 3 minutes and 53 seconds of data. The data collected with the descriptions and units are shown in Table 6.5. Preparing and processing the data for classification will be explored in the next chapter.

Table 6.5: Details of the data collected through the Pozyx system [119].

Name	**Units**	**Description**
POS_X	mm	Position of sensor relative to the origin in the X axis
POS_Y	mm	Position of sensor relative to the origin in the Y axis
POS_Z	mm	Position of sensor relative to the origin in the Z axis
Heading	deg	Heading orientation of the sensor
Roll	deg	Roll orientation of the sensor
Pitch	deg	Pitch orientation of the sensor
ACC_X	g	X axis acceleration with gravity
ACC_Y	g	Y axis acceleration with gravity
ACC_Z	g	Z axis acceleration with gravity
LINACC_X	g	X axis acceleration with the gravity removed
LINACC_Y	g	Y axis acceleration with the gravity removed
LINACC_Z	g	Z axis acceleration with the gravity removed
GYRO_X	deg/s	Angular Velocity in the X axis
GYRO_Y	deg/s	Angular Velocity in the Y axis
GYRO_Z	deg/s	Angular Velocity in the Z axis
Pressure	Pa	The pressure (low-resolution)

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