

Fine-Grained Activity Detection in the Kitchen with UWB

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Contents

1	Introduction	2
2	System Tuning at the Independent Living Suite	4
2.1	Methodology	4
2.1.1	Setup	5
2.1.2	Protocol	7
2.2	Results	8
2.3	Discussion	12
2.3.1	X Position	12
2.3.2	Y Position	12
2.3.3	Z Position	12
2.3.4	Overall	13
3	Pilot Testing of Detecting Activities to make a Sandwich	15
A	Appendix	16

Chapter 1

Introduction

This thesis project will investigate how to detect fine-grained action within the meal preparation activity of daily living (ADL) in the home without the use of privacy-intruding cameras. ADLs are common activities that an individual performs inside their homes. These include walking around, eating, dressing, personal hygiene, toileting, transportation, meal preparation, house cleaning, and managing medication. The meal preparation ADL was chosen as the main focus because cooking is a uniquely enjoyable activity while being procedurally dense. Meal preparation can include the following actions: opening the fridge, retrieving ingredients, cutting vegetables, and assembling the ingredients. Monitoring these actions may be used as part of a health monitoring program by enabling the assessment of the presence and length of each individual step in a goal-orientated activity. This information may help guide interventions and track the effectiveness of interventions in clinical populations such as people with dementia or frailty.

Several studies have used features from inertial data to classify these fine-grained action. . .

It is hypothesized that inclusion of context to this inertial data, such as hyper accurate indoor localization (down to 30 cm), can result in more accurate and more reliable classification of fine-grained ADLs. The system used for indoor localization is the Pozyx Creator Kit which provides a wrist mounted wearable that can obtain data at a maximum of 60 Hz [2]. This data includes position relative to a floorplan, and inertial data from a BNO055 which outputs 3D Acceleration, 3D angular velocity, 3D Linear Acceleration, and the Heading, Pitch and Roll.

Prior to any experiments related to classification of these cooking actions,

the optimal configuration of the system that provides reliable position data had to be investigated. The next section details the different attempts at changing the configuration of the Pozyx Creator Kit to obtain the most reliable positioning data in X, Y, and Z at a satisfactory sampling rate.

Chapter 2

System Tuning at the Independent Living Suite

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 [3, 1] 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 will be described.

2.1 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.

2.1.1 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 2.1 outlines some examples of tape placements.



Figure 2.1: 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 2.2):

- 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.

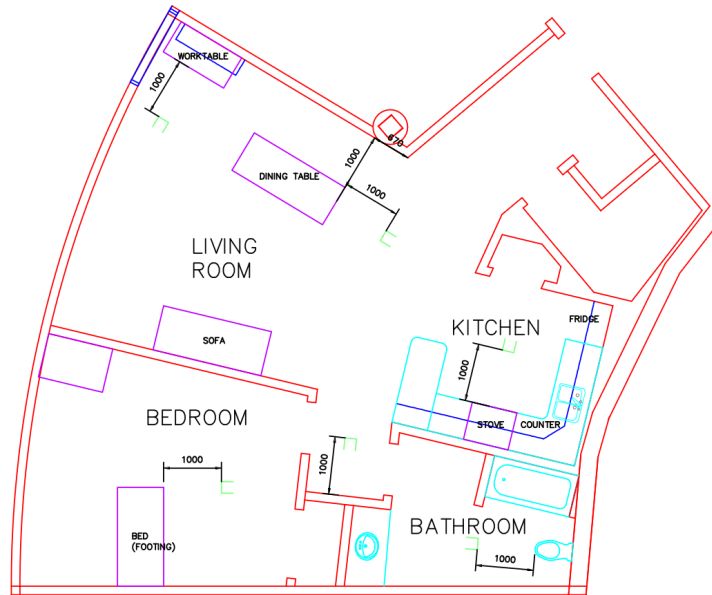


Figure 2.2: Floor plan of the ILS. Positions where the participant stood 1 meter from appliances or furniture are marked in the green "open" box on the floorplan.

2.1.2 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 2.3). 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 2.3: 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 [1] 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.

2.2 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 2.4, 2.5 and 2.6) 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 2.4: 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 2.5: 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 2.6: The positional error in Z (a) and the standard deviation in Z (b) at each location and body position

2.3 Discussion

2.3.1 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.

2.3.2 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.

2.3.3 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.

2.3.4 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 2.7

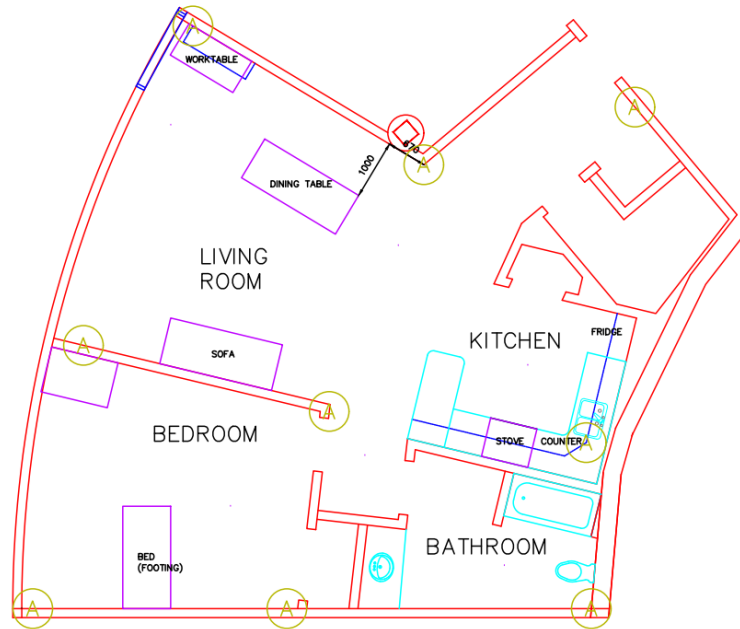


Figure 2.7: ILS Floorplan with the 9 anchors all high.

Though the inaccuracies in the hallway, living room, bathroom and bedroom may prohibit 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 3

Pilot Testing of Detecting Activities to make a Sandwich

Continuing from the findings from Chapter 2, the 9H anchor configuration was used to perform a preliminary classification of activities in the kitchen.

Appendix A

Appendix

Bibliography

- [1] Configuration of the UWB parameters (Arduino).
- [2] Creator One Kit for research and prototyping - Pozyx.
- [3] Hardware setup.