

# Bibliography

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WORKSHOP 7 :

# Embedded Systems Engineering IoT Applications Prototyping

Team B: SmartCart  
Date: 21st April 2017  
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## List of Abbreviations

## Abstract

Das vorliegende Dokument beschreibt das Produkt SmartCart des Teams IoT-Designers. Das Ziel der Anwendung ist es einen smarter Way of Shopping zu ermöglichen. The application offers the possibility of easily marking items as added to the cart and the navigating through a list via gestures, um den User beim Einkauf zu unterstützen und entlasten. Therefore, the recognition of gestures is done via the built-in acceleration sensor.

Anstatt umständlich mit Stift und Papier die Einkaufsliste abzuarbeiten soll diese App durch die Gesternsteuerung erleichtertern. Dabei fokussiert sich diese App auf zwei use cases welche dem Benutzer angeboten werden. Dem Benutzer soll es ermöglicht werden mit einer Hand und einfachen jedoch eindeutigen Gesten sowohl zwischen den Items in der Einkaufsliste hin und her zu wechseln als auch die bereits gefundenen Items abzuhaken.

To recognize the chosen gestures, the acceleration sensor and the magnetic field sensor are used. The retrieved acceleration values are used to determine the movement that is made. The magnetic field sensor serves to recognize the orientation of the smartphone and to be able to subtract out its influence out of the acceleration values.

Um aus den von den Sensoren erhaltenen Werten Gesten abzuleiten wurden zunächst Daten erfasst, welche die jeweilige Gesten wiedergeben. Damit die verschiedenen Sensorwerte zuordbar sind wurden viele Messungen durchgeführt. Damit die Gesten möglichst unabhängig der Ausrichtung des Mobile Phones durchführbar sind werden verschiedene mathematischen Berechnungen benötigt.

Das Ende dieses Dokuments beschreibt das Ergebnis der App sowie deren Nutzung.

# Chapter 1

## Smart Cart - A smarter Way of Shopping

In the following sections, the idea and implementation of SmartCart – an Android application that will simplify your shopping experience – will be exposed. The application was created in the course of the workshop “IoT Applications Prototyping” by the team IoT-Designers:

Timo  
Acquistapace



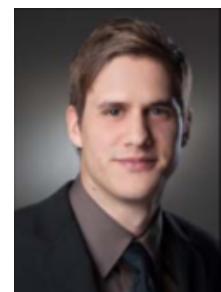
Wojciech  
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Markus  
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Simon  
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Project Leader

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Data Analyst

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## 1.1 Introduction

Since the idea of SmartCart evolved during the workshop, this section firstly introduces the initial product idea of SmartCart and the change of scope that project went through. Later on, the architecture and the system's context as well as the used state machine and its evolution are described. The following sections focus on the recognition of gestures. For this purpose, the mathematical basics that are necessary to recognize gestures are derived and the gestures that are used to control the system are introduced.

### 1.1.1 Initial Idea of SmartCart

The first concept of SmartCart was to offer its user the possibility to add items to a shopping list and to get this shopping list ordered automatically as the user enters a supermarket. The entered grocery is determined with the help of the Microsoft Here API. Based on the knowledge of the accessed shop and the ordering of its departments, the items that were previously added to the shopping list, should be ordered.

### 1.1.2 Change of Scope and final Idea of SmartCart

Even though the initial idea of SmartCart would have been a very helpful application to the user, it is strongly based on the collaboration with the operators of the supported supermarkets. This is especially true for the data acquisition regarding the offered products and the available departments of a supermarket. Therefore, the initial scope of the application was changed towards an application that is less dependent on master data.

The revised concept of SmartCart focusses more on the interaction of the user and the application. It omits the features of recognising a shop that is entered and ordering the list of shopping items according to the recognised shop. Instead, the application should offer the possibility of easily marking an item as added to the cart and of navigating through the list via gestures. The recognition of gestures is done via the built-in sensors for acceleration and the magnetic field sensor.

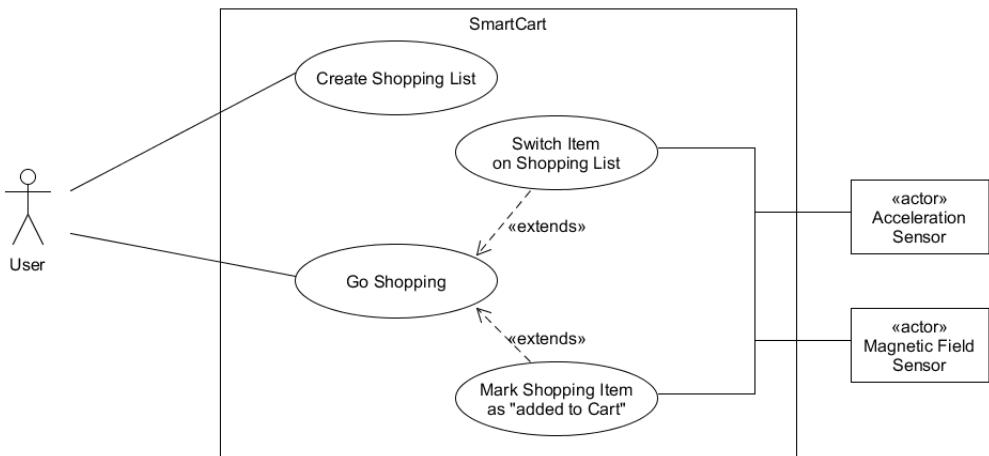


Figure 1.2.1: Overview of the System's Use Cases

Even the initial idea was discarded during the workshop for the mentioned reasons, the focus that is now put on the user interaction might nevertheless support the initial idea.

## 1.2 System Analysis

The upfront steps that were taken to create a shared understanding and to examine possible solutions in building the application are shortly presented in the current section.

### 1.2.1 Use Cases

SmartCart in its final scope addresses two main use cases: the use case of creating a shopping list and adding items to it as well as the process of going shopping itself (see 1.2.1). The use case “Go shopping” implements the main user interaction that consists of switching the next item to buy and of marking an item of the shopping list as ‘added to cart’. This interaction takes place via gestures made by the user with its smartphone that are detected by the SmartCart application.

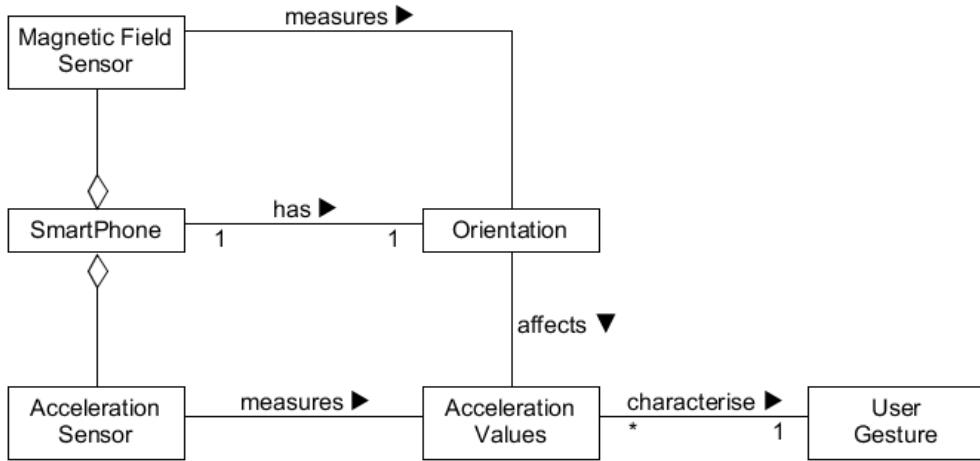


Figure 1.2.2: Data Model of the User Gestures to recognize

### 1.2.2 Relations between the captured Gestures and the used Sensors

Figure 1.3.1 shows a model of how the smartphone, the sensors and the gestures that should be recognized are related to each other. The acceleration sensor provides information about the smartphone's speed-up along its coordinate axes. In the most cases, these axes are not aligned with the standard x-y-z axes because of the smartphone's orientation. Since the orientation affects the measured acceleration values, it has to be taken into account when recognizing the user's gestures.

### 1.2.3 Application Context

The context of the application can be retrieved from figure 1.2.3. The inputs are the values of the accelerometer  $a_x$ ,  $a_y$  and  $a_z$  as well as the angles *azimuth*, *pitch* and *roll* that determine the smartphone's orientation. The current state and any other information of the application are visualized on the smartphone's display.

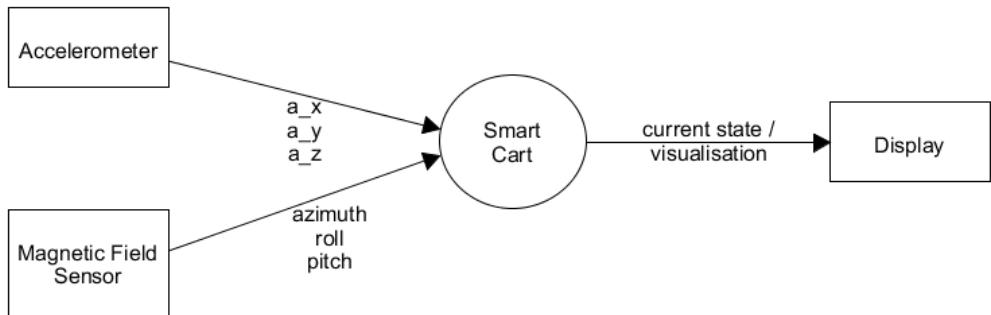


Figure 1.2.3: Context of the Application to develop

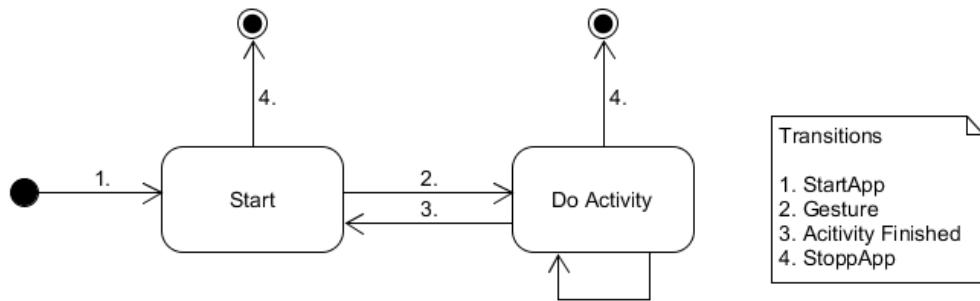


Figure 1.2.4: First Finite State Machine

### 1.2.4 Finite State Machine

hier war noch nicht sicher welche gesten berhaupt verwendet werden und bla bla bla (vllt einfach ner murks state machine machen weil die vom dio der letzte rotz ist und absolut flasch)

#### First State Machine

auf jedenfall zuerst diese kackendreck state machin richtig falsch machen aber dennoch wenigstens halbwegs sinnvoll

#### Evolutioned State Machine

auch diese self bergnge erklren... also alles darf passieren uznd er bleibt in diesem state

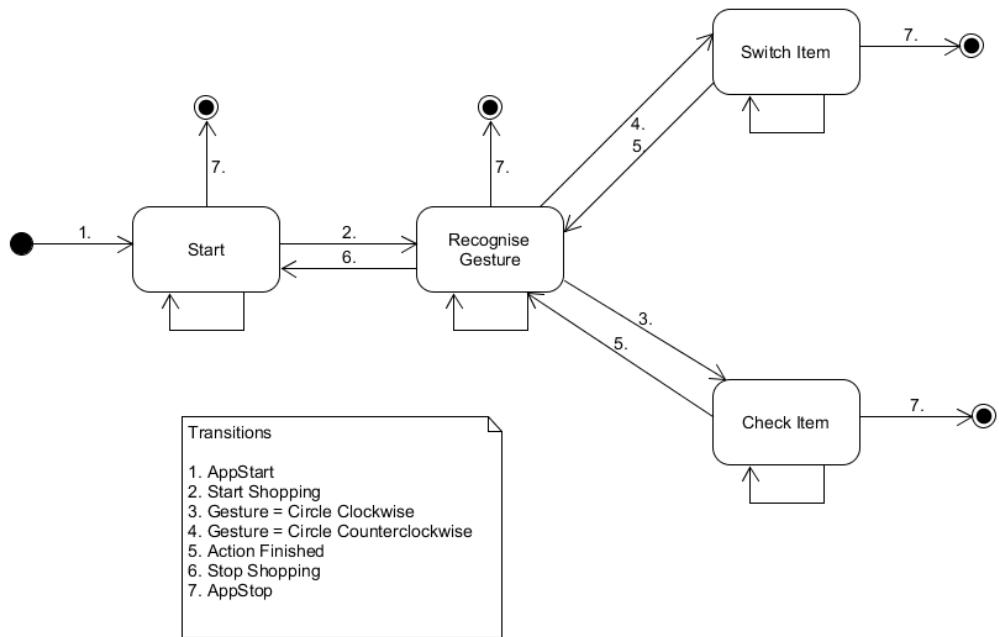


Figure 1.2.5: Evolutioned Finite State Machine

Statemachine nochmals anpassen weil weniger states inzwischen haben. Urhzeigersinn = abhaken, gegen=nchstes item. in start kann die liste angelegt werden usw und wenn mer nach rechts swiped ist das start shopping

## 1.3 Mathematical Basics of Gesture Recognition

The recognition of gestures is based on measured acceleration values. These values depend, as it was already depicted in section 1.2.2, on the orientation of the smartphone. The mathematical relation of the measured acceleration values and the smartphone's orientation will be derived in this chapter. At first, the impact the smartphone being rotated along one of its axes is investigated in isolation. Afterwards, the results are combined and the final equation for each of the acceleration values is set up.

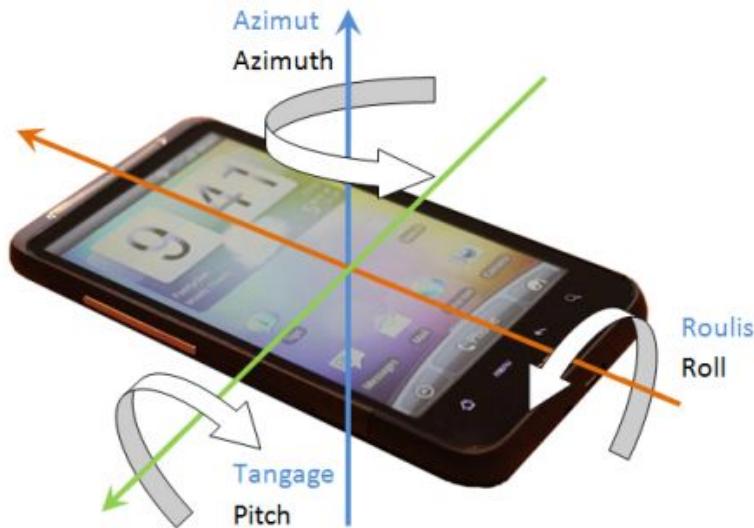


Figure 1.3.1: Possibilities of rotating a Smartphone, see Objectif Nux [2012]

### 1.3.1 Terminology of the possible Rotations

There exist three different possible rotations that are measured by the magnetic field sensor:

- **Pitch**

The angle of a rotation around the x-axis is called pitch. In the following equations,  $\alpha$  will be used to describe the value of pitch that is retrieved from the magnetic field sensor.

- **Roll**

The angle of a rotation around the y-axis is called roll. In the following equations,  $\beta$  will be used to describe the value of roll that is retrieved from the magnetic field sensor.

- **Azimuth**

The angle of a rotation around the z-axis is called azimuth. In the following equations,  $\gamma$  will be used to describe the value of azimuth that is retrieved from the magnetic field sensor.

### 1.3.2 Acceleration depending on Pitch

The current section investigates the effect of a rotation around the smartphone's x-axis on the measured acceleration values. Figures 1.3.2 and 1.3.3 show how accelerations in the direction of x and of z respectively might be decomposed into the different acceleration vectors that are parallel to the smartphone's axes. The magnitudes of these vectors are measured by the smartphone's acceleration sensor.

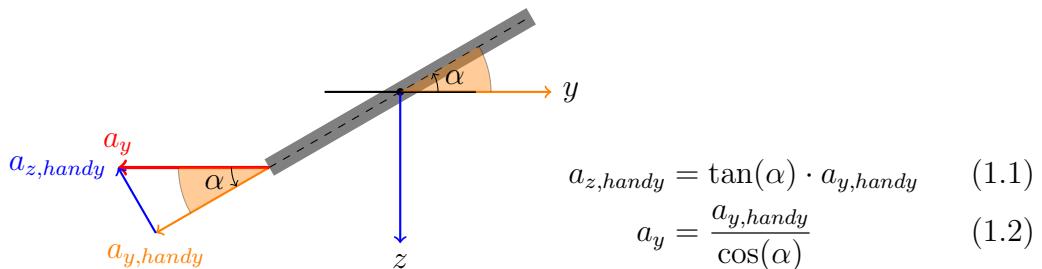


Figure 1.3.2:  $a_y$  depending on Pitch

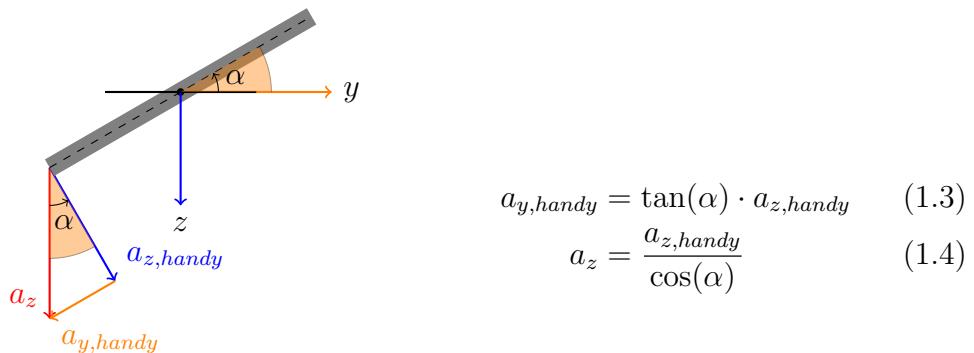
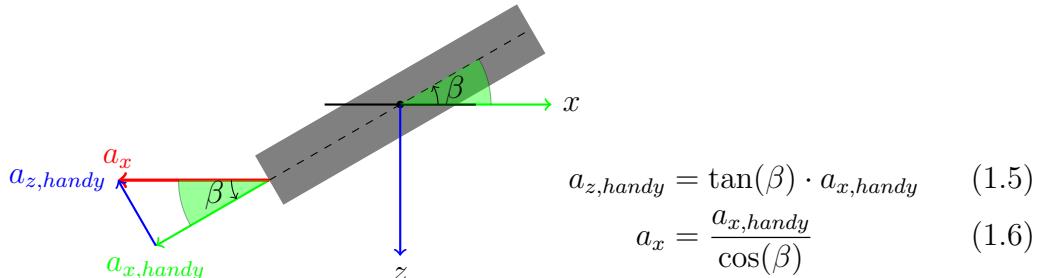


Figure 1.3.3:  $a_z$  depending on Pitch

### 1.3.3 Acceleration depending on Roll

A rotation around a certain axis affects the measured acceleration values of the axes that are parallel to axis of rotation. Therefore, if the smartphone is rotated around its  $y$ -axis, the accelerations in the direction of  $x$  and  $z$  have to

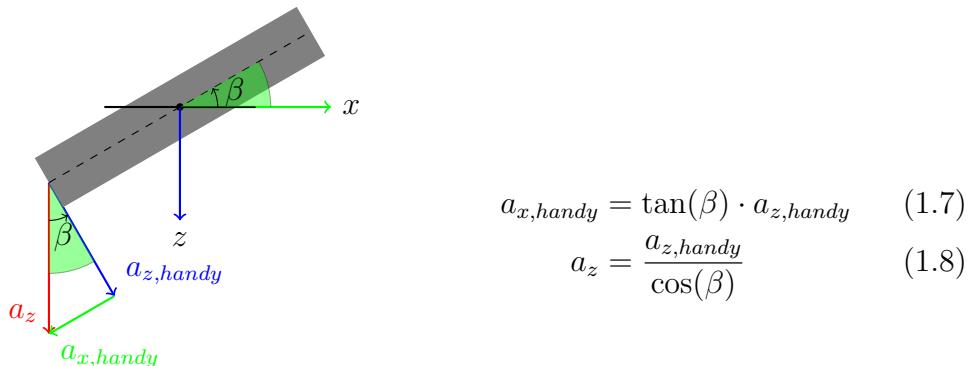
be investigated. The composition of the acceleration vectors can be retrieved from the figures 1.3.4 and 1.3.5.



$$a_{z,handy} = \tan(\beta) \cdot a_{x,handy} \quad (1.5)$$

$$a_x = \frac{a_{z,handy}}{\cos(\beta)} \quad (1.6)$$

Figure 1.3.4:  $a_x$  depending on Roll



$$a_{x,handy} = \tan(\beta) \cdot a_{z,handy} \quad (1.7)$$

$$a_z = \frac{a_{z,handy}}{\cos(\beta)} \quad (1.8)$$

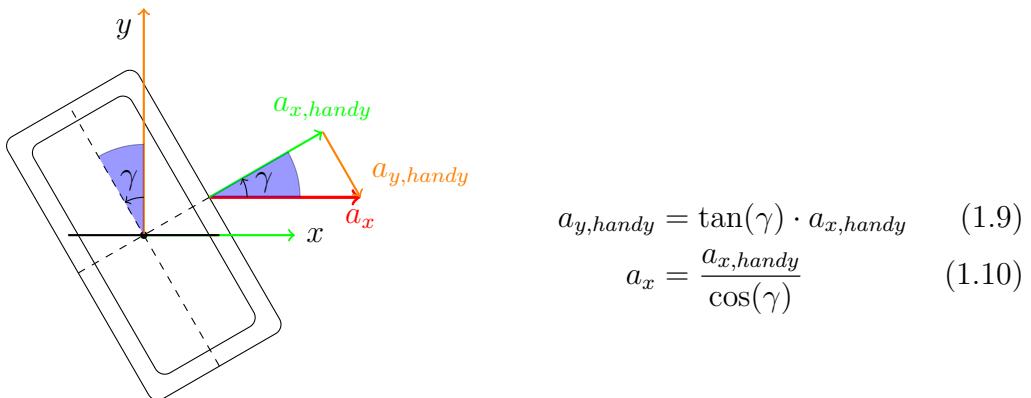
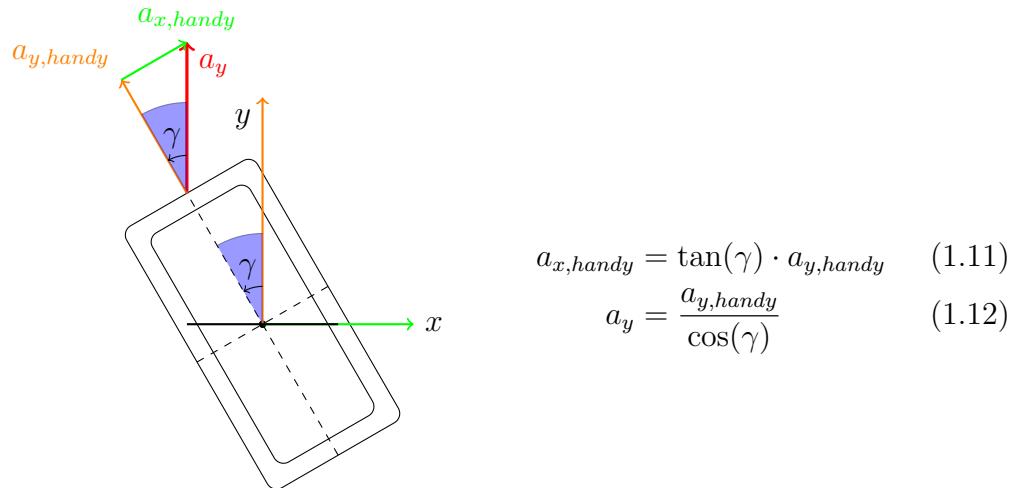
Figure 1.3.5:  $a_z$  depending on Roll

### 1.3.4 Acceleration depending on Azimuth

The last rotation that is examined is the one around the  $z$ -axis. This rotation affects the measured acceleration values in the direction of  $x$  and  $y$ . The vector-decomposition is depicted in the figures 1.3.6 and 1.3.7.

### 1.3.5 Final Equations for the Acceleration Values

After the acceleration values have been examined depending on each rotation value in isolation, the results are combined together in this section.


 Figure 1.3.6:  $a_x$  depending on Azimuth

 Figure 1.3.7:  $a_y$  depending on Azimuth

### Final Equation: X-Acceleration

As it has been shown in the equations (1.6) and (1.10), the acceleration in the direction of x depends on the values of roll and azimuth. Combining these two equations leads to the following equation:

$$a_x = \frac{a_{x,handy}}{\cos(\beta) \cdot \cos(\gamma)} \quad (1.13)$$

The measured value of  $a_{x,handy}$  is affected in two cases:

- if the handy is accelerated in the direction of z and the value of roll is not equal to 0

- if the handy is accelerated in the direction of y and the value of azimuth is not equal to 0

These affectations are defined by the equations (1.7) and (1.11). Taking these equations into account leads to the following, final equation:

$$a_x = \frac{a_{x,handy} \cdot (1 - \tan(\beta) \cdot a_{z,handy} - \tan(\gamma) \cdot a_{y,handy})}{\cos(\beta) \cdot \cos(\gamma)} \quad (1.14)$$

### Final Equation: Y-Acceleration

The equations (1.2) and (1.12) show the dependency of an acceleration in the direction of y on the values of pitch and azimuth. If these equations are put together, the result is given by:

$$a_y = \frac{a_{y,handy}}{\cos(\alpha) \cdot \cos(\gamma)} \quad (1.15)$$

The measured value of  $a_{y,handy}$  is affected in two cases:

- if the handy is accelerated in the direction of z and the value of pitch is not equal to 0
- if the handy is accelerated in the direction of x and the value of azimuth is not equal to 0

Therefore, the equations (1.3) and (1.9) have to be included in the calculations. This leads to the following, final equation:

$$a_y = \frac{a_{y,handy} \cdot (1 - \tan(\alpha) \cdot a_{z,handy} - \tan(\gamma) \cdot a_{x,handy})}{\cos(\alpha) \cdot \cos(\gamma)} \quad (1.16)$$

### Final Equation: Z-Acceleration

The basic equation for the acceleration in the direction of z is retrieved by assembling the equations (1.4) and (1.8) that define the accelerations dependency on the values of roll and pitch respectively.

$$a_z = \frac{a_{z,handy}}{\cos(\alpha) \cdot \cos(\beta)} \quad (1.17)$$

The measured value of  $a_{z,handy}$  is affected in two cases:

- if the handy is accelerated in the direction of y and the value of pitch is not equal to 0
- if the handy is accelerated in the direction of x and the value of roll is not equal to 0

If these cases (see equations (1.1) and (1.5)) are considered, the final equation is given by:

$$a_z = \frac{a_{z,handy} \cdot (1 - \tan(\alpha) \cdot a_{y,handy} - \tan(\beta) \cdot a_{x,handy})}{\cos(\alpha) \cdot \cos(\beta)} \quad (1.18)$$

## 1.4 Recognition of Gestures

The system recognizes two kind of gestures (see also 1.4.1):

- A circle that starts from the bottom and runs clockwise
- A circle that starts from the bottom and runs counter-clockwise

The first gesture is used to mark an item as “added to cart” while the second one serves to switch through the items on the shopping list.



Figure 1.4.1: Gestures to Recognize

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