Requirement Specification

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Version 1.0

Status

Reviewed	Mikael Karlsson	2015-09-28
Approved	Hien Ngo	2015-10-07

Project Identity

HT 2015
Linkoping University, ISY

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Contents

DOCUMENT HISTORY

Version	Date	Changes	Sign	Reviewed
0.1	2015-09-21	First Draft	Martin A	Mikael K
0.2	2015-09-28	Second Draft	Martin A	Mikael K
1.0	2015-10-07	First Version	Marin A	Mikael K

1   Introduction

We plan to demonstrate the Zero Forcing capabilities and possible applications of Massive Multiple Input Multiple Output (Massive MIMO) for the project course TSKS05 CDIO Communication Systems, building upon the work done by a previous project [2]. MIMO is an essential element of wireless communication that uses multiple antennas at the transmitter and receiver to enhance the capacity of the radio link. Massive MIMO is a new innovative version of MIMO which uses a very large number of transmitter antennas that are operated in a complete coherent and adaptive manner to focus the transmission of signal energy into small regions of space. Massive MIMO can potentially increase the capacity by at least 10 times due to its aggressive spatial multiplexing while simultaneously improving the energy-efficiency with a factor 10-100. Research into Massive MIMO has yielded promising results and it is going to play a big role in the future of wireless communication.

Zero Forcing is a type of beamforming technique used in Massive MIMO for a multi-user environment where we transmit the signals such that the received signal energy for the relevant user is strong while that of the other users is zero. This is an excellent quality to have in a wireless communication system since, in the ideal case, transmission to one user causes no interference to other users.

1.1   Partners

Table 1: A list of all partners involved with the project.

Name	Role
Danyo Danev	Examiner
Hien Ngo	Customer
Antonios Pitarokoilis	Supervisor
Students (see Project Identity)	Project Group

1.2   Aim and Goal

The goal of the project is to be able to use the available hardware for parallel communication to two terminals using Massive MIMO beamforming and Zero Forcing applied to audio signals. The project also provides the students with an opportunity to put their knowledge of communication systems to practical use.

1.3   Usage

The product should be able to be used as a tool to educate people about Massive MIMO and to demonstrate its beamforming capabilities.

1.4   Background

The previous project group (HT-2014) of the course TSKS05 worked on the project Massive Audio Beamforming where they successfully built hardware and software for a Massive MIMO system that used audio signals and demonstrated beamforming using the Maximum Ratio algorithm. Building upon the work already done by the previous group the goal of 2015 year's project group is to implement the Zero Forcing algorithm for the Massive MIMO system and use this for parallel data transmission to two different terminals, at the same time.

1.5   Definitions

See Table 2 for definitions of words used in this document.

Table 2: Definitions of words used in this document.

Word	Definition
MIMO	Multiple Input Multiple Output
A/D	Analog to Digital
D/A	Digital to Analog
L/M unit	Loudspeaker/Microphone unit
L/M-pair	A pair of Loudspeaker/Microphone units
MIMO-array	The array of L/M pairs used to generate the Zero Forcing beam
Terminal	One of the two units in the receiving L/M pair.
OS	Operating System
Subsystem	A part of the whole system

The requirements specified in this document follow the template below where the requirement number column is merely used for referencing. The change column can take one of the two values, "Change" or "Original". The value "Original" is used when the requirement, described in the third column, is unaltered from the approved version 1.0 of this document. In case of revision of a requirement the value "Change" shall be used together along with the date of revision. Requirements with priority 1 shall be fulfilled by the time of delivery.

Requirement number	Change	Description of the requirement.	Priority

2   Overview of the system

The system will basically be an upgrade of the existing system which was built in the previous project. The system will consists of two subsystems, namely the Software and the Hardware. The Hardware of our project is the same as that of the existing system, so this project's focus is just the Software. The new system should be able to demonstrate the capabilities of Zero Forcing by using it for parallel data transmission to two different terminals.
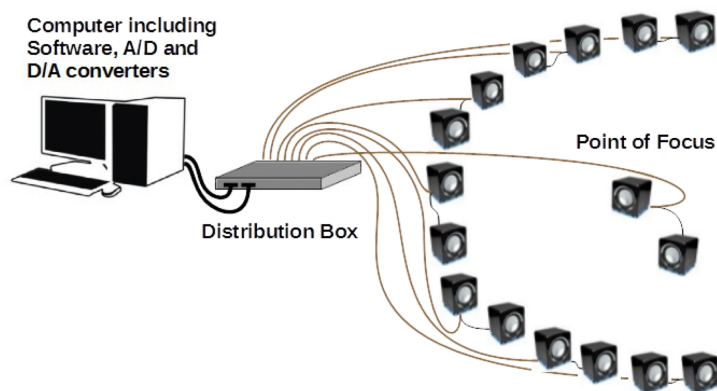
Figure 1: Overview of the Hardware in the system. [2, Fig. 1]

2.1   Existing System

The Hardware consist of eight L/M pairs of which seven act like a MIMO-array while the last pair receives the signals from the MIMO-array. An overview of the system is depicted in Figure 1.

The Software of the existing system consists of MATLAB scripts for channel estimation, signal generation and spectral analysis. It also includes drivers for communication between a Windows operative system and the Hardware.

2.2   Included Subsystems

There are two subsystems which are Software and Hardware, the entities in the respective subsystem are listed below. The Software and the Hardware interact with each other through the drivers on the computer.
Software entities:

- Operating System

- Drivers

- MATLAB code

Hardware entities:

- Computer.

- A/D converter.

- D/A converter.

- Amplification circuits.

- L/M-pairs.

2.3   General Description of the Product

The product will demonstrate Massive MIMO and Zero Forcing by using the MIMO array to send data , in the form of audio signals, in parallel to two different receiving L/M-units (terminals). The user can choose mode of operation for each L/M pair and thus choose if they should act like loudspeakers or microphones. By being able to communicate different data, at the same time, to the two terminals, the capabilities of the Zero Forcing technique can be shown.

2.4   General System Requirements

Below are the general system requirements.

1.	Original	Be able to estimate the channel state information for every channel between each of the two receiving terminals and each of the terminals in the MIMO-array.	1
2.	Original	The system shall be able to focus sound energy from the MIMO array in such a way that it adds up constructively at one of the terminals and destructively at the other one, using MIMO and Zero Forcing.	1
3.	Original	Be able to send data to *one* terminal, error free.	2
4.	Original	Be able to send different data to *two* terminals simultaneously, error free.	3

3   Available Hardware

The hardware from the previous project will not be altered and the description given here is therefore heavily based on the technical report produced by the previous project [2].

The existing hardware consists of a computer, an A/D converter, a D/A converter, a distribution box and L/M-pairs. All these entities are described in this chapter. An overview of the hardware is given in Figure 1.

3.1   Computer

A computer is an electronic device for manipulation of information or data, which can be stored, retrieved and processed. The model of the computer used in the project is a Hp Compaq Elite 8300 running Windows 7 as its operating system.

3.2   L/M pairs

A L/M unit is a modified loudspeaker that can also act as a microphone. The L/M unit can operate either as a loudspeaker or a microphone based on the input from the user. A L/M pair is a set of two L/M units in which one is a master unit and the other a slave unit. The system has 8 L/M pairs and one of these pairs is depicted in Figure 3.
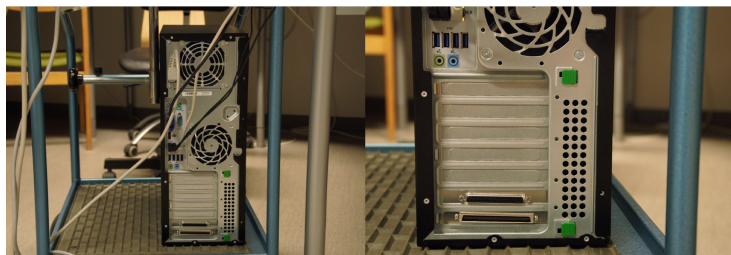
Figure 2: The computer back panel with A/D and D/A slots. [3, Fig. 2]

The master unit is made of an original amplifier board and additional detection board designed by Mikael Olofsson. The detection makes it possible for the L/M pair to operate as both loudspeaker and a microphone. The 9-pole D-sub connector (DB-9) mounted on top of the master unit serves as interface for signal to, or from, the L/M pair. The power supply to the L/M pair is done through the USB cable, connected to the wall via a USB adapter.

3.3   A/D and D/A converters

An A/D converter is an electronic circuit used to convert an electrical signal into binary numbers to be used in a digital controller (computer). A D/A converter circuit is used to convert binary numbers to analog voltage or current. One A/D converter (Contec AD12-64) and one D/A converter (Contec DA12-16) are attached to the computer motherboard through PCI slots to ensure the communication between the computer and the distribution box. With the help of the internal sample clock in each card, resolution of 12V and highest conversion speed of 100 kilosamples/s are attained for both converters. The voltage levels for both converters are in the interval [-10, 10] V. Of the 64 analog input channels only 16 are used in the product. The A/D converter also has 4 digital inputs and 4 digital outputs for TTL level signals (Transistor-Transistor-Logic). In the product only two of the digital outputs of the A/D converter are utilized and these are responsible for switching between the two operation modes of the L/M pairs.
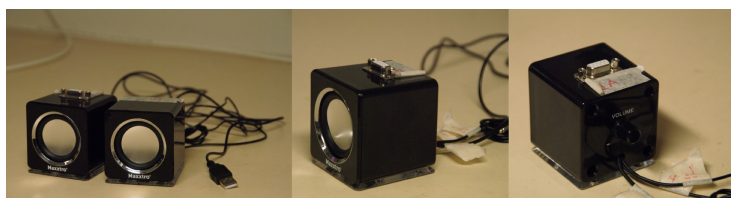

Figure 3: The L/M pair and the master unit from different angles. [3, Fig. 6]

3.3.1 Detection Board

Microphone mode operation for the L/M pair is possible by means of the detection board. When the L/M pair is working in this mode the circuit amplifies the audio signals received using a differential-in-differential-out amplifier with a voltage gain of 23 dB. Thereafter, the amplified signals are forwarded to the collection board for further amplification.
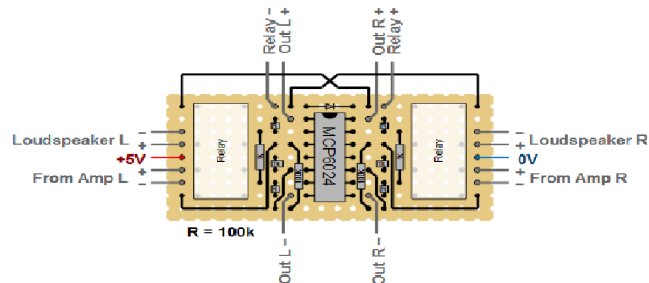
Figure 4: Detection board. [2, Fig. 3]

3.3.2 Maxxtro Mini Speaker 4W

A master loudspeaker and a slave loudspeaker constitute the main parts of the L/M pair. Both speakers, joint by a stereo cable of length 0.3m, are supplied 5V by the USB cable of 1m length connected to an adapter. The adapter, called *Euro-USB-laddare*, has the stock number 25-249-98 at ELFA. The USB cable and volume controller are attached only to the master loudspeaker.

Figure 5: Overview of the L/M master unit. [2, Fig. 7]

3.4   Distribution Box

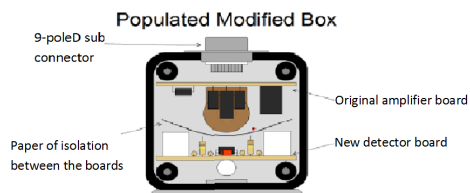The distribution box works as a hub and distributes the signals between the computer and the L/M pairs. It has 11 connections: eight for the L/M pairs, one for the A/D and D/A converters respectively and a power supply connection. For the purpose of letting the user choose which control group a L/M pair is part of the distribution box also has a control board consisting of eight physical switches.
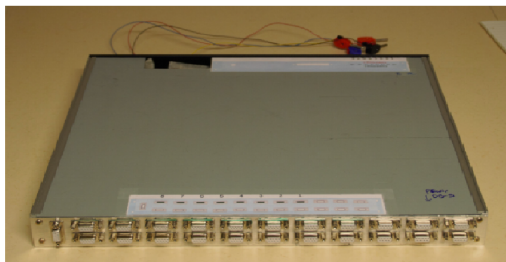
Figure 6: The Distribution Box. [3, Fig. 3]

3.5   Limitations on available hardware

Limitations on the hardware available from the previous project are presented below in the different sections.

3.5.1   Sampling frequency

The maximum sampling frequency that can be used for the A/D and D/A converter is 100 kHz. These 100 kHz are divided among all channels in use. Thus, when all 16 L/M units are in use the maximum sampling frequency is limited to 6250 Hz in theory. But the sampling frequency is fixed to certain values so in practice the maximum sampling frequency is 6024 HZ.

3.5.2   Data transmission

The limit of the amount of data that can be put through the D/A engine is limited to 250 000 samples, which translates to about 2.5 seconds of continuous sound, when using a sampling frequency of 6024 Hz and 16 channels.

3.5.3   A/D converters

The A/D converter has a voltage range of [-10,+10] V. However the power supply can deliver voltages in the interval [-11,11] V which means that the A/D converter can be damaged by a too high sound level from the loudspeakers.
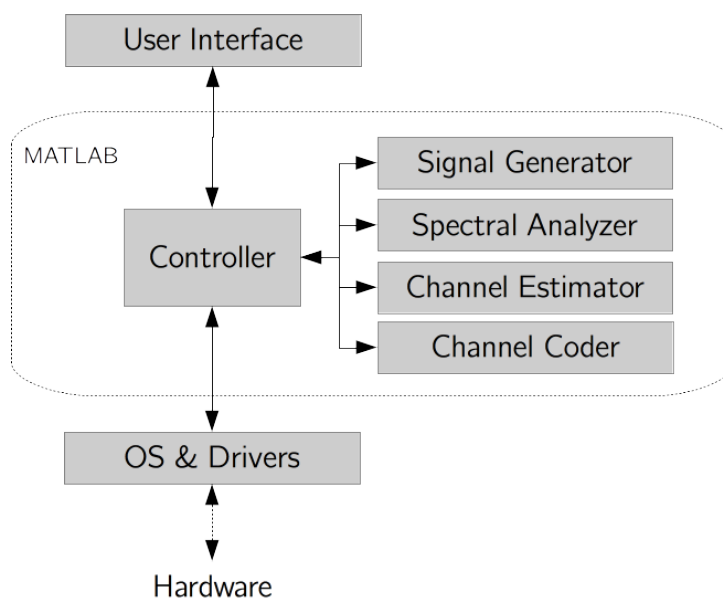
Figure 7: Overview of the software.

4   Software

The software shall be written in a modular fashion with interfaces to the user and through drivers to the hardware, as depicted in figure 7. The code will be based on the work from the previous project, at least initially. The code shall be written in MATLAB and shall consist of the five main modules listed below:

- *Controller* – This module shall control the work flow and call relevant functions in the other modules.

- *Signal Generator* – This module shall generate the signal for each terminal to send.

- *Spectral Analyzer* – This module shall analyse recorded signals and extract relevant characteristics such as main frequency component.

- *Channel Estimator* – This module shall estimate the channel between the MIMO array and respective terminal.

- *Channel Coder* – This module shall perform signal modulation and demodulation in order to send data over the channel.

4.1   Design Requirements

5.	Original	The software modules shall be written in MATLAB.	1

4.2   Functional Requirements for the Software

Below are the functional requirements for the Software.

6.	Original	The Channel Estimator shall be able to estimate the characteristics of the channels between the MIMO array and the respective terminals.	1
7.	Original	The Signal Generator shall be able to output signals that can be used for Zero Forcing.	1
8.	Original	The Software shall be able to perform modulation to send and receive data.	2
9.	Original	The Software shall be able to perform error correction to send and receive data.	2
10.	Original	The Software shall be able to visualise sent and received data.	2
11.	Original	The Software shall be able to calculate and display the error rate of a data transmission.	2
12.	Original	The software shall be able to output and receive different signals in parallel for data transmission to the respective two terminals, simultaneously.	3
13.	Original	The Software shall be able to be controlled from a GUI.	3
14.	Original	The User shall be able to choose the MIMO technique to be used through the Software.	3
15.	Original	The User shall be able to choose modulation technique to use through the Software.	3
16.	Original	The User shall be able to choose error correction technique to use through the Software.	3

5   Economy

17.	Original	Every member of the Project Group shall put 240 hours of work into the development of the product.	1
18.	Original	The Project Group shall not use more than 15 hours of supervision provided by the Supervisor.	1

6   Deliverables

The following items will be delivered by the Project Group during the project. Descriptions of the different items can be found in Table 5.

19.	Original	Requirement Specification	1
20.	Original	System Design Sketch	1
21.	Original	Project Plan	1

22.	Original	Time Plan	1
23.	Original	Design Specification	1
24.	Original	Test Plan	1
25.	Original	Test Protocols	1
26.	Original	Protocols from Tollgates	1
27.	Original	Individual and collective Time Reports	1
28.	Original	Status Reports	1
29.	Original	User Manual	1
30.	Original	Technical Report	1
31.	Original	After Study	1
32.	Original	Poster	1
33.	Original	Project Conference	1
34.	Original	Web Page	1
35.	Original	The Product	1

Table 5: This table describes some of the delivery items in more detail.

Delivery	Contents/Definition
Poster	A collection of paragraphs together with informative pictures describing the result of the project and its capabilities.
Project Conference	A conference where the Project Group presents the product.
Web Page	A web page containing information about the product and its capabilities.
The Product	The system demonstrating the capability of massive MIMO and the Zero Forcing algorithm to focus signal energy at a specified terminal while adding signal energy destructively at another specified terminal. This includes well written and well commented code for the Software.

7 Documentation

Table 6: A list of all the documents that will be produced during the project.

Document	Content	Target Group	Format
Requirement Specification	Defines all the requirements on the product.	Sponsor, Project Group	pdf
System Design Sketch	Describes the initial thoughts on the design of the product.	Sponsor, Project Group	pdf
Project Plan	Describes how the project shall be performed.	Sponsor, Project Group	pdf
Time Plan	Describes when and by whom the various activities in the project will be performed.	Sponsor, Project Group	Spreadsheet
Design Specification	Describes how the product shall be designed.	Supervisor, Project Group	pdf
Test Plan	Details how the product shall be tested.	Supervisor, Project Group	pdf
Test Protocols	Specifies the outcome of the test specified in the test plan.	Sponsor, Project Group	pdf
Individual and collective time Reports	Contains individual and collective Time Reports, per activity and per group member, weekly.	Sponsor, Project Group	pdf
Protocols from milestones	Protocol to describe the progress of the product development.	Sponsor, Project Group	pdf
Protocols from tollgates	Protocols to describe the tollgates.	Sponsor, Project Group	pdf

User Manual	Specifies how to use the product.	Sponsor	pdf
Technical Report	Describes how the product is implemented.	Sponsor, Project Group	pdf
Afterstudy	Contains a retroperspective discussion about the results and the time planning.	Sponsor, Project Group	pdf

8 Education

| 36. | Original | The user manual should be detailed enough to be the only educational material needed for the user to use the product. | 1 |
| 37. | Original | The customer shall be provided a guided demonstration of the product in order to know how it is used. | 1 |

References

[1] Tomas Svensson, Christian Krysander, *Projektmodellen LIPS*. Studentlitteratur, 2011.

[2] Fredrik Stenmark et al., *Technical Report*. ISY, Linkoping University, 2014.

[3] Fredrik Stenmark et al., *User Manual*. ISY, Linkoping University, 2014.