Développement de technologies d'assistance à l'alimentation pour les personnes vivant avec des difficultés de mouvement aux membres supérieurs

Mémoire

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Résumé

Les déficiences sensorimotrices ou troubles du mouvement sont ce qui sous-tend ou cause les incapacités aux membres supérieurs. Par exemple, la spasticité musculaire, faiblesse musculaire, pauvre contrôle moteur sélectif, spasmes musculaires ou mouvements involontaires ou tremblements sont tous des exemples de désordres sensorimoteurs/troubles du mouvement. Lorsque des personnes vivent avec de tels désordres sensorimoteurs, cela peut entrainer des incapacités aux membres supérieurs et de la difficulté à réaliser diverses tâches quotidiennes. Dans plusieurs cas, les personnes atteintes n'ont pas accès aux services d'un aide-soignant. La famille doit donc s'occuper de la personne dans le besoin ou encore la personne atteinte doit se débrouiller avec les assistances techniques disponibles sur le marché. La situation risque de se détériorer dans un futur proche considérant le vieillissement de la population où il faudra prendre soin de plus en plus de personnes en perte d'autonomie avec moins de main d'œuvre active.

À la suite d'une revue de littérature, et de consultations avec des ergothérapeutes, il a été établi que les assistances techniques commercialisées ne sont pas suffisamment adéquates pour plusieurs usagers. Ce mémoire porte sur le développement d'assistances techniques mécaniques afin de venir en aide aux personnes ayant des difficultés de mouvement aux membres supérieurs.

L'hypothèse est que l'utilisation des assistances développées aidera les personnes vivant avec des troubles de mouvement à s'alimenter de manière plus autonome. Et ce, tout en réduisant la charge de travail du personnel médical.

Deux types d'aide à l'alimentation ont été développés : un système d'aide à l'alimentation passif pour la spasticité et un ustensile anti-tremblements. Le premier est un système utilisant des mécanismes à quatre barres et des amortisseurs afin de stabiliser l'ustensile et d'amortir les mouvements involontaires. Le deuxième est un ustensile de plus petite taille qui stabilise les tremblements en utilisant des contrepoids.

Abstract

Many people live with disabilities that may affect the control of their upper limbs and therefore affect their daily autonomy. These disabilities can include muscle spasticity, non-selective motor control, muscle weakness and others. This can cause spasms or tremors which will inevitably affect the person when he/she tries to eat by him/herself. In many cases, people living with that kind of disabilities do not have access to the service of a caregiver. The affected person can use technical aids available commercially or the family can take care of the person in need. The situation is likely to deteriorate in the coming years considering the aging population. It will be necessary to take care of more and more people losing their autonomy while dealing with less active medical labor.

Following a literature review, and several discussions with occupational therapists, it was established that the technical aids available commercially are not sufficiently adequate for many users. This thesis focuses on the development of mechanical feeding assistances to help people living with upper limbs movement disorders.

The hypothesis is that using the developed aids will help people living with movement disorders to eat more independently. The use of the developed mechanical aids will increase user involvement while reducing the workload of the medical staff.

Two different types of feeding aid have been developed: a passive feeding system for spasticity and an anti-tremor utensil. The first is a complex system using four-bar mechanisms and dampers to stabilize the utensil and reduce the effects of involuntary movements. The prototype is fixed on a table and is controlled with a handle. The second solution developed is a smaller sized utensil that stabilizes tremors using counterweights.

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Liste des abréviations, sigles, acronymes

CIRRIS: Centre Interdisciplinaire de Recherche en Réadaptation et Intégration Sociale

DoF: Degree of Freedom

Pro/supi: Pronation/supination

PD: Parkinson Disease

ET: Essential tremors

Fig.: Figure

RESNA: Rehabilitation Engineering and Assistive Technology Society of North America

CIUSSS: Centres Intégrés Universitaires de Santé et de Services Sociaux

PEPS : Pavillon de l'Éducation Physique et des Sports

OT : Occupationnal therapist

AT : Assistive technology

SAPA : Soutien à l'autonomie des personnes âgées

PT : Parkinsonian tremor

FFT : Fast Fourier Transform

DDL : Degré de liberté

Remerciements

Je tiens sincèrement à remercier toutes les personnes qui ont contribué de près ou de loin à la réalisation de ma maîtrise. Tout d'abord, j'aimerais remercier mon directeur de maîtrise, le professeur Alexandre Campeau-Lecours, sans qui la réalisation de mon projet de maîtrise n'aurait pas été possible. Alex, tu m'as offert un stage à l'été 2018 qui m'a fait découvrir le domaine de l'ingénierie de la réadaptation. Un domaine stimulant et important pour la société que je n'aurais probablement pas découvert si tu n'avais pas été un de mes professeurs de mon baccalauréat. Merci au hasard pour le bon *timing* entre mon parcours universitaire et le début de ta carrière de professeur. Je te remercie également de m'avoir initié au merveilleux sport qu'est le *Spikeball*. Je suis fier d'avoir représenté *TeamAT* dans les ligues du *PEPS* et d'avoir battu le laboratoire de fluides à maintes reprises. Plus sérieusement, merci pour ton expertise et pour les bons conseils qui m'ont guidé durant la réalisation de ma maîtrise et des 1000 autres projets réalisés qui ne seront pas présentés dans ce mémoire. Je tiens à remercier ma co-directrice de recherche, la professeure Véronique Flamand, qui a contribué, par son expertise en ergothérapie au développement et aux essais des assistances techniques présentées dans ce mémoire. Je souhaite également remercier Thierry Laliberté, professionnel de recherche au laboratoire de robotique, qui était un peu comme mon maître *Jedi* de la conception mécanique. Ton expertise a été essentielle à la réalisation de mes projets et ce fut un bonheur de travailler avec toi.

Je remercie également l'équipe du CIRRIS qui m'a aidé à mieux comprendre les enjeux et la réalité des personnes vivant avec des handicaps physiques. Vos connaissances en matière de réadaptation ont été très utiles à la réalisation de mes différents projets.

Sans oublier la contribution des membres du Laboratoire de robotique qui m'ont aidé à différentes étapes de mes projets, particulièrement aux membres de *TeamAT* qui étaient là au commencement de ma maîtrise. Spécialement, un grand merci à Marianne, une amie formidable avec qui je peux partager mon amour pour le café et le houblon et à Samuel, un ami et coéquipier hors-pair au *Spikeball*.

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Avant-propos

Ce mémoire est présenté par l'insertion de deux articles qui ont été rédigés par l'étudiant lors de son parcours aux études supérieures.

Le premier article, intitulé *Mechanical Design Improvement of a Passive Device to Assist Eating in People Living with Movement Disorders,* a été rédigé en 2019 pour le *Assistive Technology Journal* de la *Rehabilitation Engineering and Assistive Technology Society of North America* (RESNA). L'article a été présenté par l'étudiant lors de la conférence annuelle de RESNA qui s'est tenue de façon virtuelle le 23 et le 24 septembre 2020. Dans cet article, le développement du système d'aide à l'alimentation passif est présenté. L'étudiant a participé à la rédaction à titre de premier auteur, sous la supervision du directeur de recherche, le professeur Alexandre Campeau-Lecours et de la co-directrice de recherche, la professeure Véronique Flamand. Les coauteurs ayant participé au projet de conception et à la révision finale sont Thierry Laliberté et François Routhier.

Le deuxième article, intitulé *Development of a new and mechanically intelligent anti-tremor spoon,* sera soumis sous peu au *Journal of Rehabilitation and Assistive Technologies Engineering*. Il présente le développement d'un nouvel ustensile qui vise à réduire l'effet des tremblements pour les personnes atteintes de la maladie de Parkinson ou encore pour les personnes vivant avec des tremblements essentiels. L'étudiant a participé à la rédaction à titre de premier auteur, sous la supervision du directeur de recherche, le professeur Alexandre Campeau-Lecours et de la co-directrice de recherche, la professeure Véronique Flamand. Thierry Laliberté est également cité comme coauteur pour avoir participé à la conception de l'ustensile.

Introduction

La maladie de Parkinson, la dystonie, la sclérose en plaques, la sclérose latérale amyotrophique, des tremblements essentiels ou encore la paralysie cérébrale sont des pathologies qui peuvent entrainer des désordres sensorimoteurs tels que spasticité musculaire, faiblesse musculaire, pauvre contrôle moteur sélectif, spasmes musculaires ou mouvements involontaires ou tremblements. Lorsque des personnes vivent avec de tels désordres sensorimoteurs, cela peut entrainer des incapacités aux membres supérieurs et de la difficulté à réaliser diverses tâches quotidiennes. De plus, la proportion de personnes vivant avec des incapacités est d'environ 42,5% pour les gens de 75 ans et plus (Statistics Canada, 2013). Comme la population est vieillissante et que la proportion de personnes âgées de 65 ans et plus augmentera considérablement, il faudra plus de solutions et plus de ressources afin d'accompagner ceux qui vivent avec des incapacités (canada.ca, 2014), (census.gov, 2018). Parallèlement au vieillissement de la population, le système de santé fait actuellement face à un manque de personnel et la situation ne va pas s'améliorer dans les prochaines années (lapresse.ca, 2019), (ledevoir.com, 2019). La société devra s'occuper de plus en plus de personnes vivant avec des incapacités physiques tout en ayant accès à de moins en moins de ressources. D'autres solutions devront donc être envisagées et l'utilisation de technologies d'assistance est une des options ayant le potentiel d'améliorer le niveau d'autonomie des personnes vivant avec des difficultés de mouvement.

La tâche de l'alimentation présente un grand défi pour les personnes touchées par des difficultés de mouvement aux membres supérieurs. S'alimenter soi-même est un aspect très important d'un mode de vie autonome (Turgeon, 2020). Afin d'aider les personnes vivant avec des incapacités physiques, plusieurs assistances techniques sont disponibles commercialement, mais certains facteurs limitent leur utilisation. En effet, le taux d'utilisation des systèmes d'aide à l'alimentation disponibles sur le marché est faible et plusieurs éléments sont en cause. Les coûts élevés, les difficultés d'opération, les performances inadéquates, le manque de financement et le manque d'adaptation aux besoins des utilisateurs sont les principales raisons pourquoi les systèmes disponibles sont peu utilisés (Statistics Canada, 2013), (Federici, 2016), (Turgeon, 2020), (Smith, 2002).

Problématique

Les personnes vivant avec des difficultés de mouvement aux membres supérieurs (spasmes, tremblements, ataxie) rencontrent quotidiennement des défis, entre autres, lorsque vient le temps de s'alimenter. Plusieurs aides techniques à l'alimentation sont disponibles commercialement et sont présentées en détail dans le mémoire de Philippe Turgeon. Par contre, une revue des produits existants a pu démontrer que les solutions disponibles présentent plusieurs lacunes, ce qui fait en sorte que les solutions sont peu utilisées. Ce constat a également été validé auprès de différents ergothérapeutes (Turgeon, 2020).

Objectif de la maîtrise

L'objectif de cette maîtrise est de développer des technologies d'assistance à l'alimentation pour les personnes vivant avec des difficultés de mouvement aux membres supérieurs. Plus particulièrement, les assistances techniques développées viseront à réduire l'effet des spasmes ainsi que des tremblements lors de la prise des repas dans l'optique de rendre l'utilisateur plus autonome. Les travaux effectués ont permis de développer deux différents types d'aide à l'alimentation, le premier est un système mécanique muni d'amortisseurs qui maintient l'orientation de la cuillère et diminues l'amplitude de mouvement requise pour amener la nourriture à la bouche alors que le deuxième est une cuillère anti-tremblements équilibrée par des contrepoids.

Le projet de recherche a été réalisé au Laboratoire de robotique de l'Université Laval, en collaboration avec le Centre interdisciplinaire de Recherche en Réadaptation et Intégration Sociale (Cirris) et le Centre Intégré Universitaire de Santé et de Services Sociaux (CIUSSS) de la Capitale-Nationale.

Méthodologie

Le premier projet réalisé au cours de la maîtrise est le mécanisme d'aide à l'alimentation comprenant des amortisseurs. La première itération de ce mécanisme a été développée par Philippe Turgeon lors de sa maîtrise (Turgeon, 2020). Une deuxième version entièrement mécanique a ensuite été développée par l'auteur du présent mémoire lors d'un stage effectué à l'été 2018 avec le professeur Alexandre Campeau-Lecours. Le prototype a ensuite été testé avec des utilisateurs potentiels au CIRRIS et certains inconvénients ont été observés par les ergothérapeutes qui ont mené les tests expérimentaux. Le projet a ensuite été sélectionné comme sujet de cette maîtrise afin de développer une version améliorée selon les commentaires des ergothérapeutes. L'approche utilisée pour le développement est une démarche design (*design thinking* en anglais), dans laquelle les besoins de l'utilisateur sont placés au centre des réflexions, la méthode implique donc la participation active des utilisateurs potentiels (Brown & Katz, 2011). Le développement du mécanisme s'est fait de façon itérative en collaboration avec les professionnels de santé du CIRRIS afin d'avoir leur opinion sur les modifications apportées.

Le deuxième projet réalisé au cours de la maîtrise est un prototype de cuillère anti-tremblements. Contrairement au système d'aide à l'alimentation qui avait été entamé par Philippe Turgeon, l'étudiant est le premier au sein du laboratoire de robotique à entamer le processus de développement pour la cuillère. Ce projet a été réalisé en utilisant la même méthodologie que pour le précédent, c'est-à-dire, une approche centrée sur les besoins des utilisateurs potentiels. Le développement s'est fait de façon itérative en collaboration avec des ergothérapeutes du CIRRIS et différents ingénieurs du laboratoire de robotique. Au cours du processus, plusieurs prototypes ont été créés afin d'explorer différentes avenues possibles. Tous les prototypes développés ont été testés par différents membres de l'équipe de conception afin d'en ressortir les points positifs et négatifs, ce qui a guidé les itérations subséquentes.

Structure du mémoire

Le chapitre 1 de ce mémoire porte sur le développement d'un mécanisme d'aide à l'alimentation. Le chapitre suivant porte sur des avancées qui ont été réalisées suite à la publication de l'article du chapitre 1. Le chapitre 3 présente le développement d'un nouveau modèle de cuillère anti-tremblements.

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Chapitre 1 - Mechanical Design Improvement of a Passive Device to Assist Eating in People Living with Movement Disorders

Résumé

Plusieurs personnes ayant subi un accident vasculaire cérébrale, ou vivant avec des troubles neurologiques tels que la paralysie cérébrale, la dystrophie musculaire ou la dystonie vivent avec des troubles de mouvement aux membres supérieurs (spasticité musculaire, contrôle moteur non sélectif, faiblesse musculaire, spasmes), ce qui rend la prise des repas difficile. L'objectif de ce projet est de développer un nouveau système d'aide à l'alimentation pour stabiliser les mouvements des personnes vivant avec des difficultés de mouvement. Une première itération du système a été validée auprès d'enfants atteints de paralysie cérébrale et les résultats ont été prometteurs. Cette validation a également fait ressortir plusieurs points négatifs. Cet article présente les étapes du développement de la deuxième itération du système d'aide à l'alimentation qui comprend des modifications telles que la réduction de la distance verticale à parcourir, l'amélioration de la sécurité et de l'amortissement ainsi qu'une modification quant au poids ressenti du mécanisme.

Abstract

Many people living with neurological disorders, such as cerebral palsy, stroke, muscular dystrophy or dystonia experience upper limb impairments (muscle spasticity, loss of selective motor control, muscle weakness or tremors) and have difficulty to eat independently. The general goal of this project is to develop a new device to assist with eating, aimed at stabilizing the movement of people who have movement disorders. A first iteration of the device was validated with children living with cerebral palsy and showed promising results. This validation however pointed out important drawbacks. This paper presents an iteration of the design which includes a new mechanism reducing the required arm elevation, improving safety through a compliant utensil attachment, and improving damping and other static balancing factors.

Introduction

Being able to eat without the assistance of a caregiver is an important aspect of independent daily living (Turgeon, 2020). Unfortunately, many people living with conditions such as cerebral palsy, stroke, muscular dystrophy or dystonia experience movement disorders to the upper limbs (muscle spasticity, unselective motor control, muscle weakness or tremors) and have difficulty eating on their own. Numerous solutions have already been created to assist people living with such conditions. Liftware offers two intelligent handles to help people suffering from tremors or muscular stiffening, i.e. the Liftware Steady™ and Liftware Level™ handles [www.liftware.com], each available with the soup spoon, everyday spoon, fork and spork attachments. There are also mechanical devices to reduce the effect of spasms, e.g. the Neater Eater [www.neater.co.uk], the Action Arm [www.flaghouse.ca], the Friction Feeder [www.ncmedical.com] and the Nelson [www.focalmeditech.nl]. Some devices feed the users autonomously and require few actions, e.g. the iEAT Feeding Robot [www.assistive-innovations.com], the Winsford Feeder (North Coast Medical, 2011), and the OBI arm [www.meetobi.com]. Even if several solutions have been proposed or commercialized, the literature also points to a number of factors that limit the adoption of assistive technology (AT) devices in general: high cost, difficulties of operating devices, poor performance, and insufficient adaptation to the users' needs (Statistics Canada, 2013), (Federeci, 2016). We also know, from scientific literature (Turgeon, 2020) and non-formal discussion with therapists, that many people living with movement disorders cannot eat independently and that the AT on the market are not suitable for their special needs and do not help them to eat by their own. This led to the creation of a first design for a mechanical AT that addresses two types of motor disorders: a) contractures due to spasticity or joint deformities which prevent the user from holding the utensil parallel to the ground, and b) abrupt movements such as spasms, ataxia or dystonia. The device was designed to stabilize the user's motion and to enable independent eating. Once developed, the device was tested in a trial with potential users (Turgeon, 2019), (Turgeon, 2020). Occupational therapists supervised the trial and noted different improvements that could be brought on to the prototype. The main comments were that a) bringing the utensil to the mouth with the device required too much arm elevation, thus raising safety issues relative to the utensil attachment (i.e. if the utensil is rigidly attached to the mechanism, it could hurt the user if he/she makes an involuntary movement while the utensil is in the mouth) b) the motion damping presents a dead-zone (there was no damping for small movements), and c) the static balancing of the mechanism weight was not optimal. The work described in the current paper addresses these issues through the design of mechanical improvements. The first section hosts the description of the previous design, followed by the objectives of the project, and a summary depiction of the device. Then, each improvement to the first prototype is detailed: the handle attachment, the compliant spoon design, the static balancing, and the new dampers. Finally, the work is shortly discussed and concluded.

Previous design

This section presents the general mechanical design of both the first prototype and the new one. Fig. 1.1 presents, in order of increasing complexity (Fig. 1.1a, b, and c, respectively), three variations of the mechanism, all of which allow the same three degrees of freedom (DoF). Fig. 1.1a shows a simple system with three pivots (J1, J2 and J3), which is known as an RRR (three rotary joints) mechanism. The parallelogram added in Fig. 1.1b is used to damp L2-bar’s rotation around J3. L1-bar is damped using the J2 pivot. Fig. 1.1c shows the complete assembly with the two other parallelograms used to maintain the orientation of the spoon (Turgeon, 2020). This design was also used as a basis for the development of a writing assistive device (Lemire, 2019). Fig. 1.2a depicts the first iteration of the prototype while Fig. 1.2b displays the prototype with the modifications that will be described in the following sections.

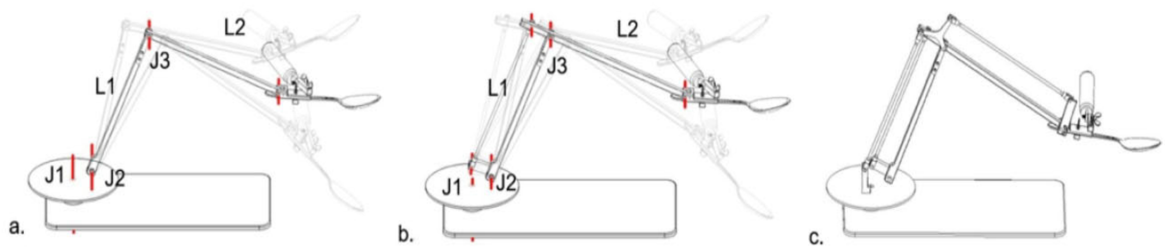


Figure 1.1: Presentation of the planar parallel bar assembly. The base mechanism is shown in Fig. a., Fig. b. shows the added parallelogram indicating where the second damper would be located on the base. Shaded positions of the spoon show the unconstraint spoon rotation. Fig. c. shows the complete assembly with the two parallelograms used to maintain the orientation of the spoon.

Objectives

The main objective of the project is to design an improved version of an assistive eating device prototype aimed at stabilizing the motion of people living with movement disorders. More specifically, based on a previous iteration, four features are addressed in this work: 1) reducing the required shoulder elevation, 2) making the spoon compliant to avoid injuring the user if he/she has a head spasm while eating, 3) statically balancing the mechanism and 4) exploring a new kind of damper in the prototype.

Summary description

The proposed mechanism, which is designed to be mounted on a table, is shown in Fig. 1.2b. The mechanism has three DoFs (J1, J2, J3 in Fig. 1.1a). A spoon is attached at the end of the mechanism. The user operates the device by grasping and moving a handle. The orientation and the height of the handle can be adjusted to the user's preference, inside a predetermined range (detailed in the next section). The device allows moving the spoon in every direction inside the working area and, as a result of the mechanism design, maintains the spoon and the handle in a constant orientation. The spoon orientation can be changed depending on the food that the user is eating. Mechanical inertia and dampers allow stabilization of the user's motion. The device thus assists the user in two different manners. First, by holding the spoon in the same orientation, it facilitates a task that is difficult or impossible for some people because of spasticity or upper limb impairments. Second, the added inertia and damping stabilize uncoordinated movements (i.e. spasms). Although the mechanism is shown here with a spoon attached to it, a fork can also be used. A scooper plate with a suction cup base is attached to the mechanism. This prototype has already seen a first design, which will be presented, followed by the four major improvements brought on to the new version of the prototype: 1) a modified handle attachment to reduce arm elevation requirements, 2) a compliant spoon attachment, 3) the static balancing of the mechanism, 4) a new type of damper.

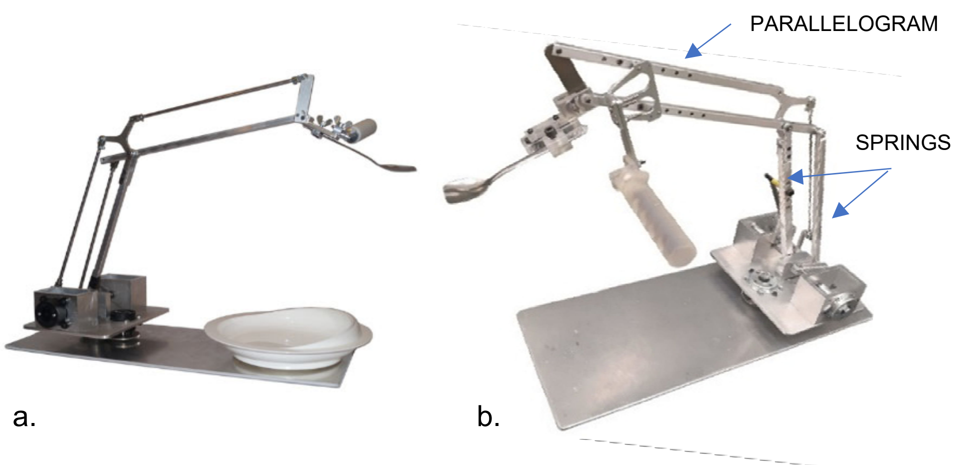
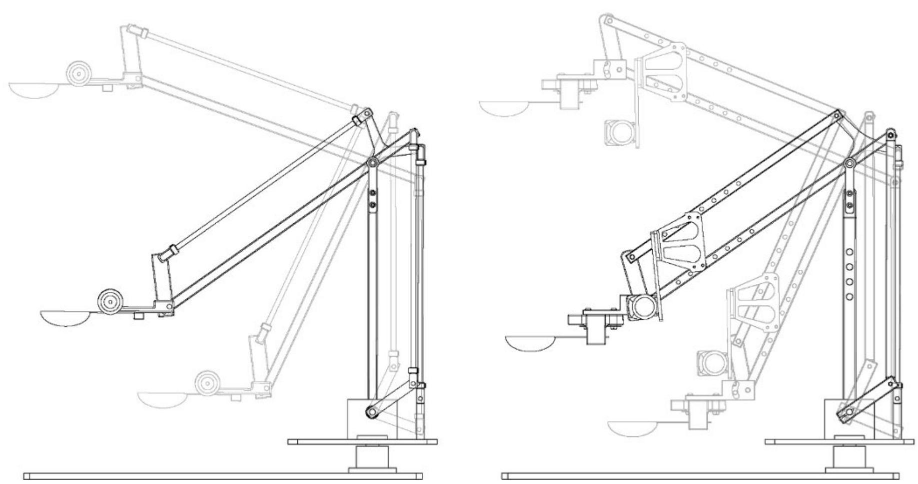


Figure 1.2: Comparison of the 2 iterations of the assistive eating device. Fig. a. shows the first iteration and Fig. b. shows the novel.

Handle attachment design

The main difference between the previous design (Fig. 1.2a) and the novel design (Fig. 1.2b) is a new handle mechanism which allows the user to reach his/her mouth with less arm elevation amplitude. This was an important suggestion from the occupational therapists in the previous design trials that will help users who do not have the capacity (or have difficulty) to raise their hand up to their mouth (majority of users tested). By fixing the handle within the parallelogram (Fig. 1.2b) instead of fixing it at the end of it (Fig. 1.2a), the required upward handle movement amplitude to generate the same spoon vertical movement is much reduced.



a. b.

Figure 1.3 : Comparison of the upward handle movement for three positions between a. the first iteration of the design and b. the novel iteration.

By comparison, with the previous design, raising the utensil by 33 cm (average mouth height from the table) required the same handle upward motion. With the proposed design, the required upward motion of the handle is 24 cm. The handle's bracket is attached to the parallelogram farther from the utensil and thus makes the movement reduction possible. The bracket positions the handle higher than the utensil when the utensil is in the plate, and it positions the handle lower than the utensil when the utensil is at the user's mouth level. The bracket is L-shaped to position the handle closer to the user. Another bracket is also positioned between the L-shape bracket and the handle to lower the handle and make it easier for the user to manipulate it. The bracket can be assembled for both right-handed and left-handed users. The orientation of the handle can also be set to five different angles to meet the user's needs. For the user's comfort, the handle is free to rotate around its own axis but can also be locked with a small socket head screw.

Compliant spoon attachment design

During the tests, occupational therapists raised safety issues relative to the utensil attachment (i.e. if the utensil is rigidly attached to the mechanism, it could hurt the user if he/she makes an involuntary movement while the utensil is in the mouth). A compliant utensil attachment was thus designed. The compliance gives a flexibility so that it does not hurt the person in such a case. The utensil attachment's compliant DoFs are presented in Fig. 1.4. Parts #1 and #2 in Fig. 1.4 are fastened together with two loose socket head screws enveloped with rubber.

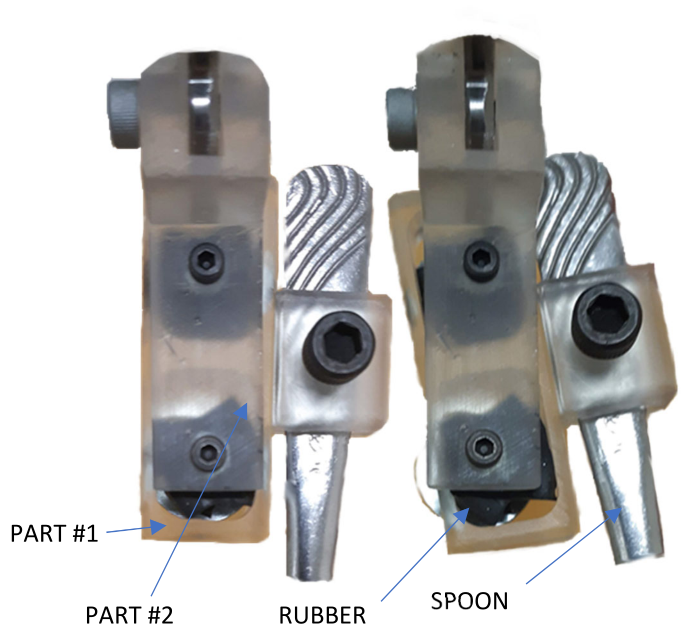


Figure 1.4 : Compliant spoon attachment.

The rubber damps the shock if the user has a spasm and hits himself/herself. It is also used to re-center the spoon. In this design, it is important that the utensil moves if it is hit by the user. However, for intuitiveness purposes, it must also move back to the center position afterwards (otherwise, the user will always be chasing the utensil, which could be in a different orientation). To this end, a compliant utensil attachment was designed. It consists of flexible rubber cushions that can deform and absorb shock if there is a contact, and that will also move the utensil back to the center position afterwards.

Static balancing

The previous version of the prototype used 2 torsion springs to balance the mechanism but it did not prove efficient enough. To help the user use the prototype, the mechanism is balanced by 2 linear springs, their placement is shown on Fig. 1.2b. With the springs, the user doesn't have to lift the weight of the mechanism, it is therefore easier when a user tries to take food from the plate to his/her mouth. This improvement could be useful for users who do not have much arm or hand strength (e.g. the elderly).

Inclusion of new dampers

Another point that was revealed during the trials with the previous design was that the dampers were not good to stabilize the beginning of the motion although they were correct for the rest of the motion. Several commercial dampers were bought from ACE Controls Inc. and were tested (FRT-F2-203, FRT-F2-403, FDT-47, FDT-57) and the one that meets the needs of this application the most is the FDT-47 damper (Ace Controls, 2019). Since the design of the chosen damper is different from the previous one, adjustments had to be made to ensure a right fit on the mechanism. The two kinds of dampers can be seen on Fig. 1.2, where the old ones are black and the new ones are metallic. The new dampers improved the fluidity of the motion assistance.

Discussion and conclusion

In this paper, a novel design of a 3-DoF assistive eating device was presented. The device is used to support people living with movement disorders. The objectives were to develop an improved version of the first design iteration of the prototype based on a trial with potential users. The modifications made on the mechanism include the redesign of the handle and spoon attachment, the improvement of the static balancing, and a new kind of damper. Future work will consist in evaluating the novel prototype with potential users in order to assess the efficiency of the improvements in the eating process compared to the last version.

Acknowledgments

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Chapitre 2 – Développements suite à la publication de l'article sur l'aide à l'alimentation

Modifications de l'aide à l'alimentation

Ce chapitre présente les travaux effectués sur le système d'aide à l'alimentation suite à la publication de l'article. Après avoir effectué quelques tests de fonctionnement sur le prototype tel que présenté dans l'article, des modifications ont été apportées sur le mécanisme d'aide à l'alimentation. Les modifications concernent le degré de liberté J1 de la figure 1.1 de la section précédente, qui se trouve à être un axe de rotation vertical. Initialement, l'amortisseur était assemblé de façon parallèle au degré de liberté (DDL) mais l'axe de l'amortisseur n'était pas colinéaire avec l'axe du DDL J1. Pour transmettre le mouvement de rotation de J1 à l'amortisseur, deux roues dentées étaient utilisées comme le présente la figure 2.1.

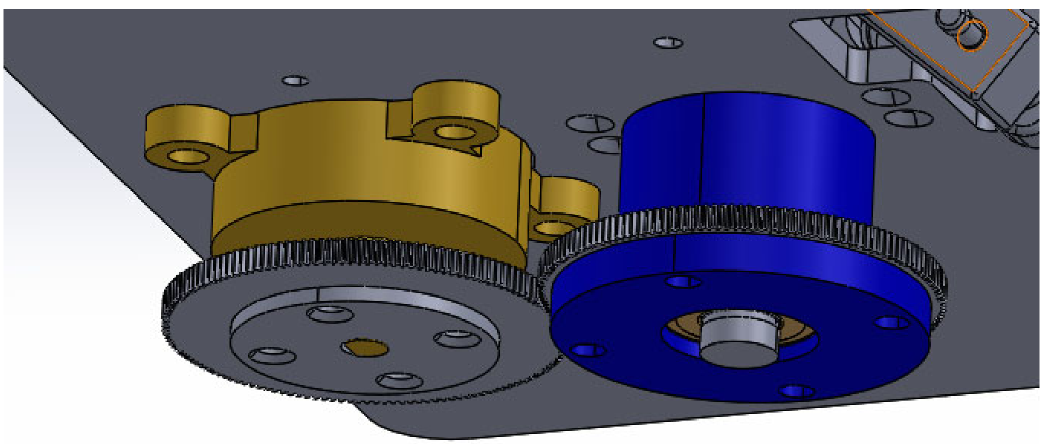

Figure 2.1 : Disposition de l'amortisseur (couleur dorée) du degré de liberté J1 (aligné avec l'axe de la pièce bleue)

Initialement, lorsque les amortisseurs ont été changés pour un modèle plus performant, le principe de fonctionnement avec les roues dentées a été conservé et l'amortisseur que l'on voit sur la figure 2.1 (qui est l'ancien modèle FRT), a seulement été changé pour le modèle plus performant. Après avoir effectué quelques essais, la conclusion était que les roues dentées créaient un certain jeu dans le comportement du mécanisme et lorsque la poignée bougeait de gauche à droite, le petit jeu présent entre les dents des roues dentées, était amplifié pour créer un jeu beaucoup plus grand au niveau de la poignée, variant selon la position de celle-ci. La solution afin de régler ce problème a été d'abandonner l'assemblage de roues dentées et d'aligner le nouvel amortisseur FDT avec l'axe du DDL J1. Ceci a été possible parce que le modèle FDT comprend un alésage carré contrairement au modèle FRT qui doit s'assembler à partir d'un essieu, tel que présenté à la figure 2.2.

Figure 2.2 : Modèle d'amortisseur FRT (gauche) et le modèle FDT (droite) [www.acecontrols.com/]

Afin de placer l'amortisseur dans l'axe de rotation, plusieurs pièces ont été modifiées ou changées. Premièrement, l'essieu a dû être modifié afin d'en fabriquer un avec un bout carré qui puisse se connecter à l'intérieur de l'amortisseur. Les roulements utilisés ont été changés pour un modèle avec un diamètre interne plus grand afin de pouvoir y passer l'essieu avec le bout carré. La cage de roulement (en bleu sur la figure 2.1) a dû être changée afin d'en fabriquer une plus longue et plus large afin d'y insérer les nouveaux roulements. Une pièce rectangulaire avec un espace libre en dessous a été fabriquée afin de surélever le mécanisme pour que ce soit possible d'installer le nouvel amortisseur. L'assemblage final est présenté à la figure 2.3 et une section de cet assemblage est présentée à la figure 2.4. La pièce jaune sur ces deux figures représente l'amortisseur FDT, la partie en bleu est une cage de roulements, qui sont en rouge sur la figure 2.4. Les deux roulements sont séparés par une entretoise, orange sur la figure 2.4. La pièce grise verticale qui est au centre de la figure 2.4 est l'essieu qui assure la rotation du mécanisme, le bout inférieur de celui-ci a un profil carré afin de se fixer à l'intérieur de l'amortisseur.

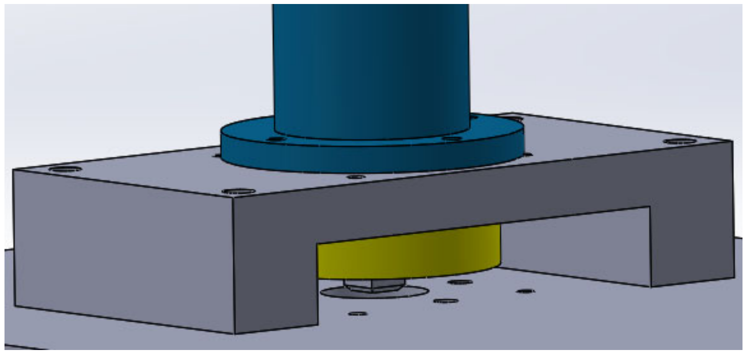

Figure 2.3 : Disposition de l'amortisseur (jaune) sur le nouvel assemblage de l'axe de rotation J1. La pièce bleue est la cage de roulements.

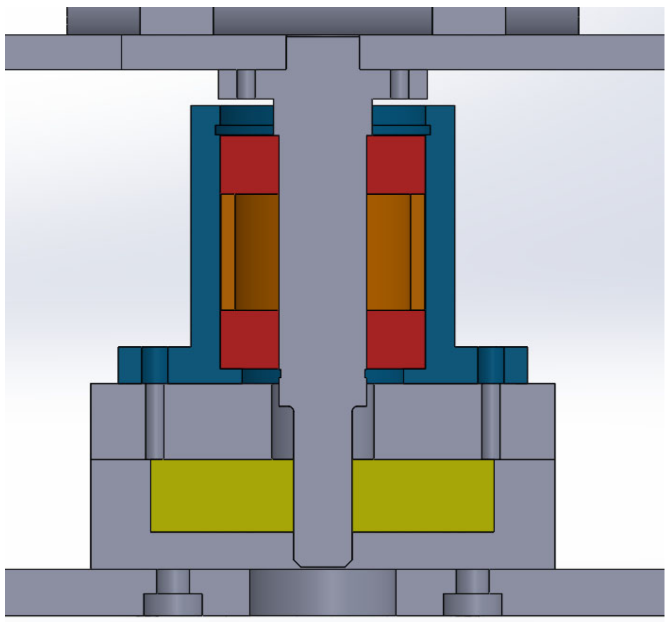

Figure 2.4 : Section de l'axe de rotation J1 comprenant l'amortisseur (jaune), la cage de roulements (bleu), les roulements (rouge), l'entretoise (orange).

Avec ce nouvel assemblage, la réponse de l'amortisseur pour ce degré de liberté est plus directe que lorsque l'assemblage était composé de roues dentées. Ça a permis d'éliminer le jeu présent entre les dents des roues dentées et d'améliorer le contrôle général du mécanisme.

Alternative aux amortisseurs

Suite aux essais expérimentaux, les ergothérapeutes ont suggéré qu'un amortisseur ajustable serait un très bon atout pour le système d'aide à l'alimentation. De cette façon, le taux d'amortissement pourrait être choisi en fonction des besoins de chaque utilisateur. Par exemple, le taux d'amortissement pourrait être réduit pour les enfants et les personnes âgées alors qu'il serait augmenté pour un adulte. En se fiant aux caractéristiques du modèle d'amortisseur présentement utilisé sur le système, le modèle FDT-47, l'équipe de conception a cherché des amortisseurs rotationnels ajustables mais aucun modèle n'offrait des caractéristiques similaires. La décision de développer un amortisseur ajustable a donc été prise. Par contre, après avoir analysé différents concepts existants, il a été conclu que la conception d'un amortisseur rotationnel ajustable était trop complexe étant donné la nécessité de contenir un fluide visqueux. Une différente solution a donc été envisagée, il s'agit d'un frein comprenant des plaques de friction, une série de rondelles coniques qui maintient les plaques en contact et des vis pour l'ajustement. Le prototype de frein ajustable est présenté à la figure 2.5. L'essieu métallique sert à transmettre le mouvement alors que les trois vis noires servent à ajuster le couple qui résistera au mouvement.

Figure 2.5 : Prototype de frein ajustable

La figure 2.6 présente un schéma simplifié de l'intérieur du frein ajustable. Lorsque les vis sont vissées, elles poussent sur le disque d'ajustement ce qui la déplace vers la droite. Ce déplacement resserre les rondelles coniques (ou rondelles *Belleville*), ce qui fait augmenter la force normale présente entre le disque et la plaque de friction. Comme la force de friction présente entre les plaques dépend de la force normale à la surface, ceci fait augmenter le couple que peut appliquer le frein. Le frein peut appliquer un intervalle de couple assez grand qui part de pratiquement zéro et allant jusqu'à un couple assez élevé, qui sera calculé dans la présente section.

Un des avantages qu'il y a avec l'utilisation des rondelles *Belleville,* outre le fait qu'elles sont plus compactes qu'un ressort et plus faciles à assembler, est que celles-ci peuvent être assemblées de différentes façons. Selon la configuration choisie, les forces appliquées par les rondelles ne seront pas les mêmes. La figure 2.7 présente différentes configurations possibles pour les rondelles.

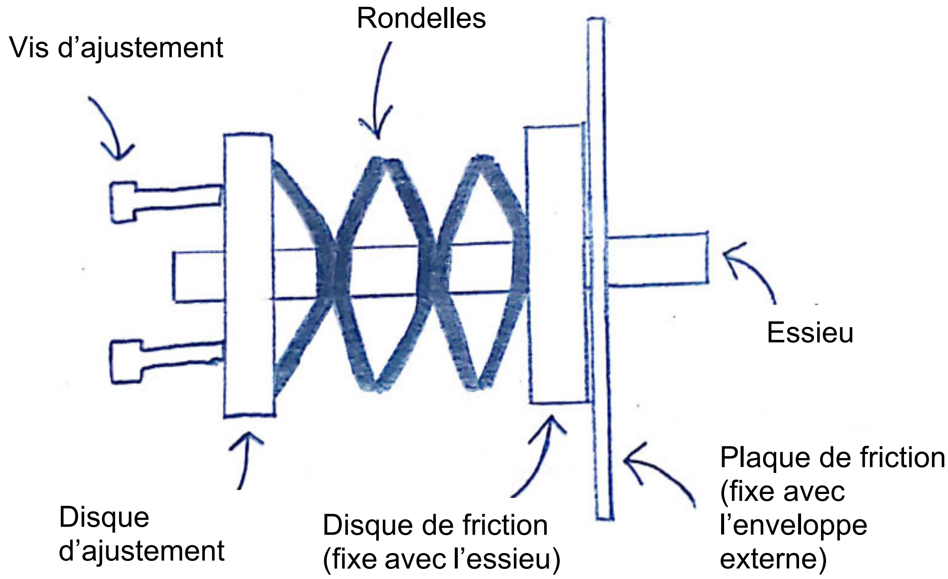

Figure 2.6 : Schéma simplifié représentant le système à l'intérieur du frein ajustable

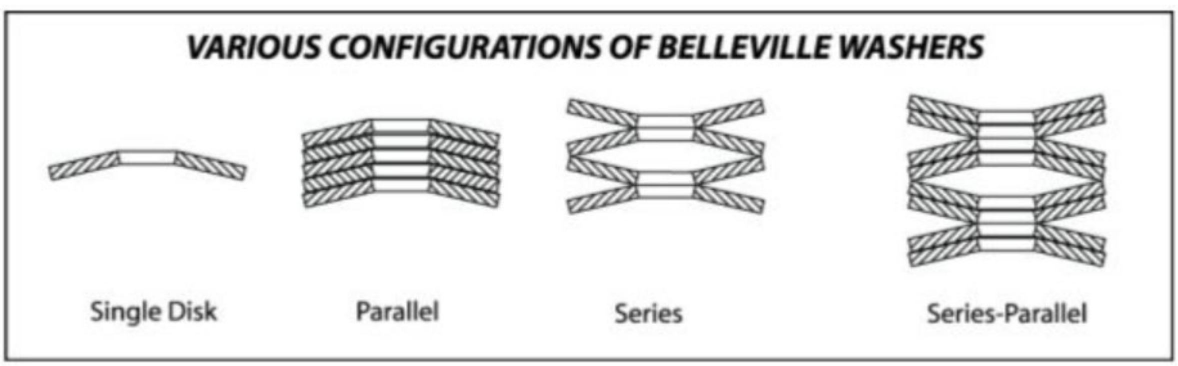

Figure 2.7 : Différentes configurations des rondelles coniques [http://springipedia.com/belleville-washers-stacking.asp]

Les configurations peuvent être modifiées pour obtenir des variantes, par exemple, une rondelle dans un sens, deux dans l'autre sens suivi de trois à l'inverse. Il existe une notation pour différencier les différentes configurations. Sur la figure 2.7, en allant de gauche à droite, la première est notée « 1 », la deuxième « 4 », la troisième « 1-1-1-1 » et la quatrième configuration est notée « 2-2-2-2 ». Le frein de la figure 2.5 comporte 19 rondelles coniques avec les caractéristiques suivantes : diamètre externe de 0.5'', diamètre interne de 0,255'', charge de 190 lbs (845,16N) à une déflexion de 0,004'' (0,1016mm) (mcmaster.com). Avec ces données, il est possible de calculer la raideur d'une rondelle (k) avec le calcul suivant :

$$k = \frac{F}{\Delta L}$$

k : Raideur de la rondelle [N/mm]

ΔL : Différence de longueur [mm]

F : Force appliquée par la rondelle à ΔL [N]

$$k = \frac{845,16}{0,1016} = 8318,5\ N/mm$$

Les rondelles sont assemblées dans la configuration « 1-1-1-… » et avec la formule suivante, il est possible de calculer la raideur de l'ensemble des 19 rondelles (http://springipedia.com/belleville-washers-stacking.asp):

$$k_{total} = \frac{k}{\sum_{i=1}^{g} \frac{1}{n_i}}$$

k_{total} : Raideur de la série de rondelles [N/mm]

n_i : Nombre de rondelles dans le $i^{ème}$ groupe

g : Nombre de groupes de rondelles

k : Raideur d'une rondelle [N/mm]

$$k_{total} = \frac{8318,5}{\frac{1}{1} + \frac{1}{1} + \cdots + \frac{1}{1}} = \frac{8318,5}{19} = 437,82\ N/mm$$

Avec la raideur totale de la série de rondelles, on peut calculer la force maximale que les rondelles peuvent appliquer en fonction du déplacement maximal possible. L'épaisseur d'une rondelle à plat est de 0,038'' (0,9652mm) donc l'épaisseur minimale de la série de rondelles est de 18,34mm. L'épaisseur d'une rondelle est de 0,047'' (1,19mm), ce qui donne une longueur totale de 22,68mm. La force maximale que peut appliquer la série de rondelles est donc calculée de la façon suivante :

$$F = k_{total} * \Delta L$$

$$F = 437,82 * (22,68 - 18,34) = 1900,14N$$

En connaissant la valeur de la force maximale, il est possible d'estimer le couple maximal que le frein peut appliquer de la façon suivante (Mechanics Map - Disc Friction (psu.edu)):

$$M = \frac{2}{3}\mu_k F \left(\frac{R_o^3 - R_i^3}{R_o^2 - R_i^2}\right)$$

M : Moment (ou couple) [Nm]

μ_k : Coefficient de frottement cinétique entre les disques (μ_k=0,42, https://www.engineeringtoolbox.com/friction-coefficients-d_778.html)

F : Force appliquée sur les disques [N]

R_o : Rayon extérieur [m]

R_i : Rayon intérieur [m]

$$M = \frac{2}{3} * 0{,}42 * 1900{,}14 * \left(\frac{0{,}0315^3 - 0{,}00635^3}{0{,}0315^2 - 0{,}00635^2}\right) = 17{,}33Nm$$

Cette valeur de couple est amplement suffisante étant donné que le couple maximal que peut appliquer l'amortisseur FDT-47, utilisé sur l'aide à l'alimentation, est d'environ 2Nm. La valeur de 17Nm semble être exagérée comparativement à celle de l'amortisseur FDT-47 mais comme le prototype de frein est ajustable, il sera possible de réduire le couple afin d'obtenir le bon ajustement. En ayant un couple possible de 17Nm, il sera possible d'amortir l'effet des spasmes pour les utilisateurs avec une plus grande force physique.

La prochaine étape du développement du frein ajustable consiste à valider expérimentalement si le calcul du couple est représentatif du couple réel transmis par le frein. Par la suite, le prototype de frein devra être installé sur le système d'aide à l'alimentation afin de valider si celui-ci est adéquat.

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Chapitre 3 – Development of a new and mechanically intelligent anti-tremor utensil

Résumé

Les personnes vivant avec la maladie de Parkinson ou avec des tremblements essentiels font face à plusieurs obstacles dans leur vie quotidienne. Un de ces obstacles est le fait d'avoir de la difficulté à se nourrir de façon indépendante. Plusieurs technologies commerciales sont disponibles afin d'aider les personnes vivant avec des tremblements à se nourrir de façon autonome. Par contre, à la suite d'une revue des systèmes existants et à la suite de séances de partages de connaissances avec une équipe d'ergothérapeutes, il a été conclu que les systèmes disponibles commercialement, comportent plusieurs inconvénients ou sont trop dispendieux. Cet article présente le développement d'un nouvel ustensile anti-tremblements pour assister les personnes vivant avec la maladie de Parkinson ou avec des tremblements essentiels. Une analyse fréquentielle et une évaluation menée par des ergothérapeutes montrent que le prototype développé est prometteur.

Abstract

People living with Parkinson's disease or with essential tremors face many obstacles in their everyday lives. Being able to eat independently is one of them. Many technologies already exist to help people who have difficulty eating independently. However, following a revue of existing devices with a team of occupational therapists, we found that many commercially available solutions were either unhelpful or too expensive. This paper presents the development of a new anti-tremor spoon to assist eating in people living with tremors. A frequential analysis combined with an occupational therapist review indicates that the prototype developed is promising.

Introduction

People who are 44 years old and under represent less than 10% of people living with disabilities; this proportion grows exponentially as individuals age, and for those over 75 years of age, 42.5% live with disabilities (Statistics Canada, 2013). Movement disorders, such as tremors, are one of the disabilities affecting the elderly. The most frequently occurring movement disorders are tremors caused by Parkinson's disease, which affect approximately 1M people in the US (parkinson.org) and 55,000 people in Canada (Ramage-Morin, 2014) and essential tremor, a neurological disorder that affects mainly the hands, which is experienced by 7.01M people in the US (Louis & Ottman, 2014) and 1.14 M people in Canada (sunnybrook.ca). Tremors can considerably reduce the ability to use one's arms and hands to grasp, handle, and move objects which limits the activities individuals can accomplish in everyday life, or for leisure (Sonn, 1996). Most elderly people living with upper limb tremor require the daily assistance of a caregiver to accomplish basic tasks such as eating (statcan.gc.ca). The inability to eat independently limits the possibility of those living with tremors to continue to live autonomously, a situation that accelerates transfer to nursing homes. The resulting loss of autonomy can affect their well-being, self-confidence, social participation (people with tremors tend to avoid eating with others to hide their disability) and quality of life in general. Even if ATs are currently available, many people living with disabilities do not have access to the appropriate assistive technologies (ATs) to meet their daily needs and must therefore depend on help from family or remunerated caregivers to perform many activities (Federici, 2016), (Verza, 2006). The main factor influencing access to ATs is the high cost of assistive devices (Statistics Canada, 2013), (Arim, 2013), (Dell, 2008), (Statistics Canada, 2008). Other reasons are that ATs are often complex to use, don't work well enough, or don't fit the user's needs. As a result, users tend to abandon ATs (Riemer-Reiss, 2000), (Verza, 2006).

Currently, elderly people living with upper limb tremors generally try to eat on their own (which can be a long, difficult and energy-consuming process) or ask caregivers or family members to help them (Guo et al., 2017). Caregiver assistance requires time and resources, and availability of caregivers may be limited by labor shortages in the health sector (lapresse.ca, 2019), (ledevoir.com, 2019). This situation is likely to worsen as the population ages: in the near future, we will have to collectively care for more and more people living with physical disabilities with a smaller workforce (Van der Loos, 2016), (Choinière, 2010). Indeed, demographic data show that the number of individuals over 60 will grow from 841 million people in 2013 to 2 billion people in 2050 (Chatterji, 2015). In Canada, the proportion of the population over 65 will grow from 15.6% in 2014 to 23% in 2036 (canada.ca, 2014). In the USA, this proportion will grow from 15.2% in 2016 to 23.4% in 2060 (census.gov, 2018).

Medical approaches designed to reduce the impact of physical disabilities and help people regain their autonomy tend to focus on finding the root causes of the diseases and addressing them with medication, surgery or cerebral stimulation (Rana, 2015). Although research on these approaches is necessary, they have many practical issues (e.g., side effects, habituation, low success rates, and surgical operations on difficult to access brain regions) which make short—and long-term developments very uncertain. In rehabilitation, one commonly used approach to address persistent deficits that limit functioning in daily activities is the use of assistive technologies (ATs) to compensate for the loss of capacity. In fact, in Canada, 81% of people living with disabilities use at least one AT (e.g., a wheelchair, arm support, hearing aid, computer access aid, prosthesis, etc.), (Statistics Canada, 2013), (Arim, 2012). Studies have shown that the use of ATs can increase users' subjective well-being, self-esteem, sense of competence and sense of control over life events (Fuhrer, 2000), (Yachnin, 2017). It has also been proposed that social participation could be increased (Lenker, 2013).

An effective approach could therefore be the use of ATs (e.g., mechanical or robotic technical assistance) to help people with Parkinson's or essential tremors achieve a greater level of independence. In addition to promoting the independence of the elderly and allowing workers in the health care system more time to accomplish other tasks, the use of ATs adapted for tremors is also likely to influence the overall quality of life for those living with these types of disabilities. There are a number of commercially available ATs in existence designed to facilitate autonomous eating for people living with tremors. A basic solution, presented in Figure 3.1, is weighted utensils, which have bigger handles and are heavier than normal utensils; these are designed to reduce the amplitude and frequency of tremors. Swivel utensils are also available, like those presented in Figure 3.2, which can reduce the tremors transmitted to the spoon and help keep the food inside the utensil by providing a rotational degree of freedom between the spoon and the handle. More recently, active solutions have emerged such as the Liftware Steady (presented in Figure 3.3), a device that uses sensors and motors to compensate for tremors. However, a preliminary study (discussed in detail below) indicates that adoption of ATs is limited by the high cost of devices, difficulties operating them, poor performance, and insufficient adaptation of the devices to the user needs.

Preliminary study

As a preliminary study to determine whether any of the existing solutions address user needs, several assistive eating devices were acquired by the project team. The university team (engineers and occupational therapists) first studied these technologies. We then loaned the devices to a team of occupational therapists (n = 8) from the *Support Program for the Autonomy of Seniors* (*Soutien à l'autonomie des personnes âgées)* (SAPA) of the CIUSSS (Centres intégrés universitaires de santé et de service/University health and social services centres) of the Capitale-Nationale, our project partner. Members of this team were able to try the different technologies to get a firsthand impression based on their clinical experience. Occupational therapists (OTs) from the SAPA team were then able to try these solutions with their clients (n = 10). The academic team attended one of the trials and others were videotaped by the SAPA therapists so that the university team could better understand the pros and cons of each solution. This study was approved by the Research Ethics Board at the Centre intégré universitaire de santé et de services sociaux de La CapitaleNationale (CIUSSS-CN), and informed consent was obtained from each participant. Participants were recruited through the Neurological Disorders Department at the Centre intégré universitaire de santé et de services sociaux de La CapitaleNationale (CIUSSS-CN) and from a list of people who had participated in other studies and agreed to be contacted for future research. Following the trials, a roundtable was conducted with the OTs to discuss the advantages and disadvantages of the existing technologies. Through these meetings, we were able to determine that there were several drawbacks with these devices. We also conducted a literature review was also to learn more about progress in this field of research and presented it during the roundtable. Comments from OTs, engineers and end users on the existing solutions are discussed below.

Figure 3.1: Weighted spoon (https://www.caregiverproducts.com/good-grips-weighted-utensils-3.html)

Figure 3.2: Swivel spoon (https://www.caregiverproducts.com/swivel-spoon-with-built-up-handle.html)

Figure 3.3: Liftware Steady (https://store.liftware.com/products/liftware-starter-kit)

The first AT studied is a simple mechanical solution: a weighted utensil (performancehealth.ca, 2020). The OTs reported that this type of utensil decreased tremors somewhat when users were trying to eat with it, but not enough for every client to be able to use it independently because it only worked in some cases. Then, three spoons, the Steady Spoon (performancehealth.ca/steady-spoon, 2020), the Elispoon (elispoon.com, 2020), and the Liftware Level (liftware.com/level, 2020) were studied. These spoons are designed to maintain the utensil's orientation parallel to the ground. The first two devices are purely mechanical (counterweights are used to maintain orientation) and the third is active (a sensor and motor ensure that the desired orientation is maintained). These spoons were designed for people with contractures (movement limitations of their wrists), but ads for the device stated that the spoons also helped reduce the effects of tremors. According to the occupational therapists, these devices exhibited very poor performance in terms of reducing the effects of tremors due to the nature of the mechanisms (which are not expressly designed to counteract tremors, are too simplistic and involve too much friction). In the case of the Liftware Steady (liftware.com/steady, 2020), an active device expressly designed to counteract tremors, the spoon attempts to detect the tremor acceleration (by means of an accelerometer) and quickly counter it using a small motor (Pathak, 2018), (Pons, 2007). Studies have shown that this spoon reduces the effect of tremors (Pathak, 2018), and the company reports a number of successful case studies. However, the OTs found that the utensil's performance with SAPA clients was disappointing. Indeed, it worked for some but not all clients, and the performance was lower than expected. In addition, neither the clients nor the OTs felt that the spoon's handle was ergonomic and they didn't like the fact that the device's batteries had to be charged every day. Further, the range of motion the spoon allowed was too limited, and the spoon bounced more when it reached the outer limits of the range. More importantly, this spoon retails for CA$350 (compared to the previously mentioned mechanical spoons, which retail for around CA$65), a price that is generally too high for the target population. On the extreme high end of the price spectrum are robotic solutions, like the Obi (meetobi.com, 2020), which was designed for people suffering from paralysis. These solutions perform fully automated movements and cost over CA$8,000. Because these solutions are extremely expensive, it would be excessive for people who only need a simpler assistance with their movements to use fully automated solutions like the Obi.

Our preliminary assessment of the currently available technological solutions highlighted the fact that existing devices do not entirely meet the needs of people living with tremors, in terms of either performance or cost. This is a generalized trend in the field of AT. In fact, 27% of AT users indicate that they need at least one AT that they don't own. This proportion rises to 44% among people living with severe disabilities (Arim, 2012), (Dell, 2008). The main reason is the high cost of ATs (Statistics Canada, 2013), (Arim, 2012), (Dell, 2008), (Statistics Canada, 2018). Another factor is that many ATs are abandoned by their users because their operations are too complex, their performance is weak, or they have not been sufficiently adapted to the needs of individual users (Riemer-Reiss, 2000), (Verza, 2006).

Objectives

The overall goal of the ongoing research is to enable people living with tremors to eat independently, our objective is to develop and validate a mechanically intelligent low-cost anti-tremor utensil. The specific objective of the current paper is to develop a solution that addresses the identified issues. As a constraint, our aim is to pursue a purely mechanical solution in order to develop a low-cost and easy-to-use device (e.g., one that doesn't require the user to manage a battery). Our hypothesis is that the utensil will reduce the effect of tremors, allowing users to eat more independently and that this solution will be acceptable to individuals and occupational therapists. This project was a collaboration between a university research team that includes members from the Center for Interdisciplinary Research in Rehabilitation and Social Integration (CIRRIS), a research center affiliated with Laval University; members from one of the CIUSSS research centers of the Capitale-Nationale; and a clinical team from the Support Program for the Elderly (SAPA) of the CIUSSS of the *Capitale-Nationale*.

This paper is structured as follows. First, the main characteristics of tremors will be presented to better illustrate the underlying problems. Second, the development methodology followed during the project will be described and the different prototypes created during the process will be presented. Then, the chosen prototype will be presented in detail. The method used to evaluate its effectiveness will be presented and the results will be described and discussed.

Tremor characteristics important for the design

The development of an anti-tremor spoon requires knowledge of the origins of tremors and the related movement they cause. First, there are two types of tremors 1) tremors that occur when the person is sitting or lying (resting tremors), which often affect the hands or the fingers, and 2) tremors that appear while the person is in motion (action tremors). The second type of tremor is divided into five subcategories: intention tremors, postural tremors, task-specific tremors, kinetic tremors and isometric tremors (Hallett, 2013; Ahmed A, et al., 2017). When people are eating, the most frequently occurring tremors are the resting tremor, the intention tremor, and the postural tremor. Intention tremors occur when a person is trying to target something with their hands or fingers, e.g., when the person tries to pick up food from their plate or bring the spoon/fork towards their mouth. Postural tremors occur when the person is trying to hold their hand against gravity, which is what you need to accomplish in order to eat properly. Finally, resting tremors affect people when they are trying to eat because they are sitting. In addition to the types of tremors, there are also different categories: essential, Parkinsonian, dystonic, cerebellar, psychogenic, orthostatic and physiologic tremors. This paper will focus on the essential tremor (ET) and the Parkinsonian tremor (PT). Parkinson's disease is a chronic progressive disease of elderly populations; the mean age at diagnosis is approximately 60 years (DeLong et al., 2014). The average age of people dealing with ETs is around 70 years (Louis et al., 2006). These two categories of tremors are important to consider because they are the main reason elderly people have difficulty eating independently and require the help of a caregiver.

Once the kinds of tremors the utensil will have to isolate or cancel are known, the specific characteristics of these tremors can be analyzed in detail. The main technical information to analyze in relation to the tremors is their amplitude, frequency and direction. In a study of 59 patients living with ET in which the objective was to classify hand tremor amplitude and frequency, researchers found that the mean frequency is 6.24 Hz and that the mean tremor amplitude is 9.4 mm of hand displacement (Calzetti et al., 1987). During data collection for this study, the participant's arms were supported horizontally in front of them, except for the wrist; while this is not the exact situation of someone eating, it gives a good approximation of the tremor characteristics. Another study performed using a different protocol concludes that the range of ET is from 4 Hz to 8 Hz, which validates Calzetti's study (Woods et al., 2014). In Woods' experiment, participants had to hold a mobile phone and keep their arms in the air without support while performing different tasks, which requires basically the same effort as eating. In the Woods et al. study, the researchers replicated Calzetti's experiment on people living with Parkinson Disease and found that the frequency range of the tremors was 3 Hz to 6 Hz. These data will be useful in evaluating the effectiveness of the anti-tremor spoon and during the development process. However, neither of these studies provides information about the direction of the tremors.

Studies on tremor direction are rare; the only ones found were on subjects living with ET who were asked to draw spirals on sheets of paper. A study found that an axis with a characteristic orientation is present in most patients with ET (Louis et al., 2006). However, the goal of the study was to distinguish ET from dystonia cases and not to rate tremors axis in different tasks. To learn more about the tremor orientation, we analyzed several videos of people living with ET or PT eating or doing similar tasks to find a common tremor direction or axis (link to the videos in the references section). Although this method gave us some idea of the tremor axis, it was not very robust. Only 11 clips in which an axis could be identified were analyzed and the tremor axis was not the same in every case. In addition, when a tremor axis was observed, other smaller movements in different directions were occurring simultaneously, which did not make the task easy. In the videos we watched, the dominant axis observed was the pronation/supination (pro/supi) axis, which is along the forearm. The pro/supi tremor movement was also noted by an occupational therapist observing one of her clients. Tremor origins can be located in the shoulder, the elbow or the wrist, which creates complex hand movements. The fact that there are different tremor axes forced development of our solution towards designing a device that would address more general tremor control, i.e., one that would work with different tremor frequencies and orientations.

Methodology

We began the development process by trying out the different spoons available for people living with tremors. These spoons were analyzed to learn more about why they did or didn't work well. A brainstorming session was then conducted to discuss different ideas about what could help people living with tremors to eat independently. From the discussions that emerged in the roundtable discussions with the OT team, we explored different solutions, and developed an assistive device prototype through an iterative process in collaboration with OTs and researchers in engineering and rehabilitation, through an approach based on Design Thinking (a user-centered approach that places the individual and his/her needs at the center of the reflection and involves active participation of the user in the innovation) (Brown & Katz, 2011). The prototypes created in this process were produced using the Form 2 printer from *Formlabs*. The different solutions are presented here, along with their advantages and drawbacks. The solution we finally adopted is presented in greater detail.

Prototype 1 – Swivel spoon

The first proposed prototype is a 1-degree-of-freedom (DoF) swivel spoon (shown in Figure 3.4). The working principle is relatively simple: one small bearing inside the handle allows the spoon to rotate freely around the handle axis (axis Z). A distance of 60 mm separates the spoon from the axis of rotation. The fact that the center of mass of the spoon is below the axis of rotation ensures that the spoon remains vertically under the axis of rotation in the static condition; this prevents food from falling off the spoon. The swivel spoon works well in terms of stabilizing the spoon in a neutral position. However, one disadvantage of this configuration is that it only counteracts vibrations in 2 directions: X translations and rotations around the Z-axis. Another downside is that users have to raise their hands higher than their mouths in order to eat the food.

Figure 3.4: Swivel spoon prototype

Prototype 2 – Four-bar mechanism spoon

The prototype shown in Figure Y is an attempt to create a behavior similar to that of the swivel spoon (isolating x-axis translation and z-axis rotations), but with one main improvement. Indeed, even though the swivel spoon design works in terms of maintaining the spoon in a horizontal orientation under static conditions, the spoon oscillates around the Z axis in the dynamic condition. When this occurs, the spoon is not horizontal (as shown in Figure 3.5) since it follows a circle around the handle axis. With the four-bar mechanism, instead of following a circular trajectory, the spoon follows the trajectory directed by the configuration of the four-bar mechanism. As shown in figure 3.6, the spoon with the four-bar mechanism has a virtual center of rotation that is higher than the mechanism itself. This has two advantages. First, it remains closer to the horizontal throughout a wider range of dynamic movements (as shown in Figure 3.6). Second, it allows the user to maintain the spoon and the handle at the same height. In this design, a weight was installed under the spoon to stabilize it. Another concept that was generated in relation to this design was to add a damper and a spring inside the four-bar mechanism to eliminate the effects of vibration. However, the behavior of the spoon was not as effective as expected; the friction present in the assembly's joints was too high and the movement of the mechanism was not smooth enough. The overall performance was thus weaker than the swivel spoon.

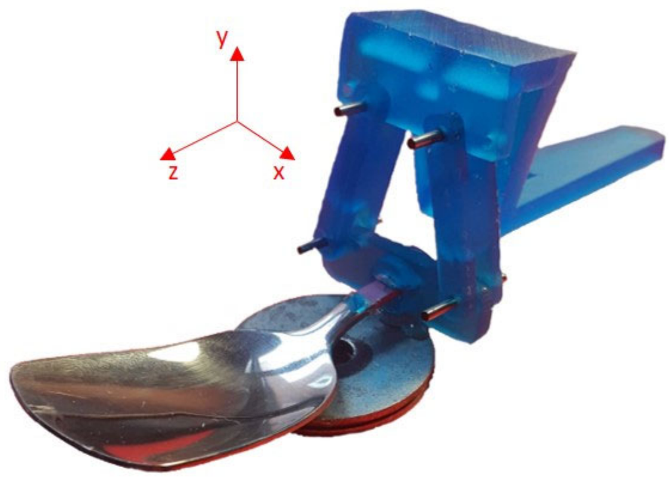

Figure 3.5: Four-bar mechanism spoon

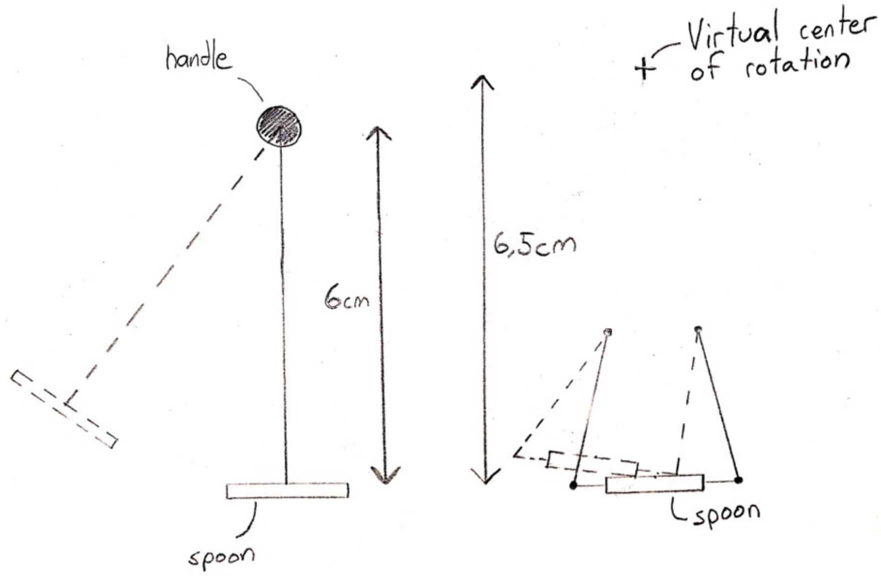

Figure 3.6: Swivel spoon trajectory (left) and four-bar mechanism trajectory (right)

Prototype 3 – Balanced spoon

While prototypes 1 and 2 focused on X translation and rotation around the Z-axis, prototype 3 focuses on rotations about the X-axis. The prototype presented in Figure 3.7 has one rotational DoF that is ensured by two pins located inside the handle, as indicated by the red line in the figure. This axis is aligned with the pro/supi movement of the arm (axis X), which is the most common tremor orientation. This way, if the user has pro-/supi-oriented tremors, the handle will follow the user's tremors, but it won't transfer the vibrations to the spoon; the handle and the spoon are independent of rotations along the joint axis. If the pro-/supi-axis and the joint axis were not aligned, the pro/supi tremors would create a translational movement directed towards the joint which would be harder to isolate. This is why the joint is located inside the handle. However, the main drawback of this prototype is that the handle must be larger. The main challenge with this DoF is that the spoon must be balanced; otherwise, the utensil will simply fall. Balancing the spoon is easy; however, the spoon's content (food) is always different. To balance the prototype, a counterweight was installed on the other end of the utensil; this brings the center of gravity lower than the X-axis and aligns with Y-axis. This allows the handle to rotate around X-axis freely without transmitting the movement to the spoon. Under static conditions, the spoon remains in a horizontal orientation regardless of the handle orientation to avoid spilling the food, as presented in figure 3.8. From ad hoc tests, the prototype worked well in terms of reducing the effect of vibrations, but only for tremors in one direction. An important challenge with balancing the spoon against gravity is that if the food scooped into the spoon is too heavy, because the prototype is balanced with counterweights, the orientation of the utensil may no longer be horizontal.

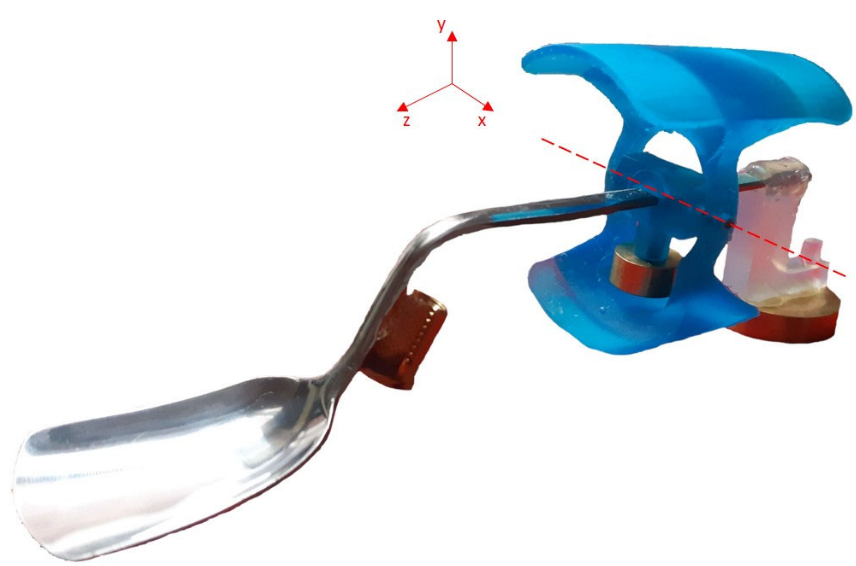

Figure 3.7: Balanced spoon prototype

Figure 3.8: Balanced spoon prototype with 2 different handle orientations

Prototype 4 – Swivel and balanced spoon

Prototypes 1, 2 and 3 focused on one DoF at a time. Prototype 4 combines prototypes 1 and 3. Figure 3.9 shows the prototype with 2 DoFs, in which a rotation is allowed by two small pins located just outside the bearing (along the X-axis) and the swivel is ensured by a bearing (aligned with the Z-axis). This prototype reduced the effect of tremors acting around both the X- and Z-axes. However, this prototype has some drawbacks. First, the handle is big and difficult to grab because the rotation joints are located inside the handle. In addition, the swivel rotation was unstable because the distance between the swivel's axis of rotation and the spoon was too small. This is an important design parameter because if this distance is longer, the movement will be more stable but the user will have to raise his/her hand higher to bring the spoon to his/her mouth. If this distance is too short, a small tremor might lead the spoon to high angles of rotation.

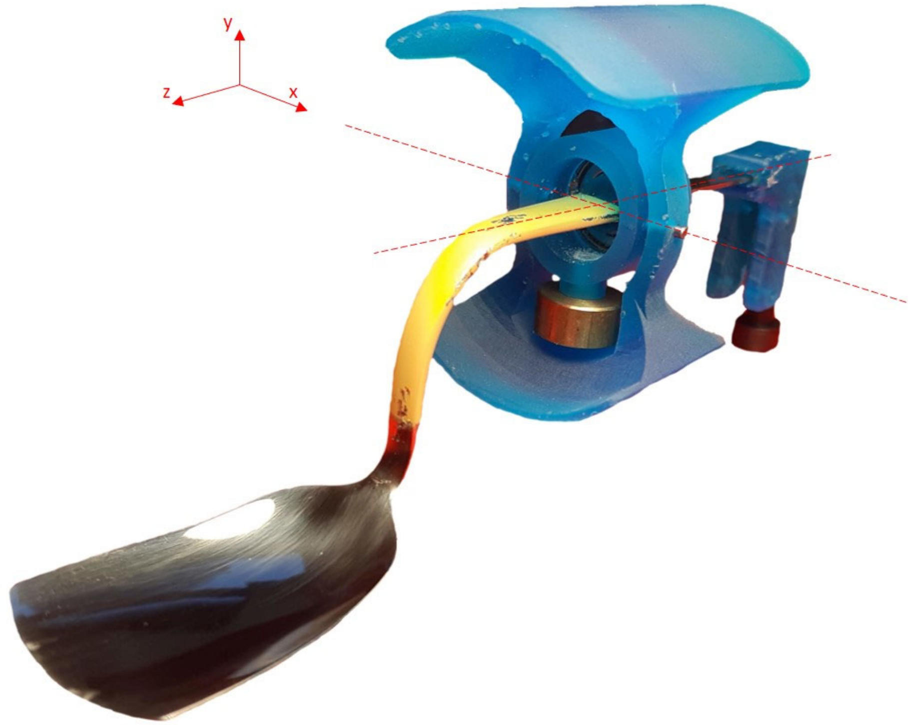

Figure 3.9: Swivel and balanced spoon prototype

Final prototype – Spherical balanced spoon

The final prototype, presented in Figures 3.10 to 3.12, is designed to have the same DoFs as prototype 4 but with major changes that will be detailed here.

With the proposed prototype, a smaller handle than the previous prototype was designed (labelled "A" on Figure 3.11). To reduce the handle's size, the rotation joint, between parts B and C, had to be placed outside the handle. The joint was moved to one side to keep the axis aligned with the pro/supi movement orientation, represented by axis 1 on figures 3.10 and 3.11. The first DoF is ensured by a bearing linking the handle part of the prototype (A and B parts) to the upper arch (C). The second DoF is ensured by a pin that links part C to parts D and E, with parts D-E moving together. Part F is a stopper that maintains the arches D-E within a given range. Part G is also a stopper; it blocks the rotation when the user tries to pick up food from the plate; otherwise, the utensil would maintain a horizontal orientation and it would be hard to pick up the food.

In order to balance the mechanism, the center of mass of parts C-F-D-E has to be lower than the axis of rotation 1. Also, the center of mass of parts D-E has to be lower than axis 2. To make this possible, brass counterweights are fixed on parts C-D-E. Because of these added weights, the spoon remains in the same orientation even if the handle rotates. To lower the center of mass even more and make the mechanism more stable, part C has several holes in it to make it lighter. In order to make the mechanism more stable than prototype 4, the distance between the spoon and the axis of the second DoF is 7.5 cm longer (11 cm versus 3.5 cm). As seen in the side view, arches D and E don't have the same shape; the arch that supports the spoon has the same vertical dimension, but it is not as wide horizontally. This brings the spoon closer to the rotation axis and reduces the impact of the food's weight on the center-of-mass position. This way, the food applies less torque around axis 1 and has less impact on the spoon's orientation. Figure 3.12 shows how the prototype is held and which hand rotations are compensated.

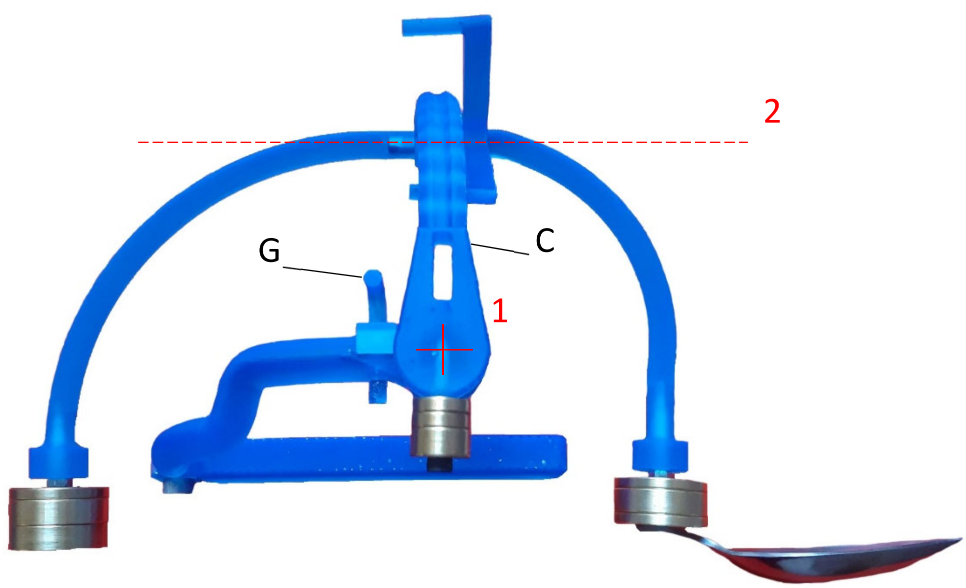

Figure 3.10: Side view of the final prototype

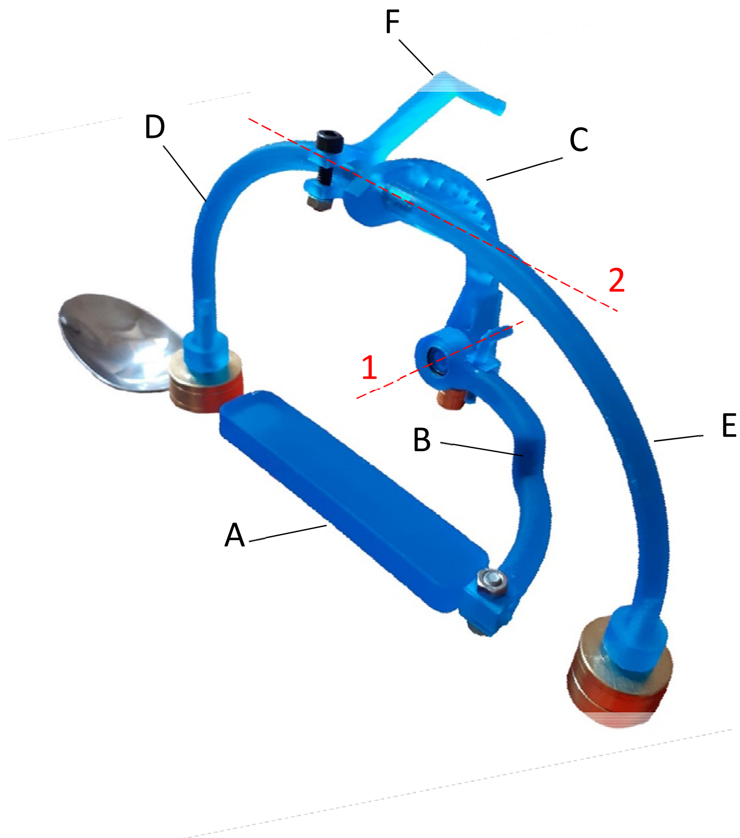

Figure 3.11: Isometric view of the final prototype

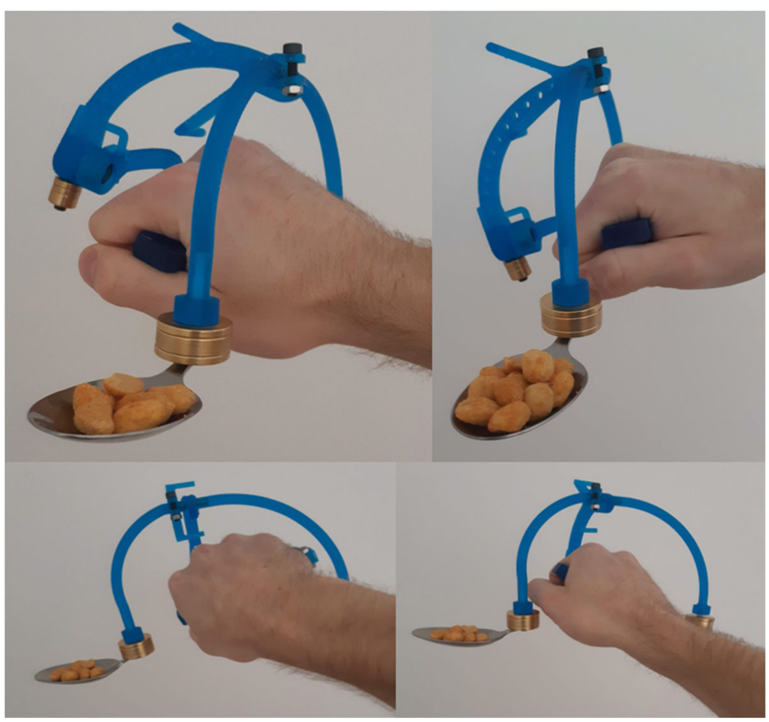

Figure 3.12: Different positions of the spherical spoon prototype

Methodology of vibration testing

In order to quantify the efficiency of the final prototype, the spherical spoon was tested using two accelerometers. The translational acceleration in three directions (a_x, a_y, a_z) was read from each IMU. As presented in Figure 3.13, one accelerometer was installed on the handle and the other one was installed on the spoon. This way, vibration input and output can be monitored and it is possible to evaluate the effect of the mechanism on tremor reduction. The spoon was tested by a healthy subject (who is not a potential user living with tremors of any kind) to reproduce different tremors in different directions. Tremor input frequency was verified to respect the average tremor frequency, which ranges from 3 Hz to 8 Hz for people living with ET or PD. The prototype was also tested for frequencies above and below the 3–8 Hz range. Two different tremor orientations were tested independently: pro/supi tremors (around axis-1 of Figure 3.10 and 3.11) and translation along the same axis. A low-pass filter (with a cut-off frequency of 30 Hz) was used on the accelerometers' raw data to eliminate the noise present in the signal. The acceleration magnitudes of each accelerometer were compared and a Fast Fourier Transform (FFT) was also performed to get a better understanding of the prototype's behavior with different frequencies. The magnitude of the filtered acceleration vector was calculated for each accelerometer as using the following formula:

$$|acceleration| = \sqrt{{a_X}^2 + {a_y}^2 + {a_z}^2}$$

The fast Fourier transform was performed on the accelerometer data using the built-in FFT function of Matlab®.

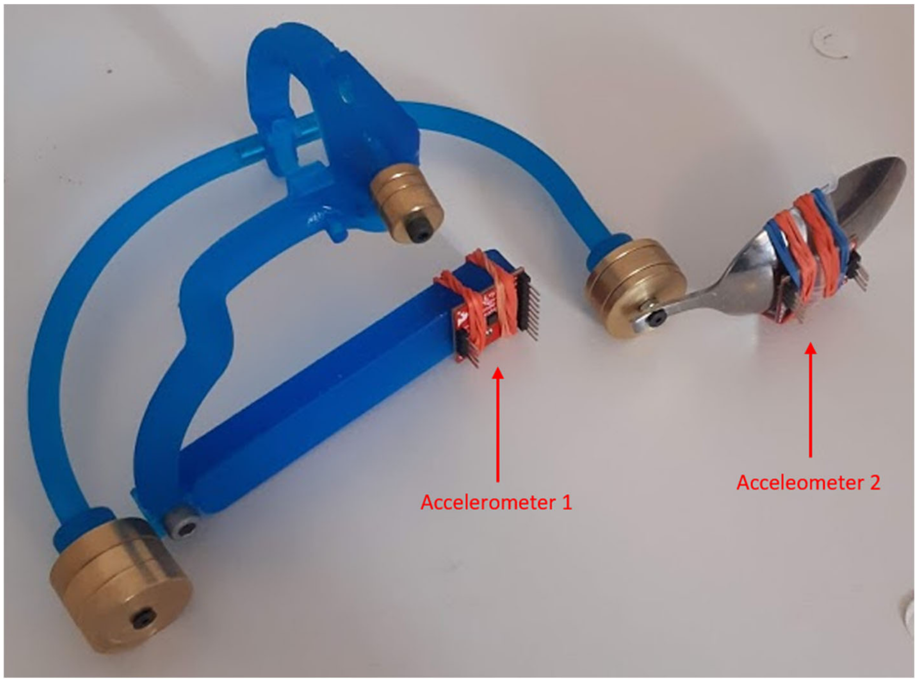

Figure 3.13: The accelerometers installed on the final spoon prototype

Test 1

A pro/supi tremor test was conducted to evaluate the first DoF of the mechanism, which is along axis-1 in figure 3.10 and 3.11. The test started with a low frequency movement, then the frequency of the tremor was increased to obtain a general view of the prototype's behavior when subjected to movements with a vast spectrum of frequencies. Results of this test are presented in the next section of this paper.

Test 2

This test was conducted by performing a translational movement of the handle along axis-1 of figure 3.10 and 3.11. This object of this part of the experimentation is to observe how the second DoF (axis-2 joint of figure 3.10 and 3.11) of the prototype behaves. As with the pro/supi tremor, the test began with a low frequency movement and ended with higher frequency movements to observe the mechanism's response under different frequencies. Results of this test are presented in the next section of this paper.

Results of vibration testing

Results of test 1

Figures 3.14 and 3.15 show the acceleration over time results and the FFT analysis of the signal for the first test conducted.

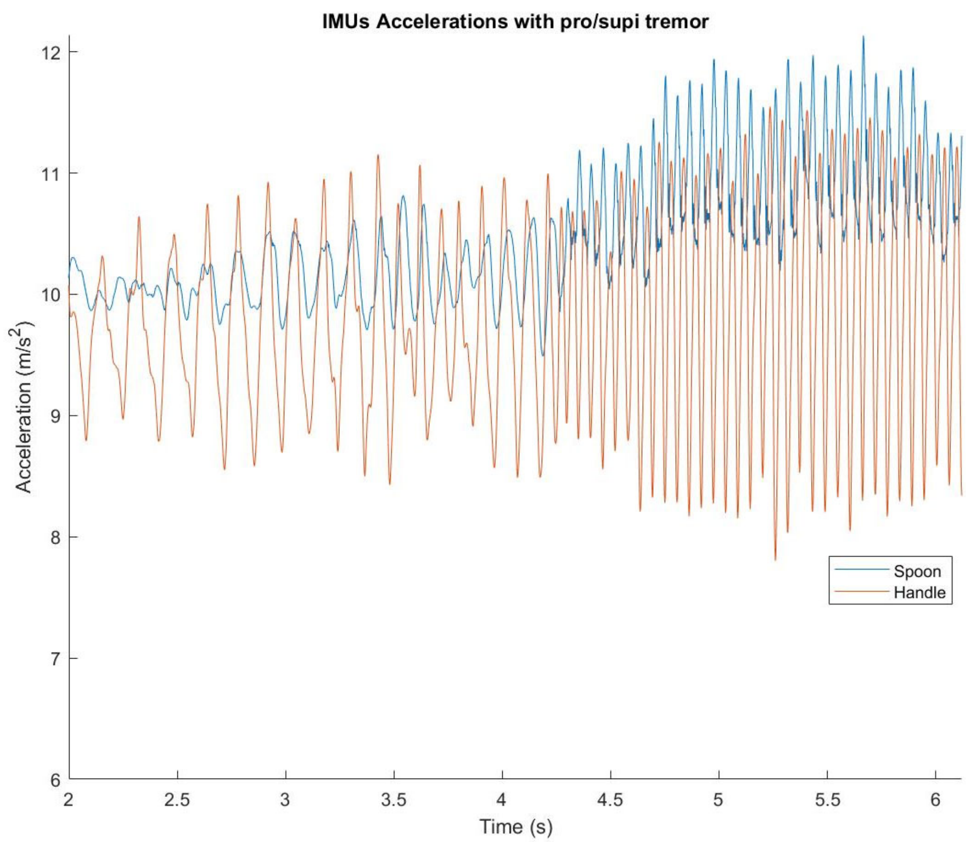

Figure 3.14: Graphic showing acceleration over time for the pro/supi tremor test

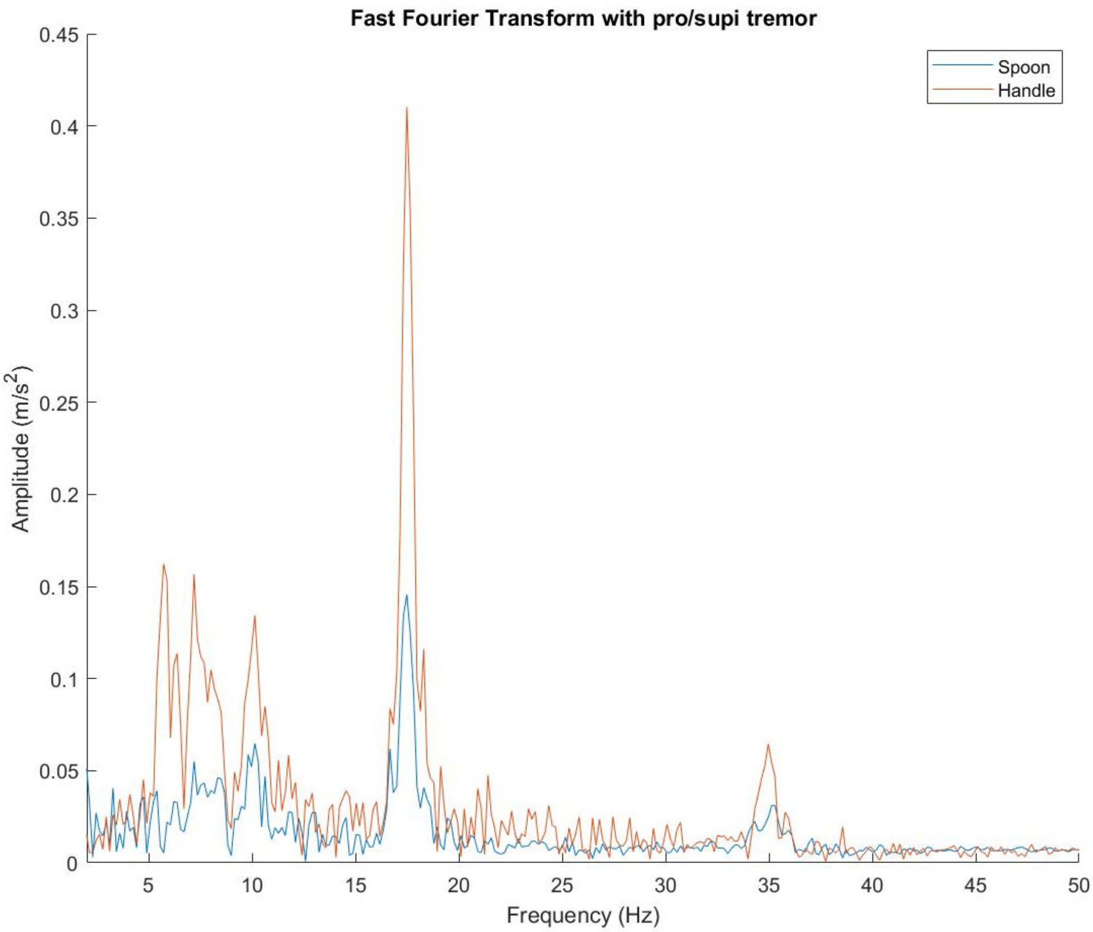

Figure 3.15: Graphic showing the Fast Fourier Transform of the pro/supi tremor test

As observed in figure 3.14, for time <4.25s, the prototype behaved as expected; the variation in the spoon signal is smaller than the handle's signal. For time >4.25s, the variation in the spoon signal is still smaller than the variation in the handle; moreover, the spoon has higher acceleration values. This is caused by the direction of the spoon accelerations. Indeed, the input frequency for time >4.25s excites the spoon in a way that the acceleration translates along the gravity vector while the handle is rotating. Accelerometers read translational accelerations; this is why the spoon values are higher than the handle values for this timeframe. This is acceptable because the spoon maintains the same orientation, which prevents the food from falling even if the spoon moves. In addition, the frequency analysis shown in figure 3.15 indicates that the main frequencies present in the handle movement (5 Hz, 7 Hz, 10 Hz and 17 Hz) are all damped by the mechanism. From 5 Hz to 20 Hz, the sum of the amplitude is 6.53 m/s^2 for the handle and 2.73 m/s^2 for the spoon, a 58.19%

reduction. This means that the spoon is effective to counteract pro/supi tremors in the interval analyzed.

Results of test 2

Figures 3.16 and 3.17 show the acceleration over time and the FFT analysis of the signal for the second test conducted.

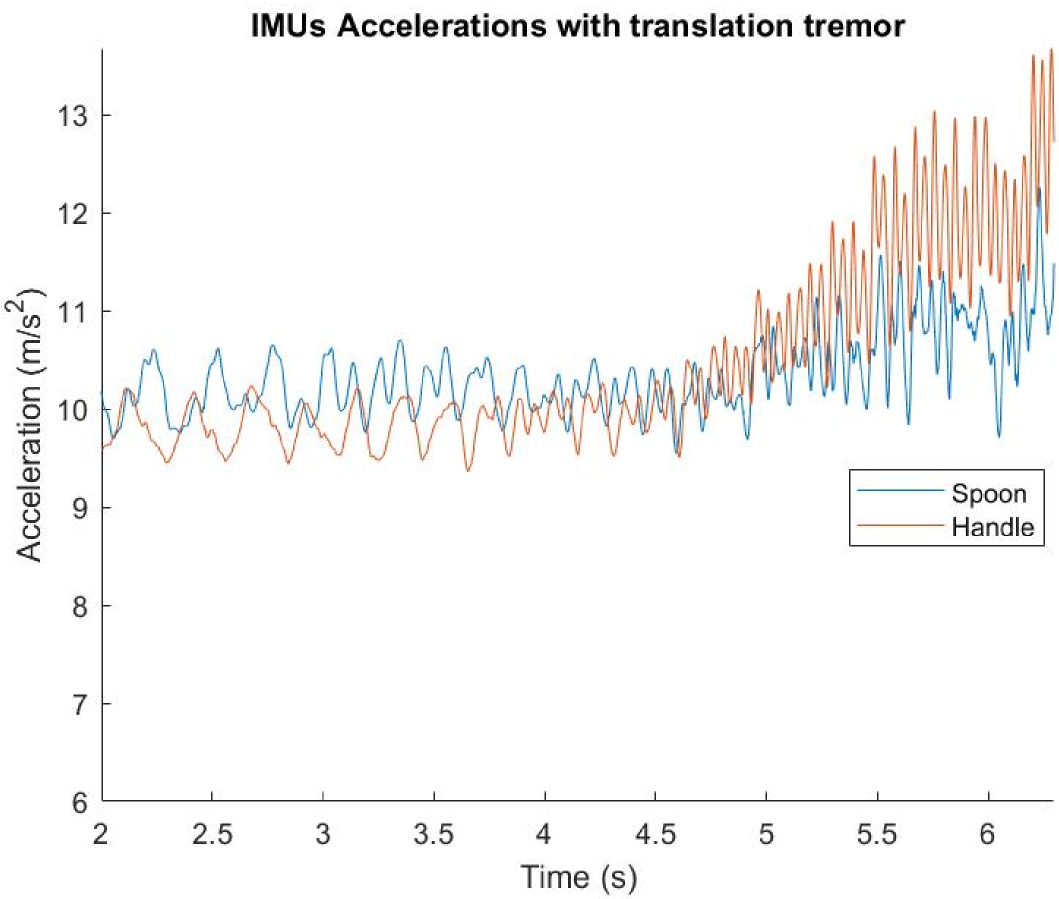

Figure 3.16: Graphic showing acceleration over time for the translation tremor test

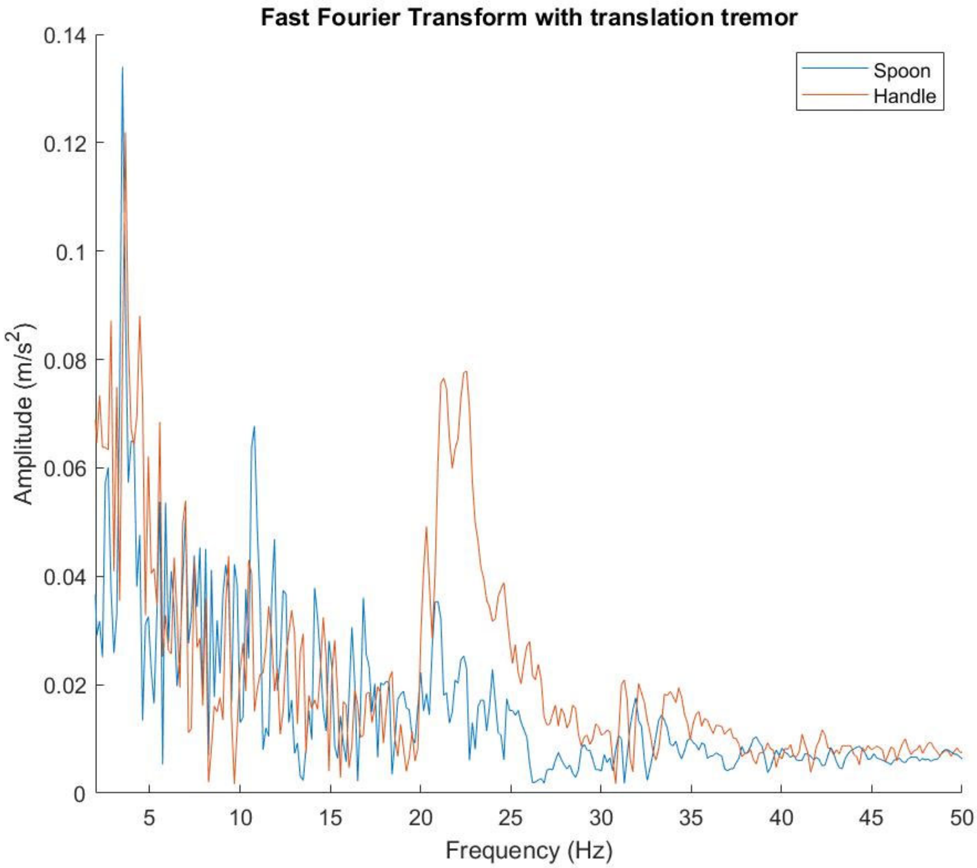

Figure 3.17: Graphic showing the Fast Fourier Transform of the translation tremor test

As presented in figure 3.16, for time <4.5s, which is a low-frequency movement, the prototype did not significantly damp the vibrations. The handle signal and the spoon signal follow each other with a small delay. Figure 3.17 confirms this and shows that frequencies lower than 20 Hz are not damped. This is not surprising considering that the second DoF of the prototype is a pendulum and that, by moving the center of rotation sideways, the lower part of the pendulum (the spoon) must follow the movement with a certain delay. However, for higher frequencies (>20 Hz), the prototype reduces the amplitude of the vibrations effectively. The fact that the prototype doesn't damp low-frequency vibrations for this direction isn't dramatic; the configuration is made this way so that the spoon always remains in an orientation that prevents the food from spilling. Also, when testing the second DoF with food in the spoon, we observed that the pendulum effect helped keep the food inside the spoon. So, even if the spoon is oscillating, the circular trajectory followed prevents the food from spilling out. From 5 Hz to 20 Hz, the sum of amplitude is 2.09 m/s^2 for the handle and 2.32 m/s^2 for the spoon, an 11% augmentation. From 20 Hz to 40 Hz, the sum of amplitude is 2.86 m/s^2 for the handle and 1.30 m/s^2 for the spoon, a 54.55% diminution. This means that the prototype doesn't counteract tremors in the 5-20Hz interval but is effective in the 20-40Hz interval.

Methodology of occupational therapists' review

During the development process, the different prototypes generated were presented to OTs and their comments were taken into account to improve the solutions. Two copies of the final spoon solution were produced and given to different therapists to test and evaluate.

Occupationnal therapists' review

The OTs mentioned that the main advantage of the final prototype is that it is less expensive than the commercially available solutions that need to be charged (active solutions). Since this is not the final version of the prototype, it is hard to conclusively evaluate the ultimate cost of the final design, but the price will certainly be under CA$100. Another advantage is that the prototype is easy to clean and it is possible to interchange the spoon with a fork.

The main drawback observed with the prototype is that its use is non-intuitive. The prototype presented in this paper doesn't have a classic utensil shape, and it may initially be difficult for users to understand how to hold it. A further drawback observed is that the utensil is not compact enough and would be difficult to transport. The final drawback is that the prototype is not "normalized" for the user, meaning that users may feel self-conscious using the utensil because of its abnormal aesthetic.

Discussion and conclusion

The results of the vibration tests show that the final prototype counteracts pro/supi tremors effectively for a vast interval of frequencies. However, the solution is not effective to counteract translation tremors with a frequency lower than 20Hz. This is not dramatic because even if the prototype doesn't counteract low-frequency tremors perfectly in this direction, the circular trajectory followed by the spoon prevents the food from spilling out. For higher frequencies of translation tremors, the prototype reduces effectively the amplitudes of vibrations. The frequency analysis show that the prototype's performances are satisfying but it also shows that it would need to be improved to counteract more lower-frequency translation tremors. A possible solution could be to improve the axis 2 joint in order to reduce the friction present. The current joint is made of a dowel pin and a slide-fit hole, a bushing could be added to reduce even more the friction. The occupational therapists review provided important information from a health professional point of view about the performances of the final prototype. The review pointed out different drawbacks that are going to be considered when future iterations of the anti-tremor utensil will be designed. Generating future iterations of the prototype that are more compact and more aesthetic will require the assistance of an industrial design professional. Even if several drawbacks were observed, the final prototype remains in their opinion a good potential option to replace the expensive active solution available on the market. The next step will also consist in testing the device with people with tremors in order to assess the solution in real situation and to improve the device accordingly with the results.

Acknowledgments

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Links to the tremor videos analyzed and the time where a tremor pattern was observed:

https://www.youtube.com/watch?v=eZvvB9WX1Tg&ab_channel=ChannelsTelevision (@ 0:45)

https://www.youtube.com/watch?v=WiVQcgmIi08&ab_channel=BrianMKAllen (@ 0:06, 0:38, 0:56, 1:14)

https://www.youtube.com/watch?v=dVd7M7xuK5w&ab_channel=CTOOMCreative (@ 0:08, 0:13)

https://www.youtube.com/watch?v=SFnWIqQ1z60&ab_channel=STAT (@ 0:42, 0:49)

https://www.youtube.com/watch?v=99t5c6j8BR0&ab_channel=AssociatedPress (@ 0:12)

https://www.youtube.com/watch?v=Yn8VDA_I6b8&ab_channel=Liftware (@ 2:33)

Lien avec les travaux du laboratoire

Les travaux présentés dans ce mémoire sont en lien avec différents travaux effectués au cours des dernières années en ingénierie de la réadaptation au Centre interdisciplinairede recherche en réadaptation et intégration sociale (CIRRIS) et au laboratoire de robotique de l'Université Laval. Afin de mettre les travaux de ce mémoire dans ce contexte et de donner des références au lecteur par rapport à ces travaux afin de continuer ses lectures, voici une courte mise en contexte. L'objectif des travaux du groupe d'ingénierie de la réadaptation à l'Université Laval est de développer des technologies d'assistances pour les personnes en situation de handicap et pour prévenir les blessures en milieu de travail. Les travaux portent sur le développement de mécanismes d'assistance [1, 2, 3, 4, 5, 6, 7], d'algorithmes intelligents pour robots d'assistance [8, 9, 10, 11, 12, 13, 14, 15] d'interfaces de contrôle pour robots d'assistances [16, 17, 18, 19, 20, 21, 22, 23, 24, 25], l'évaluation des technologies d'assistance [26,27, 28, 29], ainsi que le développement de technologies pour le suivi du mouvement et de la fatigue musculaire en milieu réel [30, 31, 32, 33, 34, 35, 36].

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Conclusion

L'objectif de ce projet de maîtrise était de développer différentes technologies d'assistance à l'alimentation pour les personnes vivant avec des difficultés de mouvement aux membres supérieurs (tremblements, spasmes, ataxie, dystonie). Afin que les personnes atteintes puissent avoir un mode de vie plus autonome, plusieurs solutions sont offertes commercialement mais il a été démontré que certains facteurs limitent leur utilisation. La solution a été de développer deux différents systèmes d'aide à l'alimentation plus abordables que ceux que l'on retrouve sur le marché et en considérant l'avis d'ergothérapeutes. La première solution développée est un système utilisant des mécanismes à quatre barres afin de maintenir l'orientation de la cuillère constante, il comporte également des amortisseurs pour réduire l'impact des mouvements brusques. La deuxième solution développée est un nouveau prototype de cuillère anti-tremblements qui utilise le principe de contrepoids afin de stabiliser la cuillère. Les deux projets ont été développés en suivant une méthodologie itérative donc les versions présentées dans le mémoire ne sont pas les versions finales de chacun des projets.

Les travaux futurs sur le premier système d'aide à l'alimentation développé consisteront à faire des essais expérimentaux avec des utilisateurs potentiels afin d'analyser les avantages et inconvénients de la dernière version du mécanisme. Les travaux futurs porteront également sur la commercialisation du mécanisme, des modifications afin de le rendre plus esthétique et plus facile à transporter devront être effectuées. Une équipe de design de produit travaille présentement sur cet aspect du projet. Les prochaines étapes du projet de cuillère anti-tremblements consisteront à améliorer le mécanisme développé en prenant en considération les commentaires émis par les ergothérapeutes et de poursuivre le processus de développement itératif en testant de nouveau les futures versions. Les travaux d'ingénierie réalisés s'inscrivent aussi dans un programme de recherche de plus grande envergure visant à développer différents systèmes d'aides techniques. Les connaissances acquises lors de la réalisation de cette maîtrise seront grandement utiles pour le développement de futures technologies d'assistances à l'alimentation.

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