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Development of a D-SPECT myocardial perfusion phantom

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Revision 0.2

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Preface

The project plan outlines an introduction and literature of the topic along with organisational information including a detailed planning.

Gijs de Vries
Enschede, 3rd December 2018

Contents

1 Introduction

[done] Read into background information on D-SPECT

[done] Write global background information

[done] Introduce the rest of the document

[done] Assignment was for dynamic SPECT scanning, but is that the same as using the D-SPECT? The D-SPECT can scan dynamically, and is available in ZGT

[done] Too much SPECT detail in introduction? Moved to literature

[todo] Give arguments why to choose SPECT

There are various types of scanners that use different techniques. Examples are Computed Tomography (CT), Magnetic Resonance Imaging (MRI), or Scintigraphy (SPECT/PET) scanners. In cardiology, the SPECT scanner is widely employed for coronary and myocardial perfusion measurements (Rahmim and Zaidi, 2008). It is known that PET scans are generally more expensive (Hlatky et al., 2014; Goel et al., 2014). Hlatky et al. (2014) followed patients for two years, recording the costs and concluded that PET costs are 22% higher than the costs for SPECT for patients with suspected Coronary Artery Disease (CAD).

1.1 Document overview

[done] Update in correspondence with meeting december 10

The project plan consists of a literature review of existing myocardial perfusion phantoms and their comparison to human physiology, and more extensive information on D-SPECT scanners (their technical background, limitations, and so forth). The literature is followed by the research methodology containing the research questions and goals of the project. The detailed planning is the last section of the project plan stating workdays and -weeks, off-days, deadlines, and meetings.

2 Literature

[todo] Read available literature

[todo] Write literature review to more accurately define research questions

- D-SPECT literature?
- Discuss division of work

2.1 Phantoms

2.1.1 Magnetic Resonance

Chiribiri et al. (2013) use a four chambered phantom, to simulate the four chambers of the heart. In addition, a vena cava, pulmonary artery/vein combination, and an aorta are present in the phantom. Contrast is injected in the same manner as is performed in patients; in a vein. In the phantom, the contrast is injected directly into the vena cava via a three-way stopcock. The contrast moves through the phantom's right atrium, right ventricle then via the pulmonary artery/vein to the left chamber and finally to the left ventricle. The phantom is not capable of simulating the contrast's behaviour in the lungs since the pulmonary artery is directly connected to the pulmonary vein. Two myocardial chambers, the vena cava, pulmonary artery, pulmonary vein, and the aorta are in the imaging plane where the proximal part of the aorta is used for the AIF. The phantom is unable to simulate the diffusion of contrast into heart tissue or the interstitial space, as admitted by the authors and confirmed by Otton et al. (2013); O'Doherty et al. (2017). Furthermore, Chiribiri et al. (2013) mentioned that the blood flow resistance is lower than in patients due to its complexity.

Otton et al. (2013) used the same phantom to compare CT against MRI. Their findings are similar; the contrast curves represent those obtained from clinical trials. Since the phantom can be used in a clinical MR scanner, the gap between phantom and clinical studies is decreased. In addition to the previous authors, O'Doherty et al. (2017) used a water-filled torso phantom to ensure more anatomically correct image in PET-MR. However, it is still unable to mimic respiratory or cardiac motion.

2.1.2 Computed Tomography

Suzuki et al. (2017) designed a straight-forward Computed Tomography phantom that uses a dry-type haemodialyzer where the dialysate space is pressurised with air to prevent the perfusate from leaving the dialysate fibres. The authors varied the dose in order determine the effects on the perfusion indices. They maintained a constant volumetric flow, Q, and concluded that the perfusion indices are susceptible to dose conditions. Furthermore, the straight forward phantom does not resemble the human brain, which caused problems in certain programs, and that the capillary possessions is much greater than in clinical situations. This may ultimately compromise the reliability of the phantom to mimic clinical situations. Hashimoto et al. (2018) used the same phantom but with a commercially synthetic bone layer such that quantification software recognises the phantom as a human head. Instead of varying the dose, the contrast injection protocol and the scanning interval is varied based on their hypothesis that it would increase the quantitative accuracy. However, they concluded that they are independent factors when using the b-SVD algorithm. The phantom, that both papers uses, does not simulate contrast uptake by the heart tissue.

2.1.3 Positron Emission Tomography / Single-Photon Emission Computed Tomography

2.2 SPECT technology

The imaging method in a typical SPECT scanner are scintillator-based gamma cameras, also known as Anger cameras. Gamma cameras use a scintillator to "transduce" gamma radiation, originating from an injected tracer, to photons. Part of these photons are directed towards a photocathode. If a quantum of light hits the photocathode, which is coated with a photosensitive coating, electrons are emitted due to the photoelectric effect. These electrons travel throught Photomultiplier tubes (PMTs) and hitting series of dynodes, which in turn trigger secondary emission effectively multiplying the number of electrons travelling through the tube. Electrons hitting the last dynode, which is known as the anode, cause a current pulse which can be detected by measuring equipment. It is proportional to the amount of gamma ray photons entering the scintillator(GE Healthcare, 2009).

Developments in imaging systems gave rise to the Digital SPECT scanner. In contrast to the analogue Anger cameras, the D-SPECT scanner utilises a direct conversion semiconductor: Cadmium Zinc Telluride (CZT). Wagenaar (2004) used CZT to develop pixelated detector units which can be used for medical imaging. In a recent study, it is shown that a Digital SPECT scanner, using multiple pixelated CZT detectors, showed significant improvements in image sharpness and contrast(Goshen et al., 2018). These detector units do not require PMTs and thus allow for a more compact and flexible design (Erlandsson et al., 2009). The D-SPECT scanner, developed by Spectrum Dynamics[1], offers improvements in sensitivity and energy resolution (Spectrum Dynamics, 2016) over Anger camera systems. However, these digital systems are relatively new and require proper validation to convince medical personnel of its value.

2.3 Comparison to physiology

[1]https://www.spectrum-dynamics.com/

3 Research methodology

[todo] Define research questions

- Discuss main research question
- Define research boundaries

[done] Define project goals

Many variations in myocardial perfusion work flow, but also the hard- and software involved, can (significantly) influence the outcome and in turn have consequences for patient treatment. These variations need to be validated against a known baseline such that the effects can be mapped to the outcome.

3.1 Project goal

The goal of the project is to develop a prototype myocardial phantom capable of repeated simulations in typical and cardiac defect situations using clinical software commonly used in myocardial perfusion scans. Most software packages require anatomical recognition points which imposes anatomical requirements on the phantom. In addition, the phantom can be used for educational and training purposes to demonstrate the impact of (poorly) chosen variables, e.g. pressure or flow, scanning parameters, cardiac defects, and so forth.

3.1.1 General concept

A general concept is shown in figure 3.1. Three main parts can be identified: flow set-up, phantom, and imaging device. The flow set-up consists of everything to produce and maintain pressures and/or flows and measure these variables. The user-interface is a computer or laptop. The phantom consist of everything needed to mimic cardiac defects and to provide a representative image for myocardial perfusion image processing software. The imaging set-up consists of the imaging device itself along with any contrast agents needed to properly image the phantom. Many imaging devices communicate with a dedicated workstation on which the image processing software runs.

3.2 Additional resources

During the individual project of Gijs de Vries, a prototype flow set-up, control module, and calibration set-up has been realised and can be used / re-cycled.

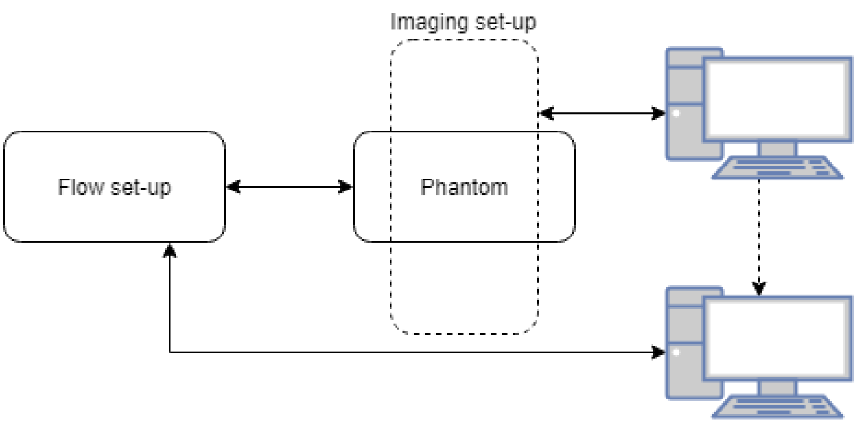

Figure 3.1: General concept, schematic

3.2.1 Flow set-up

The flow set-up uses simple, low costs pumps and available flow sensors. These might not be suitable for high precision flow systems. It is encouraged to look into alternatives.

3.2.2 Control module

The control module requires improvement when it is to be re-used. Two of the main improvements consist of improving the electro(magnetic) shielding to decrease the susceptibility to noise and to optimise the pump controllers.

3.2.3 Calibration set-up

The calibration set-up has been shown that it can be used to calibrate flow sensors. Pressure sensors have not been implemented. To increase the precision of the sensors, that are used in the flow set-up or, if decided upon, in a newly developed flow-set-up, the calibration set-up must be made more reliable. It relies too much on human interaction.

4 Planning

[done] Create graphical planning

[done] Create workday overview

[done] Create week overview

[done] Define deadlines

[inpr] Define meetings: frequency, type, and already planned

This chapter details the planning for the 40ECTS final thesis, carried out under the Robotics and Mechatronics Chair of the University of Twente. The project will be caried out in two phases; proof-of-concept (phase 1) and definitive (phase 2). The Gantt planning for phase 1 and 2 can be found in appendix B in figures B.1 and B.2 respectively.

4.1 Workdays

The planning is based on 28 hours per European Credit as per Dutch standard. The final thesis is carried out full-time (40 hours per week). The overview of working hours is shown in table 4.1.

Day	Start time	End time	Productive hours
Monday	08^{30}	16^{00}	7
Tuesday	08^{30}	17^{00}	8
Wednesday	08^{30}	16^{00}	7
Thursday	08^{30}	17^{00}	8
Friday	08^{30}	17^{00}	8
Miscellaneous*			2
Total:			40

** Miscellaneous hours are in evenings, weekends or during train rides.*

Table 4.1: Workdays and -hours

4.2 Work weeks

[done] Discuss work days between christmas and new-year

[done] Discuss work days on holidays

The works weeks can be found in table A.1 in appendix A.

The project planning spans 35 weeks. Activities are planned from week 49 of 2018 up until, and including, week 28 of 2019 which spans a total of 32 weeks. Week 29 will be used to finalise practical aspects; handing in material and documentation, report printing, and so forth. The graduation presentation (and ceremony) will additionally take place in week 29. Weeks 30 and 31 of 2019 can serve as an extension if, and only if, approved by the assessment- and exam committee.

The planning takes into account one week around Christmas and new-years, one week spring break ("voorjaarsvakantie") in 2019, and a two week buffer. See section 4.3 for more details.

4.3 off-days

The University of Twente recognises three general holidays, New Year's day, King's Birthday and Liberation day, and six Christian holidays, Good Friday, Easter Monday, Ascension day, Whit Monday, Christmas day, and Boxing day[1]. Furthermore, the university recognises five bridging days in 2018 and fout bridging days in 2019 [2].

Both the King's Birthday as well as Liberation day fall in weekends. The remainder of the holidays and bridging days are summarised in table 4.2.

Holiday	Date	Note
Bridging day	2018 December 24	*Collective closure*[2]
Christmas day	2018 December 25	*Christian holiday*[1]
Boxing day	2018 December 26	*Christian holiday*[1]
Bridging day	2018 December 27	*Collective closure*[2]
Bridging day	2018 December 28	*Collective closure*[2]
Bridging day	2018 December 31	*Collective closure*[2]
New Year's day	2019 January 1	General holidays[1]
Good Friday	2019 April 19	*Christian holiday*[1]
Easter Monday	2019 April 22	*Christian holiday*[1]
Ascension Day	2019 May 30	*Christian holiday*[1]
Bridging day	2019 May 31	*Collective closure*[2]
Whit Monday	2019 June 10	*Christian holiday*[1]

Table 4.2: Off-days

Week 4 of 2019 is a planned vacation and no work will be done. This off-week spans from Monday 21^{st} of January 2019 until, and including, Friday 25^{th} of January 2019.

[todo] Update time of lectures

Currently, three lectures are planned which will result in an absent from the workplace in order to follow these lectures. These lectures are summarised in table 4.3.

What	Day	Date	When	Where
CT lecture	Thursday	2018 December 20	13^{45} - 17^{30}	Waaijer 2
PET lecture	Thursday	2019 January 10	10^{45} - 12^{30}	HR C101
PET/SPECT Radiology	Monday	2019 January 14	08^{45} - 12^{30}	NH207

** Times will be updated when known*

Table 4.3: Planned lectures

1 https://www.utwente.nl/en/ces/planning-schedules/academic-calendar/holidays-closing-days/

2 https://www.utwente.nl/en/hr/terms-of-employment/scope-of-employment/public-holidays-leave-days/#compulsory-leave-days

4.4 Deadlines

The deadlines for phase 1 are shown in table 4.4 and those for phase 2 are shown in table 4.5.

What	R	Day	Date	Note
Project plan	0.1	Friday	2018 December 20	Before 2018 December 10
	0.2	Tuesday	2018 December 18	Before 2018 December 19
	1.0	Friday	2018 December 21	Before Christmas
System	0.1	Friday	2019 January 11	
Requirements	0.2	Friday	2019 February 1	
	1.0	Friday	2019 February 8	
Design	concept	Friday	2019 March 1	
	choice	Monday	2019 March 4	
	final	Friday	2019 March 15	Parallel development
Realisation		Friday	2019 March 29	Including testing

Deadlines subject to change depending on weekly meetings

Table 4.4: Deadlines phase 1

What	R	Day	Date	Note
Project plan	1.1	Friday	2019 April 5	
	2.0	Friday	2019 April 12	
System	1.1	Friday	2019 April 26	
Requirements	2.0	Friday	2019 May 3	
Design	concept	Friday	2019 May 24	
	choice	Monday	2019 May 27	
	final	Friday	2019 June 7	
Realisation		Friday	2019 July 12	Including testing
Final report	0.1	Friday	2019 June 14	
	0.2	Friday	2019 June 28	
	1.0	Friday	2019 July 12	

Deadlines subject to change depending on weekly meetings

Table 4.5: Deadlines phase 2

4.5 Meetings

- Plan weekly progress meetings

Two types of progress meetings will be regularly planned. Weekly progress meetings between Marije Kamphuis and Gijs de Vries, and progress meetings every four to six weeks where Kees Slump joins. The weekly progress meetings will, unless otherwise discussed, take place on ....

What	Day	When	Participants
Progress meeting	Monday	2018 December 10 14^{00}	Gijs de Vries, Marije Kamphuis, Kees Slump
Progress meeting	Wednesday	2018 December 19 15^{30}	Gijs de Vries, Marije Kamphuis, Kees Slump
Orientation intro ZGT	Wednesday	2018 January 2*	Gijs de Vries, Marije Kamphuis
To be filled			

** will be planned on this day.*
Will be updated when new meetings are planned. Does not relate to weekly recurring meetings

Table 4.6: Planned meetings

A Appendix: Work weeks

Week	Monday	Working	Note
49	2018 December 3	Yes	
50	2018 December 10	Yes	
51	2018 December 17	Yes	
52	2018 December 24	Partly	*See off-days*
1	2018 December 31	Mostly	*See off-days*
2	2019 January 7	Mostly	*CT college*
3	2019 January 14	Mostly	*PET college*
4	2019 January 21	No	*Vacation*
5	2019 January 28	Yes	
6	2019 February 4	Yes	
7	2019 February 11	Yes	
8	2019 February 18	Yes	
9	2019 February 25	Yes	
10	2019 March 4	Yes	
11	2019 March 11	Yes	
12	2019 March 18	Yes	
13	2019 March 25	Yes	
14	2019 April 1	Yes	
15	2019 April 8	Yes	
16	2019 April 15	Mostly	*See off-days*
17	2019 April 22	Mostly	*See off-days*
18	2019 April 29	Yes	
19	2019 May 6	Yes	
20	2019 May 13	Yes	
21	2019 May 20	Yes	
22	2019 May 27	Mostly	*See off-days*
23	2019 June 3	Yes	
24	2019 June 10	Mostly	*See off-days*
25	2019 June 17	Yes	
26	2019 June 24	Yes	
27	2019 July 1	Yes	
28	2019 July 8	Yes	
29	2019 July 15	Yes	
30	2019 July 22	No	*Extension when needed*
31	2019 July 29	No	*Extension when needed*

Table A.1: Work weeks

B Appendix: Gantt planning

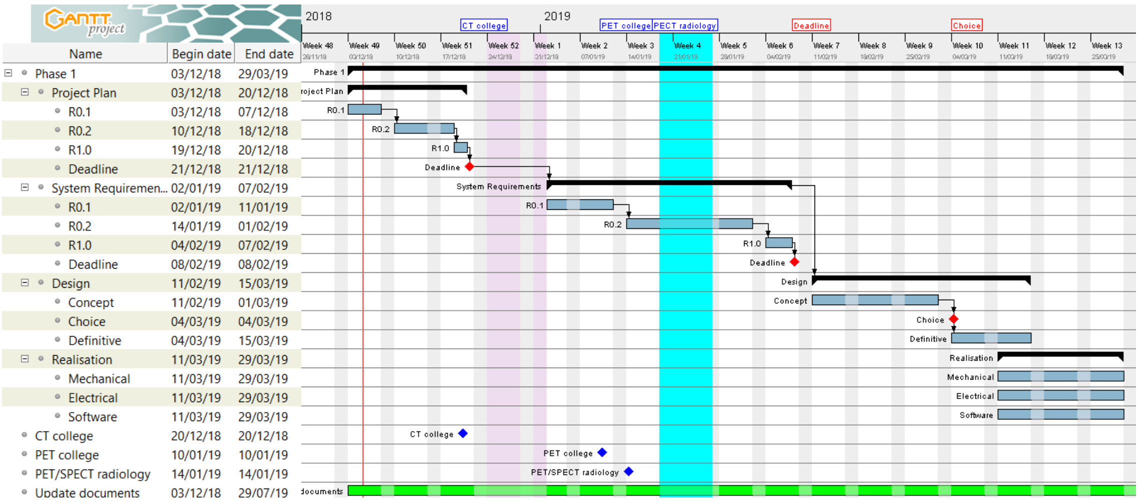

Figure B.1: Phase 1 project planning

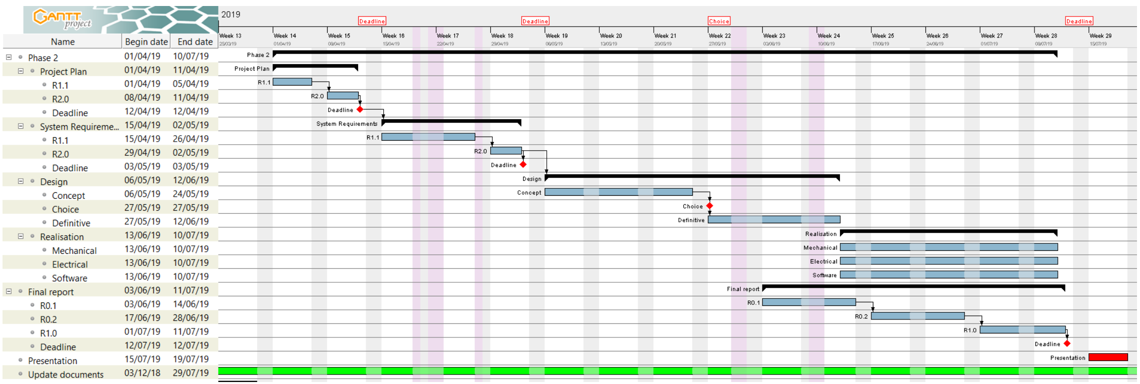

Figure B.2: Phase 2 project planning

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