HANDle: A Novel Tangible Device for Hand Therapy Exergames

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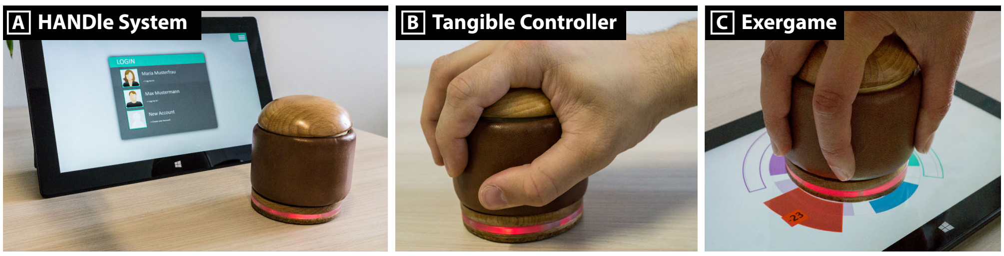

*Figure 1: **HANDle** is a novel tangible for hand therapy that captures squeeze forces as well as its position in space. Our companion Exergame uses the controller to train the finger strength, coordination and wrist agility.*

Abstract

Today's working environments are characterized by and at the same time highly depending on many repetitive hand movements, such as typing or assembling tasks. The physical health of hands is thereby becoming increasingly valuable. Guided by the idea of Tangible User Interfaces (TUIs), we introduce a novel graspable device, called HANDle, that we developed to train wrist agility, finger strength as well as its coordination in a motivational game. Therefore, we iteratively prototyped a fully-functional controller that senses multiple finger forces, its relative position in space and that provides visual and vibro-tactile feedback. In addition, we implemented a therapy game that combines different physiotherapeutic motion and grasp exercises supporting custom-defined levels that match to the patient needs.

1 Introduction

Health research employing current HCI technology and novel interaction techniques to support wellbeing, recovery and maintenance of conditions, has seen significant progress in recent years, especially in the field of Exergame-based approaches for physiotherapy and rehabilitation. The spectrum of therapeutic application ranges from whole-body tracking and interaction for integral mobility, balance and posture training and prevention to very individual technical setups for certain parts of the body or specific diseases. However, such research has mostly been focused on 3D motion tracking using markers or optical sensors like Microsoft Kinect

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(Smeddinck et al., 2015), smartphone sensors (Spina et al., 2013), or close-to-body inertial or EMG sensors (Steffen et al., 2017; Vasconcelos et al., 2018).

We believe that Tangible User Interfaces offer many physical and interaction qualities that would benefit the eHealth community. We see a potential of tangibles in all cases where solid surfaces and graspable shapes provide conducive haptic feedback to better perform therapeutic exercises. Obviously, tangibles seem to be well suited for hand therapy, treating injuries and conditions of wrist and hand, but also forearm, elbow, upper arm and shoulder, in order to gain agility after accidents, stroke, etc. In contrast to other interaction techniques that were introduced in HCI literature for hand therapy, like free-hand interaction using a Leap Motion controller (Afyouni et al., 2017; Khademi et al., 2014), glove-based approaches (Biggar and Yao, 2016; Friedman et al., 2011) or touch on sensitive surfaces (Boulanger et al., 2013), tangibles inherently demand and facilitate the most important and prominent ability of the hand: to grab, hold, move and manipulate objects. Despite the application of commercial gaming controllers like Nintendo's Wiimote (Leder et al., 2008), there is little research on purpose-built graspable devices (tangibles) for serious games for physiotherapy and rehabilitation. In this paper, we introduce a novel tangible input device called HANDle that captures squeeze forces and senses its spatial orientation and position to support various hand therapy applications.

2 Design and Realization of HANDle

Our *HANDle* device is a cylindrical hand-sized controller designed for one-hand use (see Figure 1). The most important objective for us was the development of a playful and motivational tangible-based Exergame for hand therapy that supports different exercises including spatial movement, grasp and coordination tasks. Most related to this approach is the work by Varesano and Vernero, 2012, introducing a spherical tangible input device for a video game for seniors. In comparison, we particularly focused on providing a rich set of sensors and actuators and a configurable, customizable game concept, offering an easy way to define and extend existing exercises and to support different interaction contexts, such as exercises at home, to ensure that our approach fits the needs of a large group of patients and conditions. For that reason, our system had to be portable, robust and easy to setup, and deployable in several device constellations, including the stand-alone use and combinations on and with interactive surfaces like tablets. Last but not least the device should meet the requirements of pleasant haptic qualities including ergonomic and aesthetics aspects.

2.1 Concept: Look, Squeeze & Rotate

Our concept focuses on the individual and playful training of the *wrist agility*, *finger strength*, and its *respective coordination* to purposefully support hand movement rehabilitation and prevention therapies. Therefore, HANDle is able to capture radial as well as orthogonal squeeze forces, senses its relative position in space and additionally provides visual and vibro-tactile feedback capabilities. In addition to the tangible controller, we propose the combination with interactive surfaces (decoupled as shown in Figure 1A or directly placed on the interactive surface as in Figure 1C) to create playful therapy games. Therefore, we introduce:

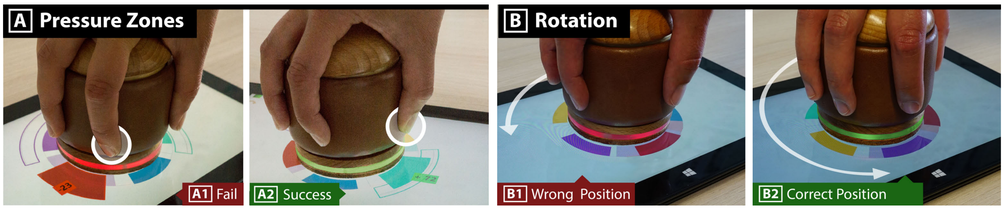

*Figure 2: Our **HANDle concept** builds on the idea of a therapy controller that supports hand movement rehabilitation therapies. Finger strength is trained by pressure zones **(A)**, while rotation tasks **(B)** focus on the wrist agility.*

▶ **The HANDle App** for playfully *Physiotherapeutic Exercises (see Figure 2)*
Our companion application organizes all exercises that are created and assigned from the physiotherapist, stores the current progress and Exergame scores from the user and simultaneously provides visual feedback during the exercises. When a user starts an exercise, a color-coded circle appears on the display. The circle element represents the main game element and the basic position of the tangible. Circular segments around it specify the current relative rotation of the tangible and for each exercise the target orientation and local amount of pressure that the user should apply in a specific time. Therefore, live sensor values from the controller are visualized around the circle. Depending on the respective task definition, wrong or correct pressure or motion sequences get negative (see Figure 2, A1/B1) or positive scores (A2/B2), which is also visualized accordingly in red or green at the controllers color ring.

▶ **Grasp Force Exercises** for *Finger Strength & Coordination (see Figure 2A)*
We introduce grasp exercises in which the user has to squeeze certain regions of the pressure-sensitive tangible. When the user radially squeezes the tangible device, five color-coded circular segments increase proportionally to the applied pressure force at the respective position around the controller. Unfilled circular segments show the target positions of the current exercise that a user has to reach to finish the level. The challenge is to correctly adjust the tangible and locally apply a certain amount of pressure.

▶ **Rotational Movement Exercises** for *Wrist Agility (see Figure 2B)*
In addition, we propose training techniques that address hand agility by rotational movements tasks. To support these kind of exercises, we integrate radial alignment tasks based on our previously introduced circular segments. Therefore, the user has to rotate the controller until its attached circular segments (B1) match the target level segments (B2). These rotational exercises can be combined with the above-mentioned grasp force exercises to train more complex hand sequences such as screw like grasp and rotation movements.

2.2 Realization

Following an iterative design process, we first built a proof-of-concept prototype (see Figure 3A) that integrates all actuators and sensors in a fully-functional unit. Our second prototype (see Figure 3B), technically based on the first one, focuses on the design goals of haptic and mobile qualities[1]. In order to capture grasp force, we used six square-shaped force sensitive resistor (FSR). The FSRs are mounted around (C1) and under the controller to sense orthogonal

[1] For further project details please refer to https://imld.de/handle/.

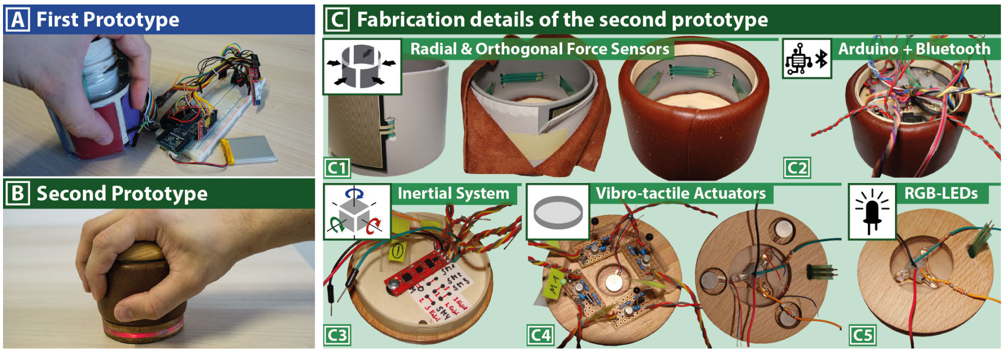

*Figure 3: Our first prototype **(A)** demonstrates the technical feasibility of our tangible concept, while our second iteration **(B)** focuses on ergonomic aspects. The construction details **(C)** shows how the tangible is fabricated.*

as well as radial forces. Finally, we covered all FSRs with foam and leather to create a nice surface. Both prototypes are built on the Arduino® platform (Fio & Mini Pro), powered by a LiPo battery and use the serial port profile over Bluetooth® (C2) for a wireless connectivity. The spatial tracking is realized with tiny 9 degrees of freedom (DoF) sensor that computes the tangible position based on a accelerometer, a magnetometer, and a gyro sensor (C3). In addition, we integrated three vibro-tactile actuators to provide haptic feedback (C4). Finally, we realize a visual feedback with an acrylic glass layer and RGB-LEDs (C5) (see also 3B).

In addition, we implemented our *HANDle App* as described in Section 2.1 using WPF and C# for the Microsoft Surface Pro. One important design goal for us was to build a system offering an easy and application-independent way to define new and extend existing exercises. Therefore, we decided to specify exercise sets and tasks in XML. Exercise definitions include sequences using keyframes, target positions and respective thresholds, scoring details and time limits.

3 Discussion and Conclusion

In this paper, we presented the idea of a novel tangible input device for hand therapy. Following our design goals, we designed a prototype of a graspable controller in combination with an interactive surface running a purpose-built game-based therapy software. We already started to evaluate the qualitative usability and satisfaction aspects of our prototype with a small group of subjects and gained first promising insights. For future work, our HANDle system needs to be examined in additional studies, e. g. by comparing it to current physical therapy solutions. Therefore, we plan to integrate a set of therapy exercises together with physiotherapy experts and integrate them into our HANDle system to run a first pilot study. Furthermore, we would like to extend our existing exercises by 3D spatial movement tasks and built a task editor for physiotherapists. Finally, we also consider a combination with head-mounted Augmented Reality technologies such as the Microsoft HoloLens.

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