Literature Review Overview

1. **Intuitive Control of a Planar Bipedal Walking Robot (1998) – Not useful**

Not particularly useful since the context is too far removed from that of the MyPAM. Also, very old. Contains a couple of useful descriptions and definitions:

“An intuitive controller is one which is based on human intuition of the system and an idea of what is going on” – Not actually based in maths but instead based on an intuitive understanding of a system (a bit like fuzzy logic).

**“**A PD (Proportional-Derivative) controller is often described as a controller which pushes in the direction of the error and pushes back with increasing velocity to take some energy out and prevent the system from going too fast. Add the I (Integral) term and the controller keeps pushing harder and harder in the direction of the error until it finally goes away.”

Update 12/10/2018 – not at all useful. Only 1 useful part (but common knowledge, not citable):

Justifies my maths, essentially:

1. **Elastic Bands: Connecting Path Planning and Control (1993) – Not useful**

Not useful. Proposes a strategy to allow the integration of local obstacle avoidance (by sensor feedback control) with global path planning for mobile robotics. There are no local obstacles for the MyPAM.

1. **The Pendubot: A Mechatronic System for Control Research and Education – Not Useful**

This paper describes the control strategy for an underactuated vertical pendulum. This paper is of little use since it describes the balancing control algorithm, which is not relevant to my application.

1. **On the identification of Inertial Parameters of Robots – Mildly Useful**

This paper presents an algorithm for the identification of the inertial parameters and friction coefficients of robots. The algorithm is computationally simple, particularly it does not require to measure or to calculate the joint accelerations. Potentially useful, I may have to read this paper again when evaluating my dynamic model. It is a bit similar to Studywolf’s stuff.

1. **Modelling, Identification and Control of a Redundant Planar 2-DOF Parallel Manipulator – Not Useful**

It looks to contain some useful details and is worthy of further detailed work.

Parallel Manipulators are more complicated, however, so it is not likely that there will be any useful control strategy.

Update 12/10/2018 – Not useful

1. **Dynamics and control of a planar 3-DOF parallel manipulator with actuation redundancy – Not Useful**

Actually looks very useful for peripheral knowledge. Describes in good detail Jacobean Matrix implementation for inverse kinematics. Not a relevant control strategy for a 2DOF arm, especially one that is not over actuated.

Update 12/10/2018 – Not relevant to MyPAM, and a confusing description of the Jacobian procedure. The control scheme is well documented, but it is not relevant to the MyPAM (or indeed any rehab robotics) because it describes a non-compliant system (indeed, compliance here is the enemy).

1. **PERFORMANCE EVALUATION OF TWO-DEGREE-OFFREEDOM PLANAR PARALLEL ROBOTS – Not Useful**

Very much not useful or relevant. No control theories at all. A completely different system with different system dynamics to MyPAM.

Updated 12/10/2018 – still not useful.

1. **Extending the capabilities of robotic manipulators using trajectory optimization – mildly useful/potentially useful**

Mainly about trajectory optimisation (essentially, a robot (and also people) can carry heavier shit longer if it uses a trajectory close it its body rather than at arms length).

Contains some very useful references that describe and explain trajectory planning for robotic manipulators. I also came across Pontryagin’s maximum principle.

The entire paper is actually very useful and deserves a more detailed review/ source review.

Update 12/10/2018 – good place to cite the equation found on StudyWolf:

Further to this, a dynamic example (with gravity) is explored.

Relatively useful document, even though I am not concerned about trajectory generation or optimisation especially since there is no evidence that trajectory is an important parameter for plasticity according to [11].

1. **Motion analysis of manipulators with uncertainty in kinematic parameters – Not useful**

~~Relatively useful document, deserving of further reading~~.

Update 12/10/2018 – not actually at all useful. The paper describes how to account for uncertainty in the end effector location due to uncertainty in kinematic parameters such as gearbox lash back etc. This is not at all relevant to MyPAM, where some uncertainty is acceptable (we are not CNC machining!). Also, massively over complicated.

1. **A Paradigm shift for rehabilitation robotics – Mildly Useful**

This provides some good background into rehabilitation robotics, without providing any detail on control strategies. Potentially a good citable paper for introduction, if a bit dated (2008)

1. **Review of Control Strategies for Robotic Movement Training after Neurological Injury - potentially useful**

A very useful overview indeed. Gives a good review of high-level control strategies. Provides advice on continuing research in the last few pages.

Update 23/10/2018

“*Assistive controllers help patients to move their weakened limbs in desired patterns*”.

Defines Slacking.

Impedance based: position is measured, corrective force is produced which is proportional to deviation from the required trajectory. “*the controller forces output increases proportionally, because the controller acts as a damped spring*”.

A common addition to impedance-based control is triggered assistance.

Does not discuss Admittance control.

1. **Rehabilitation Robotics: Performance-Based Progressive Robot-Assisted Therapy. - potentially useful**

21/10/2018

Using EMG, speed or time to initiate assistance. States that the key variables for motor control are position, velocity and interaction forces (MyPAM is missing the interaction forces measurement, making control difficult). The report states that for optimal recovery, rehab needs to be tailored to the patient.

MIT-MANUS is an impedance-controlled device. This paper describes an impedance strategy that doesn’t restrict the patient from moving past the current optimum point (ie, it doesn’t punish advanced patients).

Also, a strategy is implemented whereby the game doesn’t start until a velocity threshold is exceeded.

Ability to move and ability to aim metrics are defined and used.

Reference:

Marchal-Crespo, L. and Reinkensmeyer, D.J. 2009. Review of control strategies for robotic movement training after neurologic injury. *Journal of Neuroengineering and Rehabilitation*, *6*(1), p.20.

1. **A Survey on robotic devices for upper limb rehabilitation - potentially useful**

This is an absolute goldmine. It lists devices, as well as the control strategies alongside good citations. Further to this, it contains a glossary of useful terms. I have fully harvested this for sources.

Update 23/10/2018

*“performance-based adaptive control strategies monitor the performance of the patient and adapt some aspects of the assistance (e.g. force, stiffness, time, path) according to the current performance of the patient, as well as performance during particular number of preceding task repetitions.”*

*“In the impedance control approach the motion of the limb is measured and the robot provides the corresponding force feedback, whereas in the admittance control approach the*

*force exerted by the user is measured, and the device generates the corresponding displacement. The advantages and disadvantages of the impedance and admittance*

*control systems are complementary.”*

Reference:

Maciejasz, P., Eschweiler, J., Gerlach-Hahn, K., Jansen-Troy, A. and Leonhardt, S. 2014. A survey on robotic devices for upper limb rehabilitation. *Journal of Neuroengineering and Rehabilitation*, 11(1), p.3.

1. **Rehabilitation Robotics: pilot trial of a spatial extension for MIT-manus -potentially useful**

A description of an extension which exploits the modularity of the MIT-Manus robot. Common features of all the MIT-Manus range:

* Compliant Operation
* Impendence Control.

*Impedance control refers to using a control system (actuators, sensors and computer) to*

*impose a desired behavior at a specified port of interaction with a robot, in this case the attachment of the robot to the patient's hand*.

*For robots interacting with the human, the most important feature of the controller is that its stability is extremely robust to the uncertainties due to physical contact. The stability of most robot controllers is vulnerable when contacting objects with unknown dynamics. In contrast, dynamic interaction with highly variable and poorly characterized objects (to wit, neurologically impaired patients) will not de-stabilize the impedance controller above.* **Links to [24]**

Reviewed 23/10/2018. No further comments

1. **Potential of a suite of robot/computer-assisted motivating systems for personalised, home-based, stroke rehabilitation - One useful citeable part**

Not relevant, not applicable to MyPAM, old and contains no control.

Reviewed 23/10/2018

“*There is a need to improve the cost-to-benefit ratio of robot-assisted therapy strategies and their effectiveness for stroke therapy in home environments characterized by*

*the low supervision by clinical experts, low extrinsic motivation as well as low cost requirement*” – The only useful take away, but actually usefully citeable.

1. **Robot-assisted reaching exercise promotes arm movement recovery in chronic hemiparetic stroke: a randomized controlled pilot study – Not useful**

23/10/2018 – Not useful. Describes a study rather than a device or control strategy

1. **Rehabilitation Robotics Book 2007**

(https://www.intechopen.com/books/rehabilitation\_robotics)

1. **Rehabilitation Robotics Book 2018**

(https://www.sciencedirect.com/book/9780128119952/rehabilitation-robotics)

1. **Robot-Assisted therapy in Stroke Rehabilitation - Mildly Useful**

~~Another very useful overview into the effectiveness of rehabilitation robotics. It contains a list of comparisons of the effectiveness of various devices. Key takeaways: a useful list of robots and citations.~~

Reviewed 23/10/2018

InMOTION is the commercial variant of the MIT-MANUS

This is not particularly useful, no description of robots or control strategies. It does show evidence that robotic rehab is somewhat useful.

1. **A Control Strategy for Upper Limb Robotic Rehabilitation with a Dual Robot System - potentially VERY useful**

23/10/2018

iPAM. This paper describes the cooperative controls scheme for simultaneous control of both robots.

Contains very useful mathematic definitions for both impedance and admittance control:

Contains a control block diagram, and goes on to state why an admittance control scheme was the preferred method.

Very good description of the control scheme. Excellent.

1. **Haptic Device System for Upper Limb Motor and Cognitive Function Rehabilitation: Grip Movement Comparison between Normal Subjects and Stroke Patients.**

Placeholder

1. **A Rehabilitation Robot With Force-Position Hybrid Fuzzy Controller: Hybrid Fuzzy Control of Rehabilitation Robot**

Placeholder

1. **Robot-Aided Neurorehabilitation**

Describes the MIT-MANUS Device:

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| Figure 23.1: MIT-MANUS |

MIT-MANUS uses impedance control to ensure gentle, compliant behaviour. The

2-dof consists of a direct-drive five bar-linkage SCARA (selective compliance assembly

robot arm) mechanism.

The low-level control implementation is described in good detail and uses a mixture of both kinematic and kinetic feedback.

1. **Impedance Control: an approach to manipulation - potentially VERY useful, more in depth analysis required.**

Reviewed 23/10/2018

Control of a vector quantity such as Force or position is not sufficient for mechanically coupled manipulator systems, since it is not possible to control the interaction forces between the manipulator and its environment by these alone.. Control of the manipulator impedance is also necessary.

Need to look at in great detail.

1. **A robotic workstation for stroke rehabilitation of the upper extremity using FES**

Placeholder

1. **Robotic Assistance of an Active Upper Limb Exercise in Neurologically Impaired Patients**

Placeholder

1. **Upper Limb Robot-Assisted Therapy in Chronic and Subacute Stroke Patients**

Describes a methodology for assessing the effectiveness of the InMotion 2.0, which is a device similar to the myPAM.

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| Figure 27.1: Testing methodology for effectiveness of InMotion 2.0 |

There is no description of the control algorithm for the device beyond stating that it is ‘Assist as needed’.

1. **Recent Development of Mechanisms and Control Strategies For Robot Assisted Lower Limb Rehabilitation**

Placeholder

1. **A new haptic workstation for neuromotor rehabilitation**

Placeholder

1. **ACT3D exercise targets gravity-induced discoordination and improves reaching work area in individuals with stroke**

Placeholder

1. **Development of Isokinetic and Iso-contractile Exercise Machine "MEM-MRB" Using MR Brake**

Placeholder

1. **“Hybrid-PLEMO” Rehabilitation System for upper limbs with Active/Passive feedback force**

Placeholder

1. **Quasi-3-DOF Rehabilitation System for Upper Limbs: Its Force-Feedback Mechanism and Software for Rehabilitation**

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1. **Design of a forearm rehabilitation robot**

This article discusses the design of a forearm rehabilitation robot which both passively and actively exercises a forearm through both pronation and supination.

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| Figure 34.1: forearm rehab robot |

2 fuzzy logic controllers were used. One for passive mode and one for active mode.

There is very good detail about the controller design in the article.

1. **Unified Impedance and Admittance Control**

Placeholder

1. **Understanding and treating arm movement impairment after chronic brain injury: Progress with the ARM Guide**

Placeholder

1. **Effects of Robot-Aided Bilateral Force-Induced Isokinetic Arm Training Combined With Conventional Rehabilitation on Arm Motor Function in Patients With Chronic Stroke**

Placeholder

1. **Design, Implementation and Clinical Tests of a Wire-Based Robot for Neurorehabilitation**

Placeholder

1. **Design and control of two planar cable-driven robots for upper-limb neurorehabilitation**

Placeholder

1. **Robot-aided neurorehabilitation of the upper extremities**

Placeholder

1. **Smart portable rehabilitation devices**

Not useful. Describes 2 lower limb devices, and a passive upper limb device.

1. **A haptic-robotic platform for upper-limb reaching stroke therapy: Preliminary design and evaluation results**

Placeholder

1. **Robotic Devices for Movement Therapy After Stroke: Current Status and Challenges to Clinical Acceptance**

Too old. No technical details. Not useful.

1. **Modelling and Evaluation of Human Motor Skills in a Virtual Tennis Task**

Placeholder

1. **A Novel Robot Neurorehabilitation for Upper Limb Motion**

This paper describes a robot very similar in composition to the myPAM.

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| Figure 45.1: similar to myPAM |

There is a small amount of useful maths in here, but unfortunately the control algorithm is not described.

1. **Universal haptic drive: A robot for arm and wrist rehabilitation**

Placeholder

1. **Assistive Control System Using Continuous Myoelectric Signal in Robot-Aided Arm Training for Patients After Stroke**

This paper describes a robot very similar in composition to the myPAM (but with only 1 DoF), with EMG sensors as additional control inputs.

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| Figure 47.1: similar to myPAM, but with additional sensors. |

The device uses measured torque, EMG signals and measured position as control inputs.

1. **Design of a Mobile, Inexpensive Device for Upper Extremity Rehabilitation at Home**

Using SEAs (series elastic actuators) for a MARIONET robot. The mechanics is described in detail, but the control strategy is not.

1. **A Simple Robotic System for Neurorehabilitation**

Describes the MEMOS system, a planar robot with a cartesian configuration:

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| Figure 49.1: MEMOS |

Usefully, the low-level control algorithm is provided. User applied X and Y forces are combined with position measurements. The control algorithm is as follows:

Where the first term is essentially Hooke’s Law (patient input) and the second term is essentially the motor input (where delta relates to assistance parameters).

Overall, fairly a useful document. Rather simplistic system.

MAXON Motors used.

1. **Design of a new 5 d.o.f. wire-based robot for rehabilitation**

Placeholder

1. **Design and implementation of an assistive controller for robotic rehabilitation systems.**

Placeholder

1. **Development and Implementation of an End-Effector Upper Limb Rehabilitation Robot for Hemiplegic Patients with Line and Circle Tracking**

This is a brilliant paper, and is the absolute gold standard of what I was looking for. It describes in good detail both the kinematic and kinetic models, as well as the low level control strategies implemented. It is also relatively recent (2017).

1. Placeholder
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5. **State of the Nation, Stroke Statistics February 2018 - VERY useful and cited**

Contains useful statistics about strokes in the UK. Useful for the literature review to show why robotic rehabilitation is increasingly necessary.

Reviewed 23/10/2018

Reference:

Stroke Association. 2018. *State of the Nation. Stroke Statistics February 2018*. [Online]. London: Stroke Association. [Accessed 13 November 2018]. Available from: <https://www.stroke.org.uk/system/files/sotn_2018.pdf>

1. **Spasticity after stroke. Its occurrence and association with motor impairments and activity limitations**. - **somewhat useful and cited**

Contains some useful statistics regarding motor impairment after stroke.

Reviewed 23/10/2018

Reference:

Sommerfeld, D.K., Eek, E.U.B., Svensson, A.K., Holmqvist, L.W. and von Arbin, M.H. 2004. Spasticity after stroke: its occurrence and association with motor impairments and activity limitations. *Stroke*, 35(1), pp.134-139.

1. Placeholder
2. Placeholder
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5. **Neurological Principles and Rehabilitation of Action Disorders: Rehabilitation interventions.**

Placeholder

Reference:

Pomeroy, V., Aglioti, S.M., Mark, V.W., McFarland, D., Stinear, C., Wolf, S.L., Corbetta, M. and Fitzpatrick, S.M., 2011. Neurological principles and rehabilitation of action disorders: rehabilitation interventions. *Neurorehabilitation and neural repair*, *25*(5\_suppl), pp.33S-43S.

1. **Principles of Experience Dependent Neural Plasticity, Implications for Rehabilitation After Brain Damage**

Placeholder

Reference:

Kleim, J.A. and Jones, T.A., 2008. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. *Journal of speech, language, and hearing research*, *51*(1), pp.S225-S239.

1. **The Science of Stroke: Mechanisms in search of Treatments**

Some minor detail about brain repair after stroke. I have cited this for stroke mechanisms (Haemorrhagic Stroke and Ischaemic Stroke). This article goes into much more detail than I need to understand.

Reference:

Moskowitz, M.A., Lo, E.H. and Iadecola, C., 2010. The science of stroke: mechanisms in search of treatments. *Neuron*, *67*(2), pp.181-198.

1. The Impact of Physical Therapy on functional outcomes after stroke: what’s the evidence?

Placeholder

Reference

Van Peppen, R.P., Kwakkel, G., Wood-Dauphinee, S., Hendriks, H.J., Van der Wees, P.J. and Dekker, J., 2004. The impact of physical therapy on functional outcomes after stroke: what's the evidence?. *Clinical rehabilitation*, *18*(8), pp.833-862.