Visualization of sports performance data on Android mobile-phone acquired through a Bluetooth link

ROBERT WESTIN
2012 STOCKHOLM

Master’s Thesis in technology and teaching at Civil Engineer and Teacher
Supervisor: Dennis Sturm (KTH-STH), Assisting supervisor: Carl-Johan Rundgren (SU),
Examinator: Kaj Lindecrantz (KTH-STH)
Abstract

Recent developments in mobile architecture and the need for objective performance measurement in kayak elite sport coaching induced the opportunity for this study. We developed an application for smartphones that will help athletes evaluate their performance. Several sensors measure forces, acceleration and distance. Data is sent through a wireless connection and stored in a smartphone. The aim of this study is to evaluate technical possibilities on the smartphone in a coaching environment by comparing previous system proposals, to evaluate the learning situation when using the device as technical aid based on learning theories and technical limitations, and to design visualizations on the mobile device according to technical possibilities and learning theories. Technical research is used as a framework to compare the proposed system design to others, in sense of components used and the devices’ technical possibilities. Feedback-theory is used to explain the learning of motor skills and theory about visual literacy in the understanding of visualizations. Last cognitive models from Cognitive Load Theory (CLT), Multimedia Learning (ML) and Human Computer Interaction (HCI) are presented.

Visualizations on Android smartphones are limited by screen size and navigation possibilities. The challenge for the athlete and coach is to see patterns in acquired data and to translate it to manageable exercises suitable for the motor skill domain. In the motor skill domain it is important for the athlete to understand what behavior, e.g. what element of a movement to learn or improve. In current system designs the athlete has to wait a long time between performance and feedback. The athlete has to remember a long series of movements and match it with measured data, which could be ineffective according CLT.

The design of feedback will depend on the learning situation, technical possibilities and the information to process. When the environment is cognitively demanding the visualization should be easy to understand and the information easy to apprehend. Complex data could be presented in a graph on the mobile device but a big screen is recommended for this. The technical possibilities with the Android platform are sufficient for the intended use. Direct feedback in real-time is preferred to post-visualization in motor skill exercises.
Acknowledgement

In this thesis I would like to thank my new friends in the student room of level four that taught me a lot about other subjects that are not part of this report. Within the bounds of this report I would like to thank my supervisors Dennis and Carl-Johan, and for the programming help I thank Khurram who guided me a lot. The School for Technology and Health (STH) was an interesting institution to experience and to get a new view of cross disciplinary studies within the engineering/medical-technical field.
Contents

Abstract iii
Acknowledgement v
Contents vi
List of Figures ix
Abbreviations and Symbols xi

1 Introduction 1
  1.1 Problem motivation ........................................ 1
  1.2 Study objectives .......................................... 2
  1.3 Report structure .......................................... 2

2 Background 3
  2.1 About kayaking ............................................. 3
  2.2 About kayak sensors ....................................... 3
  2.3 Current system ............................................. 3

3 Literature Review 5
  3.1 Current technical research ................................. 5
  3.2 Learning theories ......................................... 6

4 Methodology 11
  4.1 Development ............................................... 11

5 Analysis 15
  5.1 The device as a part of the system ....................... 15
  5.2 Learning with a technical aid ............................ 16
  5.3 Visualization on mobile device ......................... 18

6 Discussion 21

7 Conclusion 25
  7.1 Conclusions ............................................... 25
  7.2 Future research ........................................... 25

A Appendix 27
  A.1 Node package .............................................. 27
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A.2 Program package</td>
<td>29</td>
</tr>
<tr>
<td>References</td>
<td>33</td>
</tr>
</tbody>
</table>
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>System setup</td>
<td>4</td>
</tr>
<tr>
<td>3.1</td>
<td>Cognitive load theory and multimedia learning</td>
<td>8</td>
</tr>
<tr>
<td>4.1</td>
<td>HTC Desire</td>
<td>11</td>
</tr>
<tr>
<td>4.2</td>
<td>Eclipse IDE</td>
<td>12</td>
</tr>
<tr>
<td>4.3</td>
<td>Example of graph produced by RGraph</td>
<td>12</td>
</tr>
<tr>
<td>4.4</td>
<td>System design</td>
<td>13</td>
</tr>
<tr>
<td>5.1</td>
<td>Aimed speed reached</td>
<td>18</td>
</tr>
<tr>
<td>5.2</td>
<td>Example of static data</td>
<td>19</td>
</tr>
<tr>
<td>5.3</td>
<td>Example of static data (zoomed)</td>
<td>19</td>
</tr>
<tr>
<td>5.4</td>
<td>Outside range of aimed speed</td>
<td>20</td>
</tr>
<tr>
<td>6.1</td>
<td>Example of self evaluation</td>
<td>21</td>
</tr>
<tr>
<td>6.2</td>
<td>System setup with database</td>
<td>22</td>
</tr>
<tr>
<td>A.1</td>
<td>Node</td>
<td>27</td>
</tr>
<tr>
<td>A.2</td>
<td>Program package</td>
<td>29</td>
</tr>
<tr>
<td>A.3</td>
<td>Handler</td>
<td>29</td>
</tr>
<tr>
<td>A.4</td>
<td>Flowchart of executor</td>
<td>30</td>
</tr>
<tr>
<td>A.5</td>
<td>Flowchart of method startRecording</td>
<td>31</td>
</tr>
</tbody>
</table>
Abbreviations and Symbols

Abbreviations

CLT  
Cognitive Load Theory

GSM  
Global System for Mobile Communications

HCI  
Human Computer Interaction

J2ME  
Java 2 Platform, Micro Edition

KTH  
Royal Institute of Technology

ML  
Multimedia Learning

MPN  
Multi-Purpose Node

MVC  
Model-View-Controller

RFCOMM  
Radio Frequency Communication

STH  
School for Technology and Health

SPP  
Serial Port Profile

UUID  
Universally Unique Identifier

WLAN  
Wireless Local Area Network
Chapter 1

Introduction

1.1 Problem motivation

Recent developments in mobile architecture and the need for objective performance measurement in kayak elite sport coaching induced the opportunity for this study. We developed an application for smartphones that helps athletes evaluate their performance. Several sensors measure forces such as acceleration and distance. Data is sent through a wireless connection and stored in a smartphone. Smartphones provides new possibilities for visualization and simple interaction with a user and auxiliary equipment. With a more complex system there is many potential problems both for the user and concerning the technical solutions. With focus on both the technical- and feedback possibilities, this thesis is written in the project phase of porting a previous application to Android.

A group of researchers at the School for Technology and Health (STH) at Royal Institute of Technology (KTH) and kayakers have since 2008 worked with user-centered research for a kayak sensor network. Today they have a system that is built on a mobile phone running a Java 2 Platform, Micro Edition (J2ME)-application that connects to three Bluetooth nodes. Two of the nodes are made for the paddle and one Multi-Purpose Node (MPN) with connections for a modified foot-plate that measures the force at left and right foot (Sturm, Parida, Larsson, & Isaksson, 2011). The hardware has been developed around the Mulle, a microcontroller module that provides Bluetooth wireless communication. Bluetooth is a standard for wireless communications, where the traffic is transmitted through different profiles depending on the kind of device attached. The nodes developed by STH use the Serial Port Profile (SPP) that is based on the Radio Frequency Communication (RFCOMM)-protocol. This is a well-known and implemented technique that emulates serial communication.

STH has previously analyzed the need for sensor technology in sports with a reference group. Athletes are today already using various technical aids in their practice, for example pulse monitors, GPS and stopwatches. An example of what would be needed was to measure paddle movement and acceleration. Another interesting fact was that two thirds of the athletes were seldom exercising with a coach. They would sometimes use video as a technical aid to visually be able to judge their performance (Sturm et al., 2011).
CHAPTER 1. INTRODUCTION

1.2 Study objectives

In this work I have studied learning theories and the design of similar smartphone systems made to evaluate sports performance. Consecutively to a literature study I designed a prototype in Android. The report summarizes the design decisions and targets readers interested in sport-science, Mobile development in a piconet environment and applied cognitive theories. The report is a cross scientific and it should be understandable, and interesting for both SU and KTH.

The particular aims were:

- to evaluate technical possibilities of a smartphone in a coaching environment by comparing previous system proposals.

- to evaluate the learning situation when using of the device as a technical aid, based on learning theories and technical limitations.

- to design visualizations on the mobile device according to technical possibilities and learning theories.

1.3 Report structure

In Chapter 2, the background to the current system setup together with a brief explanation of kayaking and the kayak sensors is presented. In Chapter 3, there are theories to be used in the analysis/construction of a prototype. These theories are mainly design theories and cognitive theories, but also some general visualization aspects are presented. In Chapter 4, the technical devices, the proposed system design and developing tools are presented. In Chapter 5, is divided in two parts: Chapter 5.1, evaluates the system from a design criteria and Chapter 5.2, focuses on visualization and the learning situation. Chapter 6, discusses future possibilities and how applicable the theories of learning and system designs are for current and future developing. In Chapter 7, the conclusions and future research are summarized. In Appendix A, the prototype is explained from a programming perspective, the technical issues and possibilities are presented.
Chapter 2

Background

This chapter contains a brief introduction to work done at STH, kayaking and the current system design, to give the reader a holistic view of the problem environment. STH is one of the 10 facilities at the KTH.

2.1 About kayaking

Kayaking is an Olympic sport where a small boat is driven by paddling. In Olympic flat water racing athletes compete at the sprint distances of 200, 500 and 1000 m. The kayak speed is determined by the athlete’s paddle force and the drag. The main drag is due to hydrodynamics and the average speed for kayaks is usually between 4.63 and 5.38 m/s (Michael, Smith, & Rooney, 2009). The paddling cycle is made up of left and right strokes. The pull time is counted from the moment the paddle enters the water and until the paddle exits the water, the time between is called glide phase. The kayaker pulls and pushes from the feet/hips as the paddle is in the water (Petrone, Quaresimin, & Spina, 1998).

2.2 About kayak sensors

In kayak performance measurement a footplate sensor and two paddle sensors are used. The footplate is connected to the MPN, that also collects GPS data. The nodes connect to a mobile device through Bluetooth and transmit serial data through the SPP protocol. The serial data’s communication protocol developed at STH is based on sequences of commands and procedures, e.g. a connection procedure could be: connect, wait 3 seconds, ping device, receive respond (and then the device is ready for new commands). The sensors are less than 5 cm x 5 cm x 3 cm in dimensions and have lightweight casing, they are charged through an external adapter and can be used for 7 hours without charging.

2.3 Current system

The current solution is made up of the following items:

- Smartphone
- Left paddle node
- Right paddle node
• MPN
• SD-card
• Computer with MATLAB

The smartphone is the central device for acquiring data and wireless handling of nodes, see Figure 2.1. To extract data for analysis in the computer it is saved on an external memory card as untagged text files. With the current system design it is possible to visualize data in MATLAB on the computer. To extract data from the device you connect it as a storage device and use a file browser.

Figure 2.1: System setup
Chapter 3

Literature Review

First technical research is presented, that is used as a framework to compare the proposed system design in Figure 4.4 to others, in sense of components used and the devices technical possibilities. The second part presents a variety of learning theories. Feedback-theory is used to explain the learning of motor skills, theory about visual literacy in the understanding of visualizations. Last cognitive models from Cognitive Load Theory (CLT), Multimedia Learning (ML) and Human Computer Interaction (HCI) are presented.

3.1 Current technical research

The project focuses on real-time force measurement, in particular paddle force and the pressure force on the foot rest. A coach without technical aid has to rely on visual impression instead of objective data. The system was developed user-centered to make the athletes involved and the result more relevant for the user (Sturm, Yousaif, & Eriksson, 2010).

In the sports science research Rowlands and James (2011) and McNab, James, and Rowlands (2011) also propose the use of sensors connected to mobile phones as a technical aid. Rowlands and James (2011) point out that Bluetooth is a good choice for short distance wireless transfer with fairly low use of battery. In a Bluetooth piconet every node connects to a master as ad hoc, it has a technical limitation of seven nodes. Rowlands and James (2011) are in their study using the protocol SPP. Alternatives would be Wireless Local Area Network (WLAN), ZigBee, ANT+ or Global System for Mobile Communications (GSM).

To aid the system design, Rowlands and James (2011) point out some important criterias:

1. The operating system has to have good usability and should be able to store data with low risk even though the system communicates, saves and visualizes data.
2. If the application should be used for visualizing real-time data, it has to be fast.
3. The device has to be able to work with concurrency, for example to read and print at the same time.
4. The system should be scalable so that more sensors and different types of sensors can connect.

McNab et al. (2011) outline a case for using the iPhone in sports as a technical aid. A big difference is made by new technology, as smartphones, is that performance measurements can be executed out of the laboratory. Previously, performance analyses were made
in laboratory environments that differ from real life exercise. McNab et al. (2011) also point out that the good distribution channels for smartphone applications make it easier for academic work to find its way to the market. The main difference of system designs is that the device connects to the Internet and the database is in this way externalized and accessible to bystanders in real-time (McNab et al., 2011).

3.2 Learning theories

Learning theories and especially cognitive learning theories have been researched for a long time. Iskandar, Gilbert, and Wills (2011) contrary write about Computer-based sport training and the motor skill domain. Motor skills coaching are often based on a behaviorist perspective, where the behavior is changed due to reinforcement and feedback. Motor skills could be seen as a series of small movements or sequences; for example, in kayak to pull the paddle and then push with the feet can be different learning objectives. A learning task should be made up of small units where the first element should be learned properly before building something new on to it, it is a basic rule of behavioristic theory. Cognitive theory on the other hand focuses on the processing of information and the change of mental schemata which is discussed later in this report. Iskandar et al. (2011, p. 405) write

The analysis and training of motor skills seems to be somewhat divorced from the mainstream of educational research and development.

In my opinion it is important to bare in mind these differences in theoretical background, though in my opinion both cognitive theory and a behaviorist perspective are applicable.

A guest editorial about cognitive load in Learning and Instruction covering interactive knowledge construction writes "Research on multimedia comprehension has moved towards models in which cognitive, memory-based views and constructivist views are integrated" (Verhoeven, Schnotz, & Paas, 2009, p. 370). This will be covered in this theory section.

Feedback

Feedback is a very important factor in improving sports skills. In the article by Liebermann et al. (2002) modern technology is said to have such a big impact the development of sports and for athletes that it is considered invaluable. However feedback is only relevant if the goal and the task are known to the athlete. An example is video training sessions that are commonly used in sports, but Liebermann et al. (2002) mention problems with this category of feedback. In particular, there is a delay between the feedback and actual motion. The memory of the senses at the time could be difficult to remember at a later point. Furthermore, for young athletes this is much more difficult because they are often not well aware of their technique.

Exercise of timing is also very relevant in many sports, where coaches traditionally have used simple methods like hand-clapping to give direct feedback. This is a method implemented in new technology by using sonic transmitting representing negative- or positive-feedback, for example to help maintain a frequency of repeated movement. There are cases where direct feedback is not good, there is a risk to overexpose the athlete and to create a dependence on technology. Liebermann et al. (2002) mean that it is important to step by step decrease the technical feedback and help the athlete to trust him/herself. It is also important to vary the kind of feedback.
3.2. LEARNING THEORIES

Visual Literacy

Schönborn, Anderson, and Grayson (2002); Schönborn and Anderson (2006) discuss visualization for biology students and visual literacy. They state that visualizations which are used in learning could abstractly be seen as an external representation of data. The purpose of the external representations is to help the creation of internal mental models of the learning object to be learned. In the use of visualization for kayak an external representation could be a theory or hypothesis of how to sum up sensor data to evaluate performance. When using external representations it is important to teach the student how to make meaning of the visualization and to understand what is visualized. Visual literacy involves the abilities to read, construct, analyze and express yourself in pictures/visualizations. Schönborn and Anderson (2006) states that it is important to explicitly teach the student how to understand the visualizations and a common misconception is that visualizations could be implicitly understood by normal cognitive skills. Graphs can be a very useful complement to words but they can also be cognitively demanding (Schönborn et al., 2002).

Even though there is a big difference between kayak athletes and biology students there are some advises that could be useful in both contexts. Schönborn and Anderson (2006) have a constructivist perspective, which briefly means that only the individual itself can explore and learn about the world from its point of view. They point out the need for using cognitive theories, such as Paivio (1986) two-coding theory and Mayer (2003) ML theory. These theories will be outlined briefly in the following sections. It is also important to share the concept of the material visualized. When there are visual objects that have a specific meaning it is important to inform about these. For example, in traffic there are stop lines: If a driver does not understand the visual object, he may not stop (Schönborn et al., 2002).

CLT

CLT was first formulated in the 1980s and was developed widely in the 1990s. The most influencing learning theory at this time was the constructivist theory with inspiration from Jean Piaget and John Dewey. Though there were different views on instruction design and the derivation of behaviorism, where one side would emphasise learning in the real environment or learning by doing, while others would see the need for instruction to be able to process information. In this paradigm shift CLT would emerge inspired of both behavioristic, constructivist and cognitive theories.

CLT is commonly associated with assumptions, such as limited working memory, unlimited long-term memory, roughly seven memory-slots (Miller, 1956) and that knowledge is stored in different mental schemata. Van Merriënboer and Sweller (2005) differentiate between three types of cognitive load: Intrinsic cognitive load is directly related to the learning material and how complex it is, Van Merriënboer and Sweller (2005) choose to call this interactivity. This means the number of elements that the learning object contains, but if the learner already is familiar with elements due to previous schemata, it may not give the same cognitive load as for an inexperienced learner. Extraneous cognitive load occurs when the learner has to search for information and other activities that are not connected to the actual information. It also occurs when visual or auditory channels are overloaded. Germane cognitive load results from the process of actually updating the schemata in other words the actual learning process (Van Merriënboer & Ayres, 2005).

Usually, a first step is to reduce extraneous load. Examples of this in CLT are:
• **Split attention effect** - It is better to integrate words and pictures, then there is no need to search and memorize information in memory.

• **Redundancy effect** - Avoid multiple sources of the same information otherwise these will occupy additional space in memory.

### Multimedia Learning (ML)

There is a lot of large scale educational technological ideas that have failed in the past due strong belief in technology itself. There are many other factors that decide if a device is useful or not, for example, if the user understands to use it as intended. Mayer and Moreno have developed a theory based on instructional technology and cognitive theories (Mayer & Moreno, 1998). Mayer uses the term Multimedia Learning and defines it as the processes when mental representations are made from words and pictures. Words can be presented as audio or text, and a picture may be dynamic or static. For his cognitive theory he uses three assumptions, and that are the 'Dual channel assumption' (Paivio, 1986), 'the limited capacity assumption' and 'the active learning assumption'. The first means that we have a possibility to process visual and verbal information separately. To assume limited capacity means that you will get an overload if you process more data than the limit. The last assumption gives that the learner will not learn if he/she is not active and tries to connect to earlier experience/schemata (Mayer, 2003).

Cognitive overload occurs when there is too much information in channels to process. To reduce cognitive load Mayer and Moreno proposed some actions (Mayer & Moreno, 2003):

- **Pretraining** - To reduce extraneous load you can first teach how the system behaves.

- **Weeding** - Remove interesting but unessential material.

- **Aligning** - Words should be close to images to reduce the split attention effect.

Mayer has overviewed a metastudy of four generally known effects in multimedia learning currently used in both books and computer environment; the multimedia effect, the coherence effect, spatial contiguity effect and the personalization effect (Mayer, 2003).

- **The multimedia effect** - Deep learning is increased if pictures and words are used together.
3.2. LEARNING THEORIES

- **The coherence effect** - Deep learning is increased when unnecessary material is removed. Extensive information can even have a negative effect.

- **The spatial contiguity effect** - When text is in close spatial proximity of the picture. This effect was not as big in computer studies as in books.

- **The personalization effect** - The text should be written in a conversation rather than formally.

Grunwald and Corsbie-Massay (2006) give an overview of the search terms "cognitive load" and "multimedia learning". They are based on Mayers work on multimedia learning and they conclude that learning is mostly affected by the learning instructions and not by the media. They also point out that feedback is more important than the multimedia learning itself.

Schnotz and Kürschner (2007) state that there are connections between intrinsic load and germane load. If the load is too low or too high there will be problems constructing new schemes.

**Integrating HCI and CLT**

The connections between CLT and HCI on the cognitive level are described by Hollender, Hofmann, Deneke, and Schmitz (2010). For example, in the field of HCI Hollender et al. (2010) find a connection to the cognitional theories: external cognition and distributed cognition. In HCI, one of the most important goals is to reduce the cognitive load caused by interaction with externalized representations. According to Sharp, Rogers, and Preece (2007) the most common methods are:

- **Externalizing to reduce memory load** - Strategy to offload the memory, this are commonly done by using a calendar or post-it notes on the screen. For example, nowadays applications have a calendar that reminds you of birthdays.

- **Computational offloading** - This mean if the user uses aid that helps to compute results from external representations.

- **Annotating and cognitive tracing** - For example, if the user marks important information and organizes in systems.

A common practice in HCI is to focus on the task to reduce the objects, which have to be kept in memory, in order to reduce cognitive load. Further it is important to reduce disorientation so that the user may instead quickly feel familiar with the program. If the program has to be complex it is important to teach the user how to use the software. There are some similarities between CLT and HCI. They have the same underlying theories of cognition. Some principles of learning instructions find common ground in basic principles of HCI. For example the redundancy of information and spatial distance are found in both fields. Hollender et al. (2010) state though that usability principles from HCI are not enough to ensure successful learning. Hollender et al. (2010) point out that CLT has a germane process that is really important for deep learning, it is also really important to individualize learning. HCI methods are useful to reduce extraneous cognitive load but the field of educational technology has better explanations of how to understand intrinsic load(Hollender et al., 2010).
Chapter 4

Methodology

Mobile device
To present and read data the mobile phone HTC Desire has been used during this project, see Figure 4.1. The phone is officially upgradeable from Android 2.1 to Android 2.3 (API-10). The phone has a 1 GHz CPU, 576 MB RAM and Bluetooth 2.1. The physical size is 11.9 x 6.0 x 1.2 cm and the touch screens diameter is 9.4 cm.

Figure 4.1: HTC Desire

4.1 Development
The software was developed in Java for Android and with compounds of HTML/JavaScript. Android is an operating system and software platform for smartphones and pads. This report always refers to Android v.2.3 (API-10) "Gingerbread" if nothing else is mentioned. In time of writing, the current Android version is v.4.x (API-15) "Ice Cream Sandwich", but there is only one supporting phone model currently available on the market. Eclipse Indigo IDE with Android Development Toolkit v.15 was used during development. Android has been developed as an open source project and does not depend on specific hardware such as the iPhone. This induces that for example screen size, CPU and other peripheral
devices may vary. The fact that it is an open system is one of the main reasons for choosing Android.

![Figure 4.2: Eclipse IDE](image)

A technical issue in Android was that insecure RFCOMM connection was not officially supported before Android API-10. Generally it is good to use common practice because of compatibility between Android versions. When connecting Bluetooth devices in Android the software uses a Universally Unique Identifier (UUID) for every device, though for SPP one ought to use the specific UUID: 00001101-0000-1000-8000-00805F9B34FB.

To produce real-time visualizations Canvas and Drawable objects are used within the Android platform. Android has these simple sets of view widgets to provide general interactive graphics. The performance is lower in Android 2.x compared to Android 3.x+ because there is no hardware acceleration of Canvas.

A WebView is used to post-visualize data; it allows simple implementation and basic functions as back, forward and zooming; it also supports JavaScript. The prototype uses RGraph to present data, RGraph is a HTML5 JavaScript chart library that is based on the HTML5 canvas technique (see Figure 4.3). It is free to use for educational and non-commercial purposes.

![Figure 4.3: Example of graph produced by RGraph](image)
4.1. DEVELOPMENT

System design

The difference from previous system design is mainly the use of multimedia possibilities as graphics and sound in Android platform (Compare Figure 2.1 with Figure 4.4).

![System design diagram]

Figure 4.4: System design
Chapter 5

Analysis

5.1 The device as a part of the system

The system described in Figure 4.4 is similar to systems in the literature review. It uses a Bluetooth piconet with the phone as an acquiring device for capturing sports data in real life exercise. The data is saved on the local device and exported through external memory. According to the four design criteria in chapter 3.1 the system is evaluated:

1. The operating system has to have a good usability and data should be storeable with low risk even though the system communicates, saves and visualizes data.

   Android has a graphical interface that corresponds to a Model-View-Controller (MVC) design pattern and a usable interface could easily be implemented. The data could be stored in internal and external memory, but there is a problem with the operating system because it is not made for the use of a single isolated application. There is a risk that the program control is handled by the virtual machine, the main risk is that other applications disturb the process. E.g. if a person calls the phone and the memory is low, Android would probably shut down the process and data would be lost. When saving and visualizing data on a single CPU device there is also a risk of a visualization thread to lock and disturb the acquisition process. Without handling thread priority there could also be problems if graphics or calculations are to demanding.

2. If the application should be used for visual real-time data it has to be fast.

   A naive example of graphics is shown in Figure 5.1. The use of simple graphics is no concern if it is kept simple, though the addition of many small parts could be demanding. To decrease graphic load it is possible to only update the screen every second for naive implementations. The device has to be explicitly tested for this purpose with filters, graphics and sensor.

3. The device has to be able to work with concurrency, for example to read and print.

   The device has support for concurrency by the VM and therefore it is dependent on the implementation. Android has support for concurrency in the same matter as Java, the prototype uses the thread class. When acquiring from multiple devices frequently it has shown to be important to handle threads when reading sockets. The default
handled would record ten packages of data from the same source before releasing
the thread, resulting in failure to read and print sequentially correct. The reason is
that the thread is blocked until data is available and the thread handler in the virtual
machine would try to balance the load by assigning each thread process time. This
could though be solved by methods of manual handling of the Thread class as
\texttt{Thread.yield}.

4. \textit{The system should be scalable so that more sensors and different types of sensors can
be connected in the future.}

Scalability is limited by the on Bluetooth standard. Furthermore, data throughput is
a limiting factor. Data throughput has to be tested for device, tests of one device give
no data loss. Problems with data loss using multiple devices have occurred in previous
versions of mobile phones. The workload is determined by the sampling frequency and
the number of devices attached, a piconet has an upper limit of seven active devices.
The system uses the SPP-protocol and assumes that all devices support it, due to
different device protocols for serial communication there may be a developing need
on the application level when integrating a new device, e.g. GPS or pulse monitors.
Within the Android platform it is also possible to connect other Android devices, e.g.

pads, that extend possibilities, but the current system needs to be complemented with
a method for connecting and authorizing devices, preferable with a UUID specified in
software.

The requirements of the current implementation are fulfilled by the Android platform and
the chosen device. Challenges were to implement data protocols of different devices and to
support complex real-time visualization or demanding algorithms. The distribution chan-
nels of Android applications are similar to those for the iPhone and give comparable pos-
sibilities for sharing and charging for the product, but there is a risk when distributing a
product that is hardware dependent. Android is an open platform and it could be used
on a wide variety of hardware. There is a risk that visualizations and sound could not be
intercepted in devices with a great difference in hardware. Battery life could be a problem
when the display and computational power are used extensively.

5.2 \textbf{Learning with a technical aid}

The challenge for the athlete and coach is to find patterns in acquired data and to translate
to manageable exercises suitable for the specific motor skill domain. In the motor skill
domain it is important for the athlete to understand what behavior, e.g. what element of
a movement to learn or improve. The Feedback could be direct or delayed. For example,
direct feedback would be if the application, sounds a warning when the stroke frequency
drops. In the current system design, the athlete has to wait a long time between a per-
formance and the feedback. The athlete has to remember a long series of movements and
match it with measured data, which could be ineffective according to CLT and memory-load.

When learning to percept average paddle frequency it could be useful to vary real-time
exercises and delayed feedback, to avoid dependency on technology. If a sound or visual-
ization is always available it may not improve the motor skill of the rhythm. A motor skill
training exercise would use real-time feedback, while post feedback can be better presented
by a summary of the frequency visualized in a graph.

**Difference in learning situation**

There are multiple data that could be presented both in real-time and in a later inspection of data. In a real-time environment it is important that the data is easily comprehensible and that it is not too cognitively demanding. There is a big difference in evaluate data at a computer and to perceive in a moving kayak, the extraneous load is high when paddling. Previously, athletes were studied in a laboratory environment which differs from the real world. This may also affect the learning situation.

There is numerous data that could be presented and its usefulness has to be tested individually. A good principle for real-time use would be to keep visualizations simple, with low interactivity and computational offloading. Post visualized data should also be kept simple in everyday use, but could use higher interactivity. The device could be used for single training session evaluation or multiple training sessions. The choice of data presented would affect the learning situation and the data that would be interesting to present may differ, for example:

**Single training session**

- Chosen part of a training session, e.g. the start.
- Similarities in stroke pattern.
- Acceleration, average speed.
- Peak values, maximum force, local minimum.

For example, to study the start would limit the memory load because the athlete would be able to focus on only one part and probably remember what to change to next time. Local minimum or maximum could be used to identify irregularities, which would be easily remembered by the athlete.

**Multiple training sessions**

Post-performance data could be analyzed and mined for explanations for performance improvements. Though data suitable to extract in general matters could be difficult to predict and would probably have to be found over time using the application. Examples of what could be analyzed:

- Correlations between efficient training sessions.
- Similarities in stroke pattern.
- Differences in equipment.
- Repeating of local min or max values.
Determination of causality is the general difficulty with multi variable data. The athlete also has to be aware of what is tested and how it is measured in order to be able to change later. For long term measurements it could be preferable to videotape the training session in order to offload memory and then synchronize the video with further performance data presented. A coach can only get a general view of the training session and could have difficulties to correlate specific events to graph fluctuations. According to CLT the possibility to process information is limited. If the movement is well understood it could be possible to identify complex patterns in data, but if there are multiple variables it may be really hard to comprehend, e.g. if the athlete both has to remember the whole training session and read data it could be very demanding. Therefore it is preferable to display data in chunks and to offload the memory with objective pictures or a coach view instead of the athletes own mental models.

5.3 Visualization on mobile device

Technical difficulties

Visualizations on Android smartphones are limited by screen size and navigations possibilities. It is also a technical issue with capacitive touch screen and wet environments, so it could be a bad user experience to scroll the visualization. If there are many choices or data presentations it could get too complicated for the user, because of limited cognitive memory. To minimize disorientation it could be useful to follow Android standards and guidelines; to reduce external load by using the user’s previous experience of Android applications.

How to visualize?

When presenting summarized data or combined data it is important to describe their content for the user. According to theories of visual literacy it is commonly assumed that images are easy to understand, it is shown in ML that pre-training is efficient and gives a better learning outcome (Mayer & Moreno, 2003). All visualizations are an external representation of an object, intended to aid the athlete. Visualization could also contain visual
5.3. VISUALIZATION ON MOBILE DEVICE

objects, as shown in Figure 5.1 and Figure 5.4. To avoid needing to instruct the user of visual objects it is good to use well known symbols, as a checker or an arrow, while red and green, and checkers is commonly recognized for that something is completed, this cannot be assumed true for all cultures. Colors could be used to aid the user when perception is limited, but for accessibility\(^1\) reasons high contrast color themes could be used to aid e.g. green-red colorblindness.

![Figure 5.2: Example of static data](image)

When presenting graphs on a mobile device it is hard to percept details on the small screen as in Figure 5.2, but it could be a useful feature. To be able to present graphs, the zoom function has to be implemented. To reduce memory load and to support aligning one could use tooltips or pop-ups to explain data in a zoomed view. For example, labels and axis descriptions may not be visible in a zoomed view.

![Figure 5.3: Example of static data (zoomed)](image)

Graphs have a high density of information or, in other words, a high interactivity of content. For example, in CLT the split attention effect states that users who need to scroll and search in a graph would use a lot of memory just to remember what is in previous screen. If possible, it would be better to view summary data as simple variables or segments of a training session that would be of direct use to the athlete.

\(^1\)Read more at [http://www.w3.org/TR/WCAG/](http://www.w3.org/TR/WCAG/)
Less is more, it is better to simplify the visualization to reduce intrinsic load when the extraneous load is high. Figure 5.4 illustrates that an aspired paddle frequency is not reached, it is complemented by a warning sound. This is an example of multimedia presentation because pictures and words are used the same time. According to dual-coding theory (Paivio, 1986) this is beneficial to learning.
Chapter 6

Discussion

Interaction

To improve the functionality implemented on the mobile device, it could be useful to collect data from users. If it would be possible for coaches and athletes to annotate interesting data in, for example graphs. Data could be collected centrally and in helpful when developing new function support. It could also help the users to remember what they want to discuss with the coach in a distant future, since the athletes often exercise by them self.

![Figure 6.1: Example of self evaluation](image)

The smartphone could also be used for the input of feelings and self evaluation as in Figure 6.1. Feedback is important for motor skill training, but the athlete should not get dependent on technology when performing. Self evaluation could be useful for practicing subception of a good or bad run. A training method can be to hide the objective data for five run and later compare the objective results with the self evaluations.
CHAPTER 6. DISCUSSION

System design
The use of an Internet connection as in Figure 6.2 could be a really interesting area of future development relevant to the kayak project, though it is not certain the mobile coverage generally allows real-time data with acceptable delays. Another contra argument is that the athletes only would benefit of this if they exercise with the coach. Instead, the main benefit would be to use interactive pads and because of similarities in architecture it is also easy to implement. A coach would be able observe real-time data simultaneously as a training session elapses. Data could be presented with almost the same screen size as in computer Matlab plots. The solution for data transfer could be a socket connection through 3G or WLAN with a proper antenna selection. If two thirds of the athletes exercise without a coach it could be useful to upload data to a central database, enabling feedback trough the Internet, but it is also uncertain how much information that would be useful without visual impression.

![System setup with database](image)

Learning theories
The difference of direct feedback for motor skills and the changing of cognitive schemata is important to bear in mind when constructing future technical aids. ML and CLT are mostly applicable in visualization/feedback designs were the multimedia effect should be noticeable, when using words (audio/text) and pictures (static/dynamic).

I think there could be a connection between the motor skill domain and the CLT at a high extraneous load. Both disciplines say that a task should be learned in divided elements until bigger sequences or chunks could be handled. In CLT it is due germane cognitive load that is dependent on the balance of intrinsic load.

In HCI it is stated that externalization is commonly used in software. An Android application could be useful to remember results and improvements over time, an athlete could make improvement visible over long time. In sports often the time or effect is the main measured variables, but it could also be good to show other improvements to build motivation. To
revise data from previous year could be a good reminder when a season starts and training feels difficult. An application could also present data in a personalized manner, according to the personalization effect it is preferable to prevent a too formal appearance.
Chapter 7

Conclusion

7.1 Conclusions

The use of a smartphone gives new possibilities of interaction and real-time feedback in sports performance measurements. With the help of learning theories and analysis of the device in a learning environment it is possible to optimize the use of such device. Some data are preferable to show real-time and some are better suited for post processing; it is important to evaluate the goal of a task before it is implemented and to teach both the coach and user to understand what to expect in practice. Real-time data should be kept simple, while post visualized data could be more complex.

- The design of feedback will depend on the learning situation, technical possibilities and the information to process.
- When the environment is cognitively demanding the visualization should be easy to understand and the information easy to apprehend.
- Complex data could be presented in a graph on the mobile device but this is more suitable for a big screen.
- The technical possibilities with the Android platform are sufficient for the intended use.
- Direct feedback in real-time is preferred to post-visualization in motor skill exercises.

7.2 Future research

It would be interesting to study the performance limitation when the tested elements are implemented together (e.g. processing, visualization, sound). Internet can be used to connect to a centralized database; it can be interesting to study if general patterns can be found. Prototyping and evaluation of how to personalize the device, with self evaluation, motivation and performance history. The connection between learning theories and HCI can be developed further.
Appendix A

Prototype explanation

This appendix explains modules used in the prototype and findings during programming. There are some parts that should be written different in a stable release, for example there should be a better handle of exceptions. The program is divided in packages that I will describe further in this text.

A.1 Node package

The Node package has the data structure of all nodes, for example sensor data and a timestamp. They are used to save every single package from the sensor and they are later put in memory (in a list on the heap). To write to file I use an override of the toString method.
that every object in java has. After the recording the data will be saved to the SD card. It’s a relative costly operation to save and there is also a risk that the user did not connect the SD card or it could also be full. You also write to the internal memory instead and then move to the SD card later. Though for battery reasons it good to keep allocations low and save data in chunks, if there is an effect on battery is possible to check with emulated battery life in the Android Emulator.

In Node there is a static method to be able to convert data from "unsigned bytes" to whole numbers. It is a good practice to use static instead of repeating the algorithm, the algorithm:

```java
static long binaryBytesToLong(byte[] byteArray, int bytes){
    long value = 0;
    for (int i = 0; i < bytes; i++){
        value = (0xff & byteArray[i]) << (8 * (bytes - i - 1));
    }
    return value;
}
```

`byteArray` are an byte array and `bytes` are a given number of elements in the array. `long` in java is an 64 bit integer that are two-complement, but in our case only positive numbers are used. To make future real-time implementations possible it is important that operations that are done a lot are fast, in this case I use the bit-operations inclusive or |, bitwise AND & and signed left shift «. To shift left with 8 bits in the binary number system correspond to multiplication of 2 powered by 8 in a ten base system. 0xff&byteArray[i] has the function to interpret the element as a bit number and not two-complement number, for example 1111 1111 & 1111 1111 are 255 and not -1.
A.2 Program package

Connections are an object that coordinate the different Bluetooth connections and has the handler that is used to for example read Bytes. It works as a naive for the recording and connections from and to sensors. In the Connections class you could easily connect real-time visualization of data by adding a view module.

Handler

A handler is an integrated functionality in Android that handles messages between different threads, but also objects could be sent. There could be a point for further versions to write
an optimized handler of threads and messages, but I think it would be very time consuming and not very giving. Though when using real-time application there could always be strange behaviors that you cannot control in pre build functionalities. The handler is owned by the creating thread and its controlling the reading of messages. The other threads will have a reference to the handler, and they can ask to obtain a message to send. In this case I use the Handler both for logic during connection and to change the UI, but this is made by two different handlers. (One in Connections and one in Activity)

Executor

![Flowchart of executor](image)

A Executor is a small class made to start Runnables. To be able to easily start next task in the program I used a list of Runnables that are read by a call function exec. The main reason for this is that next commando can be started as soon the devices responded, instead of waiting for a fixed time. The negative about this approach are that a class of Runnable is created for every command, and it can get a little messy, though you can reuse a lot of these classes for different devices. The main reason for this approach was to be able to test without rewriting a lot of code, though it may be better for a stable release to extract these in different modules with an event-based approach.

Device

Device is a class that holds information about every sensor. It owns a socket, a connection, a writer for the SD-card, status and all saved data for the node.

Connection

Connection that is owned by Device, extends Thread, because of in- and out-streams. It also contains an inner-thread that only reads the buffer, because it would otherwise lock the thread. The communication from the BluetoothSocket are read by unending while loop with an in stream. The read operation locks the thread until the buffer has something that
could be read. To avoid devices to lock the thread and stop other sensors to send it is good to make multiple threads that have their own socket reader. Though there are not as many processors in Android to separately handle all threads, so Java will try to balance the workload. If Thread.yield is not used, there is a risk that it will read 10 loops in every thread before passing to next one.

![Flowchart of method startRecording](image)

**Figure A.5: Flowchart of method startRecording**

### Synchronize

To synchronize the sensor data with same timestamp we are using an application level algorithm. Every device has its own time and ping time. The algorithm depends on that the device has an built in function to answer with a timestamp while syncing. Without this it would be needed to have access to lower levels of the communication protocol. It are shown in the study at STH, that this approach are functional and fast enough. There are always an uncertainly with the buffers, so it is important not to read many at same chunk. It is also important to redo the synchronization after some time.

The algorithm say that a Timestamp (T1) should be saved when the demand are sent to the device, then the device answers with its timestamp (T2) and the main device save T3 when answers is accepted. The delay are calculated by \( o = (T1-T2)+(T3-T1)/2 \)

The algorithm works as following: 1. T1 The mobile phone send the demand for timestamp to the node and saves it own time 2. The node gets the demand and answers with its timestamp T2. 3. The mobile phone receives the answer and saves T2, and its own time T3 4. Repeat 1-3 for 30-50 times. 5. Calculate the average of measurements. 6. Repeat 1-5 for every sensor. 7. Add the specific calculated average to every device.
WebView

To visualize data the implantation of a WebView is used, it depends on HTML5 and JavaScript. The main reason for this is that a lot of visualizations are made in web environment. It is also a more common tool for a single designer to work with. In the case of more advanced visualizations often pre made software or a developing team of programmers and designers are needed. Another point is to implement the MVC design pattern; you will have most of the Model in java background code and view in the web view. The data connection could be solved with a database or a JavaScript interface

JavaScript libraries

There are a lot of other pre made libraries for JavaScript than the one I choose. In this case I used a basic package RGraph that are free for academic use. Though it is really important to read licenses for libraries, for example if you want to use RGraph in commercial matter you have to pay 50 euro, others have developer licenses that easily cost 100-1000 euro depending on functionalities. Other examples are ZingChart and Flot. To show SVG graphics the Raphael and the libraries constructing on it could be a good start. There are also other libraries that are free to try but more expensive when selling the application as for example Highcharts.

---

1 When developing there was a bug in the emulator, JavaScript interface causing runtime error
2 https://www.zingchart.com
3 https://code.google.com/p/flot/
4 http://www.raphaeljs.com/
5 http://www.highcharts.com/
References


Miller, G. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological review, 63*(2), 81.


