SILESIAN UNIVERSITY OF TECHNOLOGY

FACULTY OF AUTOMATIC CONTROL, ELECTRONICS AND COMPUTER SCIENCE


Final Project

# The use of a three-dimensional manipulator-controlled gaming in the treatment of dyspraxia.


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# Contents

# Chapter 1

# Introduction

In the modern world, physicians are able to successfully identify and treat significantly more illnesses and disorders than a century ago. New break-through ideas in genetics and neurology help to diagnose and prevent sicknesses. Development in imaging techniques facilitates great advance in research on functioning of human body and identification of disorders.

Cutting-edge technologies are crucial in the field of rehabilitation and surgery. New artificial limbs are being developed in order to better resemble functions of its biological original. Access to robotic surgical system enables physicians to perform far more precise and difficult surgeries and procedures than ever. Because of the usage of advanced graphical tools and 3D-printers it is possible to create more accurate prostheses for patients who suffered severe body damage.

## 1.1 Haptic devices

Specialized devices are being developed to resemble real-world reaction and be able to precisely identify operators' movements and intentions. The kind that focuses on generating real-time responses is called haptic devices. The most important feature of this type of controller is a tactile feedback produced by it that render the feeling of the texture and shape of objects shown on the screen of the computer.

Haptic devices are widely used in medicine. They serve as controllers for advanced graphical tools in which one can model precise and customised prostheses. Special applications are designed for beginner dentists and other physicians in order to provide opportunity to develop and practice their skills. For example, process of identifying cavity or performing a precise biopsy can be iterated as long as necessary without endangering the patient. This solution brings richer experience to professional training with lower cost and in safe, comfortable conditions. While the physician uses the stylus as a surgical instrument, the device provides realistic tactile feedback, which can resemble tissue softness or skeleton structure. The whole process is visualised as a graphical model by the application.

## 1.2 Dyspraxia

Studies show increasing number of neurodevelopmental disorders being diagnosed among children and adults. One of them is dyspraxia, also known as developmental coordination disorder (DCD), an inability to plan, organise and coordinate movement [7]. Depending on the level of severity, it can be a reason of small difficulties in everyday activities, for example fastening buttons or shoelaces, but may also make one unable to drive a car because of affecting working memory and coordination skills.

There are several various difficulties that occur during treatment of DCD. One of the most significant obstacles is a problem with conducting proper diagnose. Another - existing systems of therapy, not all of them equally effective, but all requiring experts in rehabilitation or psychology and hours of exercises with professionals. These problems will be addressed in chapter 2: Analysis.

DCD is very often observed among children. The most efficient way of treatment for this age group seems to be the "serious game". It allows to develop the necessary coordination or mental skills. Disguising the exercise as a game makes it more entertaining and pleasurable for a child.

## 1.3 Project goal

The main goal of this project is to create a coordination improving serious game, controlled by 3-dimensional haptic device that could be an effective tool in treatment of children with dyspraxia.

## 1.4 Report content

This report consists of the following chapters:

- Analysis - consists of:
  - a detailed description of dyspraxia and its treatment,
  - usage of a haptic device in rehabilitation,
  - significance of selected haptic factors in medical use of the software,
- Design - non-technical description of project requirements and game logic,
- **??** - includes documentation, information about project composition, data structures and selected programming tools,
- **??** - includes user's manual, launching examples and testing of application,
- **??** - sums up the report.

# Chapter 2

# Analysis

Before describing the possible solution for the problem of rehabilitation for children with dyspraxia, an introduction about the disorder itself as well as its treatment methods and difficulties connected with them will be made.

## 2.1 Developmental coordination disorder (dyspraxia)

Developmental Coordination Disorder (DCD), also known as *developmental dyspraxia*, is the inability to plan, organise and coordinate movement [7]. It results in fine and gross motor problems and/or speech difficulties, which can have strong negative impact on daily activities and academic achievements. Dyspraxia was first described by WHO in 1992. It is a hard to diagnose and even harder to cure motor disorder, which is subcategory of neurodevelopmental disorder – along with autism and Down syndrome - and mostly identified among children. It often appears together with neurological illnesses from other subcategories, like ADHD, Asperger syndrome or dyslexia [6]. It is, however, also sporadically detected in completely healthy (except for DCD) children who are developing well intellectually [6]. DCD is not caused by motor or sensory impairments, similar to muscular dystrophy or Parkinson's disease. No correlation to any known neurological condition or intellectual impairment could be found.

## 2.2 Prevalence

DCD's prevalence range from 5% to 15% in the primary school and it is confirmed that about 5% of all children are affected, but not all of them have a severe case of DCD [6]. Children born prematurely [2] and children with extremely low birth weights [9] are at a significantly increased risk of having DCD. According to the majority of researches prevalence ratio is about 4:1 in boys than girls, but it is not confirmed - it differs between 5:1 to even 2:1 depending on study [6]. There are hypotheses that so high and unproven proportion is connected with the fact, that the frequent presence of comorbid conditions (e. g. ADHD) can make DCD easier to identify among boys. Also, girls do not have so strict social requirements regarding motor skills – therefore being clumsy may not be perceived as a disorder. Moreover, the majority of the children do not "grow out of" this disorder and it persists into adulthood.

## 2.3 Symptoms

There are numerous signs and symptoms of developmental dyspraxia as each case can be very distinct. The most noticeable ones are those connected with coordination and movement. Typically, representative symptoms of DCD are

- difficulty in combining movements into controlled sequence,
- remembering the next movement in sequence,
- poor timing and disturbed balance.

The common cause for all of the above and other movement problems is working memory dysfunction. Working memory, often used synonymously with short-term memory, is the system in the brain which manipulates all "current data" - visual images or verbal information - and coordinates the central executive. One of the crucial responsibilities of the latter is creating a visual representation of possible movement paths. If this subsystem does not work properly, the patient will not perform his movements accurately.

Problems with working memory may have deep impact on patient's abilities and skills. It may result in having difficulties remembering deadlines and sequences of instructions, like cooking, driving a car or playing complex games. However, this disorder does not affect one's long-term memory, which actually can be excellent, despite poor short-time memory.

There are many more possible symptoms of DCD:

- problems with spatial awareness,
- determining left or right,
- estimating the distance to objects.

Fine motor problems can occur, i.e. difficulty in acquisition of graphemes (e.g. letters or numbers – that is why people with dyspraxia also sometimes suffer from dysgraphia or dyslexia) or establishing an efficient pencil grip.

## 2.4 Real-life impact

To conclude the description of disease, it is crucial to determine its impact on real-life activities. Issues with motor coordination may cause problems with walking, running, climbing or jumping. Working memory problems can lead to having difficulties driving a car, moving in crowded places, crossing roads and make a person prone to panic attacks. People with DCD are facing difficulties using cutlery, fastening buttons or shoelaces, shaving and performing similar routine activities. In conclusion, if the disorder is not cured, it may be extremely demanding on the patient.

## 2.5 Diagnosing

Although the disease is strictly neurological, researches about detecting DCD with imaging techniques like computed tomography, magnetic resonance imaging or ultrasound are inconclusive [5]. Several theories speculate that the etiology of DCD is part of the continuum of cerebral palsy; is secondary to prenatal, perinatal, or neonatal insult; or is secondary to neuronal damage at the cellular level in the neurotransmitter or receptor systems [8]. Experiments and researches in this topic are ambiguous and cannot be a basis for definitive diagnosis.

The most popular and conclusive way of diagnosing DCD is to perform a standardized motor test. A score below 15th percentile and IQ above 69 points qualifies the patient for a diagnosis of DCD [10]. However, there is some inconsistency among tests. In one study [11], two tests were compared - the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) and the Movement Assesment Battery for Children(M-ABC). The tested group consists of children with DCD and with no motor difficulties in 1:1 proportion. The size of test group was 312 in the first trial and 202 in the second. The test results shown respectively 82% and 67% consistency in distinguishing children who had DCD from children who did not[8]. Those are two of the most commonly used tests for diagnosing DCD - the potential lack of consistency in identifying DCD among children is a serious concern.

In the majority of cases, the diagnosis is based on observation of signs and symptoms. The American Psychiatric Association considers that DCD should be diagnosed only if the following four diagnostic components are present [3]:

- Motor coordination during daily activities should be substantially below that expected for age and intelligence.
- Resulting motor difficulties interfere with academic achievement or activities of daily living.
- The coordination problems are not due to a general medical condition (e.g., cerebral palsy or muscular dystrophy) or a pervasive developmental disorder.
- If mental retardation is present, the motor difficulties are in excess of those usually associated with mental retardation.

## 2.6 Treatment

The treatment for DCD is based on rehabilitation and training. No pharmacological therapy was designed to be used during DCD's treatment. Medications are reserved for the treatment of associated conditions (e.g., attention deficit hyperactivity disorder[ADHD]) [12].

There are two basic approaches of rehabilitation procedure - top-down and bottom-up. Top-down approach, also known as task-oriented or modular, attempts to remedy or improve specific difficulties by employing specific techniques aimed at the observed motor challenge (e.q., difficulty with handwriting, catching a ball, or performing fine motor tasks with the fingers). It usually involves gradually targeting certain problem behaviours and implementing step-by-step interventions that focus on teaching and practising the skill [12]. The most important element of modular-approach is practice. Practical applications of this method are therapies such as the cognitive motor approach with task orientation or task-oriented approaches with motor learning.

Bottom-up approach (process-oriented, deficit-oriented), the more global or generalised one is based on the theoretical assumption that the motor skills problem is just a manifestation of some underlying mechanism, such as impaired sensory integration or insufficient or inaccurate kinaesthetic perceptions. In the bottom-up approach, the therapist does not initially address the observable motor challenge. Rather, the expert focuses on how children manage their bodies, process stimulation (sensory information), and deal with problems. The expectation is that the improved sensory-motor (sensorimotor) functioning becomes generalized and eventually improves the motor skills. As children become comfortable with their bodies, they gain control of their motor (and other) functions [12]. This method is represented by the kinaesthetic training approach, sensorimotor integration therapy and sensory integration therapy.

No researches show that any of this approaches is definitely effective as DCD's treatment. This is probably caused by great diversity in symptoms and severity's levels of DCD. However, data suggest that top-down approach may be more efficient than bottom-up.

## 2.7 Haptic devices in rehabilitation

There are researches that prove the sensorimotor control of limb stiffness and compliance is a key element in the organisation of movement. Though, the best training approach would be the sensorimotor training. The goal of this therapy is to improve child's perceptual abilities intrinsic to the concurrent generation and experience of their own movements as well as use of this information to guide their movements [1].

This kind of training is difficult to apply with traditional therapeutic tools. However, various robot-assisted therapies are developed in order to support sensorimotor training, some of them including haptic devices. Robot-assisted therapies allowed to perform rehabilitation without the direct supervision of a trained therapist, what is especially important in DCD, where the number of patients significantly outgrows number of therapists. What's more, the complexity or/and difficulty of the task can be controlled very precisely.

Haptic devices were used to improve the generation of handwriting movements of children with DCD [13]. The researches show that this method can be notably effective, mostly because of active sensorimotor generation and control of movement trajectories. This is the feature required for learning generalized to task-related movements other than those specifically practised [1]. This requirement is caused by "catch-22" situation connected with movement learning mechanism. This learning process for a person without dyspraxia consists of two stages. First one is learning to generate imprecise approximation of movement.

When this is achieved, one can gradually improve approximation of a movement through practice until achieving optimal route. For people with dyspraxia it is almost impossible to generate generate good enough qualitative approximation, which should allow them to make quantitative improvements through practice - this is a catch-22.

It is possible to overcome this paradox only if the support from the machine is balanced with possibility of active generation and control of movement from child. Mechanical properties of haptic devices, like inertia and tactile feedback can significantly help in achieving this result [1].

## 2.8 Haptic factors essential for rehabilitation. Phantom Omni introduction.

Figure 2.1: Sensable Phantom Omni device

Using haptic devices as controllers in application allows to benefit from the various haptic factors generated by particular haptic device. The factors vary between products and producers. Because all of quotable studies operate on Sensable Phantom Omni(Geomagic Touch Haptic Device) [14], when "haptic device" will be mentioned in text, it will always refer to Phantom device.

Phantom Omni consists of stylus connected to an arm mounted on base. It has 6 degrees of freedom and its workspace range is 160x120x70mm. Thanks to its pen-like stylus it is easy and natural to operate it, especially for children. Phantom Omni has been widely used in industry for a several years, also for medical purposes, thus it is well tested and safe-in-use device.

The haptic factors generated by this device and tested in children's rehabilitation are [13] [1]:

- inertia
- viscosity (of the space)
- magnetic attraction of the object)
- friction (of the object)

Viscosity and inertia may provide an appropriate support, but do not allow to keep track of designed movement form. Furthermore, no evidence suggest that the method could generalize the performance without support from the device [13]. Magnetic attraction help in following the generated path and this is the main haptic factor that will be used in the project. Researches show that friction has no significant impact on helping the child in performing the task [1].

## 2.9 Game rules analysis

In order to develop a serious game which can help children with dyspraxia, some basic rules and presumption must be established. The following principles are based either on [1], where similar project was developed or on the top of previous subsections analysis:

1. The game represents a bottom-up approach with sensorimotor training.
2. Basic task is to follow the path with tip of stylus, where the path is magnetically attractive.
3. The main haptic factor is magnetic attraction.
4. There must exists a levelling system.

The next chapter describes the design phase of a game based on this rules.

# Chapter 3

# Design

The design phase is focused on game logic construction. It is based on previous chapters analysis and discoveries from articles connected with the topic of haptic rehabilitation for DCD, especially [1].

## 3.1 Basic game rules and objects

As it was previously described in 2.9 - Game rules analysis, the main task performed by patients is to follow the three-dimensional wire with tip of stylus, where the path is magnetically attractive. There is a player's object which he is forced to move from "start" to "end" along the path by pushing it with the tip of stylus, represented by cursor. There is also a competitor's object, moving along the path with uniform velocity (specified for each curve). The player wins a round when his object reaches the end before competitor's one.

### 3.1.1 Path

The mathematical representation of this path is Bezier's curve. Depending on level of difficulty there are different curves - they vary in length, curvature and torsion. The are three designed curves. Each curve has defined two times of passing - one for slower and one for faster racer. Competitor's speed is calculated based on this time and current path length.

### 3.1.2 Haptic objects an displayed objects

The terms "haptic" or "displayed" are used to describe object's visibility for haptic device. Only some of the game's objects are rendered to haptic space and can be detected by player while moving stylus through the space. Those are called haptic objects.

The haptic objects are:

- path
- player’s object

None of the other objects (i.e. competitor’s object, "start" sign) is available to be detected by touch, they are only displayed on the screen. All of the haptic objects are also displayed one.

## 3.2 Levelling up

There are three parameters that are changing along the game:

- competitor’s velocity
- path’s shape (and length)
- magnetic attraction level

The player advances to the next level when he wins two times in a row with definite settings. While advancing, firstly, competitor’s velocity is increased. Then, when player wins with both competitors, slow and fast one, he change the path to more advance, but with slower competitor again. Finally, after winning games on all paths, the magnetic attraction level is decreased and player starts from the very first path with slower competitor. This process is repeated until reaching the lowest possible level of magnetic attraction.

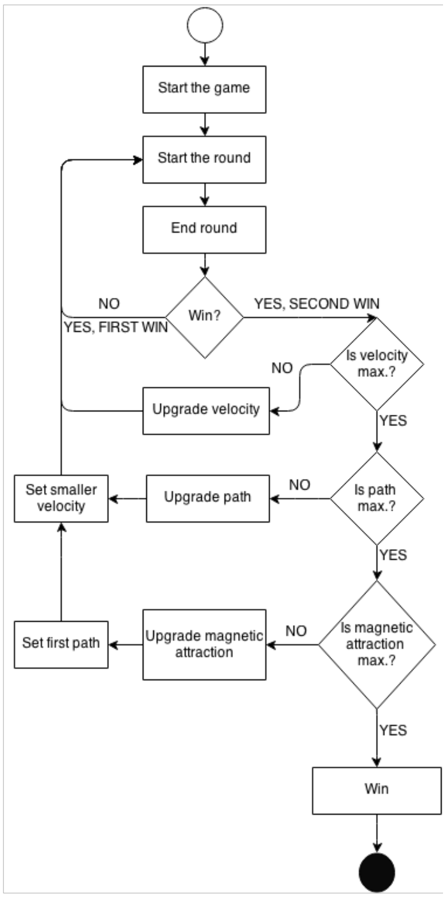


Figure 3.1: Schema of levelling process

## 3.3 Controls

There are three possible input devices: a keyboard, a mouse and the Phantom Omni. The player’s object is controlled only with a Phantom Omni to avoid the possible confusion. The mouse allows changing of camera position. The keyboard is reserved for debug operations (turning on and off scene’s objects, immediate winning of round).

## 3.4 Display and scene

The scene is closed in a skybox, a cube where inner walls are covered with textures. Path is rendered in the middle of the scene. Player's and competitor's object are attached to the path, so do start/end sign. There is also a graphic representation of a tip of a stylus.

## 3.5 Measuring player's score

Continuous measuring player's score during a game is one of the most important parts of the project, as it allows to control his progress. There are two main values measured during the game: *path length* (of the player's object) and *total race time*.

The path length may differ from curve length in case player leaves the "magnetic field" of a wire. This affect more often children with dyspraxia. This parameter decreases while trainings and therefore is index of progress. The path length is sampled with approximately 50-60 Hz frequency.

Total race time is parameter responsible for determining of win. The counting starts from the moment when first player's object moves and lasts until reaching the end point.

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# Appendix A

# Added CD's desctiption

Załączona płyta CD zawiera:

- `main.pdf` - wersja elektroniczna niniejszej pracy,
- `abstrakt.txt` - abstrakt pracy,
- `/code/*` - fragmenty kodu źródłowego opisywanego projektu,
- `/lib/*` - oprogramowanie w darmowych wersjach użyte w projekcie:
  - *soft 1.0* - wersja instalacyjna,
  - *Lib-1.31* - biblioteka w technologii kosmicznej,
  - *Moduł 4.5.6* - gotowa paczka.