Augmented Gravity

Using rope based robots to solve gravitys challenges to physical training

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***Abstract*—In some situations, gravity pose a challenge to people that want to perform physical exercises like simple strength training. This is the case for astronauts during space missions, where the absence of gravity can lead to muscle-atrophy. It is also the case for patients with partial paralysis, that are unable to stand, walk or even move their limbs, because the force exerted by gravity is higher than their redused muscular capability. In a number of research projects, University of Southern Denmark (SDU) have shown that rope-based training robots can be used to either create artificial gravity during strength training exercises, or to reduce gravity during rehabilitative training exercises.**

I. Introduction

Rope based training robots or advanced training machines like University of Southern Denmark (SDU)'s RoboTrainer-Light[1] have the ability to control length, velocity and force of the rope, wire or band that connect the robot to a human user. As shown in[1], this is based on controlling the motor of the robot based on input from multiple sensors, such as load-cells or strain-gauges for force measurement and angular position sensors for position and possibly velocity measurements. Using just input from a force sensor, constant force pull can be achieved. Using a multiple input control system to map the sensor measurements and derived values to control the motor energy supply, various combinations of force, velocity and position control can be realized to closer mimic the natural combination of constant force from gravity, combined with e.g. inertia and friction. Previous research have shown how this can be used to help people with partial paralysis to overcome gravity when training individual limbs, and recently we have demonstrated how the same technology can be used to change the experience of gravity for the entire body.

II. Equipment

The equipment used for the research is based on the same RoboTrainer-Light machines (RTL) presented in [1]. See figure 1. In order to support more weight, the RTL is equipped with a low friction pulley system (figure 2), that can multiply the force with a factor of 2-7 times, depending on configuration.

The torque measured by the rotary load-cell shown in figure 1-b is proportional to the rope force by: $F = \tau \cdot r$, where τ is the tourqe, and r is the radius of the roller winding the rope. And hence, the torqe sensor is used in a feedback control loop, to keep the rope-force constant and independent of rope length. The user in the harness experience an equal reduction in reaction force from the floor. As the update interval of the RTL controller is much shorter than human reaction time, the user in the harness experience an apparent weight reduction — or reduced gravity.

A. RoboTrainer-Lift

In order to safely experiment with the technology, a prototype **RoboTrainer-Lift** was created from a commercial-off-the-shelf (COTS) lift unit intended for lifting patients in hospitals. Several modifications and additions were added to allow the necessary feedback, resulting in the principle shown in figure **??**. The lift units original electrical system was replaced by the RTL control unit, which was reprogrammed to work with the specific motor and linear load-cells rather than the brush-less DC motor and rotary load-cell (torque sensor) of the original RTL. The modified lift unit is easy to use with the accompanying overhead track system, that allow relatively free floor movement, as well as using the system to assist in full body functional exercises, such as transitions between lying, sitting and standing, walking on the floor, walking on stairs etc.

B. RoboTrainer-Gravity

In order to create artificial gravity, that can — in time — be used by astronauts during space travel, we have connected 2 original RTL units to individual Raspberry-Pi microcomputers. Each Raspberry Pi have been configured as a node for the Robot Operation System (ROS), and connected to a local area network. This configuration allow us to control the two RTL units virtually synchronously, from a central PC, that form the system user interface. Using long extension ropes, we can place the RTL's on either side of a swimming pool, and pass the ropes through pulleys mounted on the bottom, allowing the RTL's to pull downward on a full body harness. This setup allow us to experiment with mimicking gravity for a test person that would otherwise experience virtual weightlessness from the waters buoyancy.

III. Results

Using a combination of RoboTrainer-Light and RoboTrainer-Lift, we have developed a set of training algorithms, that support exercises for stroke patients with partial paralysis. The method has successfully been tested in a single case study, where a 45 year old stroke victim that had already been through 2 years of treatment and rehab training, experienced a vastly accelerated increase in strength and mobility during 20 weeks of robot-training.

Using the RoboTrainer-Gravity setup, we have shown that our concept for artificial gravity can support a wide range of strength exercises in a weightless environment.

IV. Conclusion

Our work with Augmented Gravity is a prime example of how robot technology can be used for unobtrusive bodily interaction and create the illusion of altered gravity. This possibility appear to be usefull for enhancing rehab training, as well as strength training, in situations where gravity is too strong or too weak for the intended training.

V. Future work

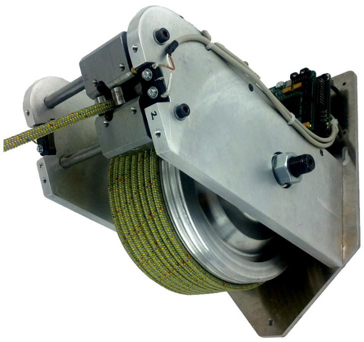
Our work has caught the attention of both academic and commercial entities local and internationally. We are currently discussing partnerships with a number of organizations, that want to participate in developing, producing and marketing equipment based on our Augmented Gravity research.

VI. HRI-2019

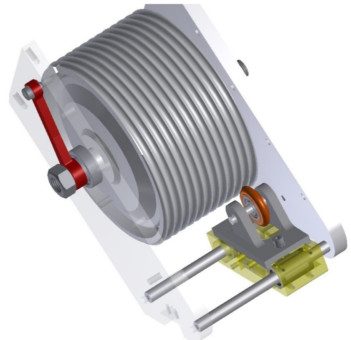
The research behind this abstract will be presented at the **Body Robot interaction** workshop, monday march 11. 2019, at the IEEE HRI-2019 confrence in Dagu, south Korea.

References

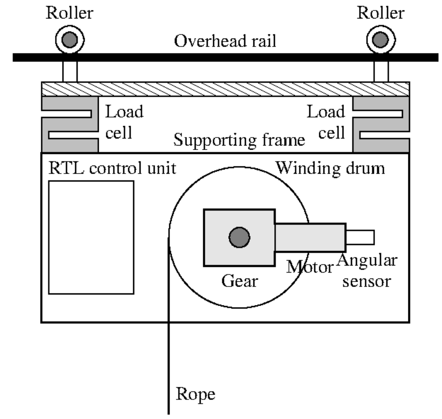
[1] A. Stengaard, J. Nielsen, M. Skriver, C.-C. Lin, U. P. Schultz, *et al.*, "Low-cost modular robotic system for neurological rehabilitative training," in *Industrial Technology (ICIT), 2016 IEEE International Conference on*. IEEE, 2016, pp. 1585–1591.



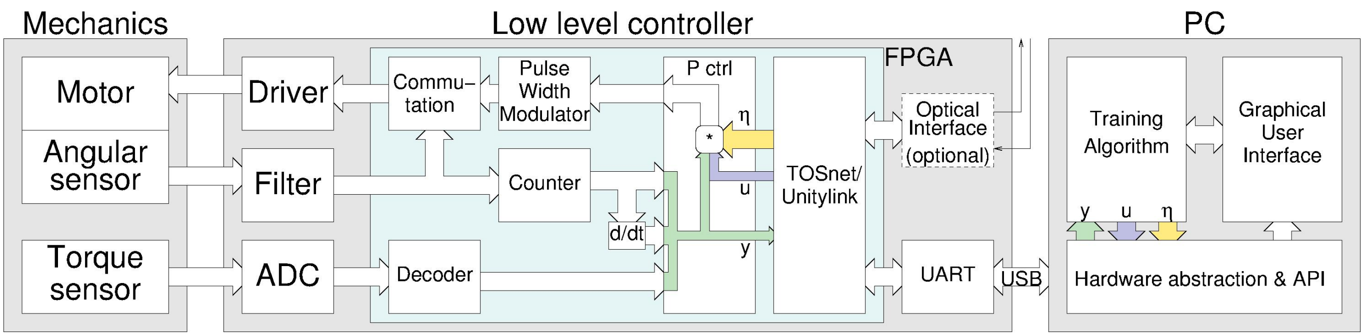
(a) Assembled inner frame



(b) Slide and force sensor

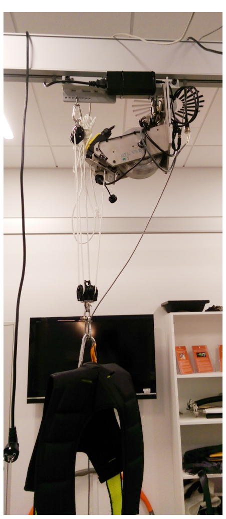


(c) RoboTrainer-Lift



(d) Control system

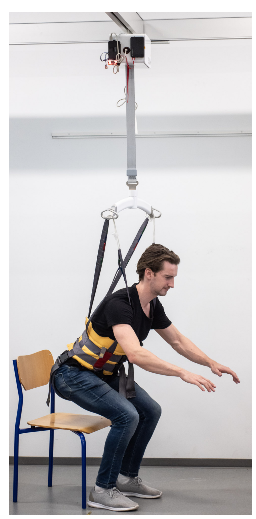
Fig. 1. RoboTrainer-Light and -Lift mechanics and control system



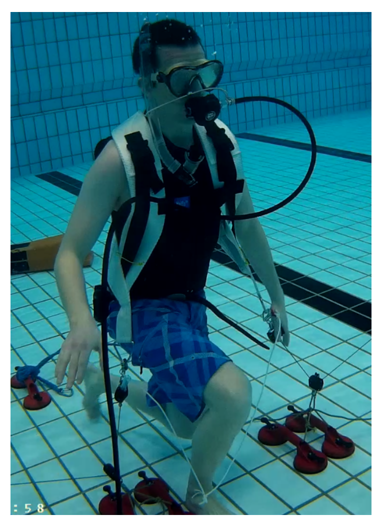
(a) RTL & pulleys

(b) Body harness

Fig. 2. RTL with pulleys and full body harness



(a) RoboTrainer-Lift



(b) RoboTrainer-Gravity

Fig. 3. RoboTrainer-Lift