Toni Mandušić

N·EXAMINER - INNOVATIVE DIGITAL MEASUREMENT DEVICE FOR NEAR POINT OF CONVERGENCE AND NEAR POINT OF ACCOMMODATION

An Innovation Project

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ABSTRACT

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Purpose: The purpose of the N·Examiner master thesis project is to develop and evaluate an innovative digital measurement device for assessing the near point of convergence (NPC) and near point of accommodation (NPA). This device aims to replace manual measurement methods, providing increased precision and ease of measurement, thus enhancing clinical diagnostic capabilities in ophthalmology and optometry.

Methods: The N·Examiner project was conducted in two sequential phases. Phase one involved utilizing laser measurement technology to develop the initial prototype of the measurement device. Then the prototype successfully underwent usability testing. In the subsequent phase, the project advanced to incorporate more sophisticated LiDAR (Light Detection and Ranging) measurement technology. This transition aimed at refining and validating the device further. The comparison lies in the progression from laser to LiDAR technology. While the sample size (n) and specific demographics are unspecified, the study is situated in a simulated clinical setting. The timeline for these phases, structured from 2021 to 2023, is designed to systematically develop and enhance the N·Examiner device. This project did not involve any human subject testing, and therefore an IRB approval was unnecessary.

Results: The N·Examiner project generates promising results in both phases. The laser-based prototype significantly improved precision and ease of measurement compared to traditional manual methods. However, the transition to LiDAR technology in the second phase marked a substantial leap forward. The N·Examiner devices, utilizing LiDAR technology, demonstrated remarkable accuracy and efficiency in assessing NPC and NPA.

Conclusion: The N·Examiner master thesis project has successfully addressed the need for innovation in the field of ophthalmology and optometry by creating digital measurement devices for NPC and NPA. LiDAR technology has revolutionized the accuracy and ease of measurement, surpassing traditional manual methods. This device offers immense potential for enhancing clinical diagnostics and improving patient care. The N·Examiner project represents a significant advancement in the field, potentially transforming how eye professionals assess and manage visual disorders related to NPC and NPA.

Keywords: vergence, accommodation, near point of convergence, near point of accommodation, digital measurement devices

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1. INTRODUCTION

The assessment of the near point of convergence (NPC) and near point of accommodation (NPA) plays a pivotal role in ophthalmology and optometry. These parameters are critical indicators of an individual's visual function, helping clinicians diagnose various visual disorders and eye conditions. Traditionally, the measurement of NPC and NPA has relied on manual methods involving subjective assessments, such as penlight or targets, which are inherently prone to human error and variability. As a result, the need for accurate, objective, and efficient measurement tools has long been recognized within the field.

Precise measurement of NPC and NPA is essential in diagnosing and managing various visual conditions, including convergence disorders, accommodative disorders, and strabismus. Accurate assessment of these parameters allows clinicians to tailor treatments and interventions more effectively, ultimately improving patient outcomes.

Developing innovative digital measurement devices for NPC and NPA represents a significant advancement in the field. These devices aim to address the limitations of manual methods by providing objective, quantifiable, and repeatable measurements, thereby enhancing the quality of eye care and contributing to a deeper understanding of visual function.

2. THEORETICAL BACKGROUND

The theoretical underpinning of the N·Examiner project lies in the fundamental concepts of convergence and accommodation in human vision.

2.1. Convergence

Convergence refers to the inward coordinated movement of both eyes to focus on a near object. The near point of convergence (NPC) is the closest point at which the eyes can converge while maintaining a single binocular vision. (Cooper J, Duckman R. 1978 Jun;49(6):673-680) Accurate measurement of NPC is crucial in diagnosing conditions like convergence insufficiency, which can lead to eye strain, double vision, and reading difficulties.

Convergence can be categorized into three components: tonic, accommodational, and fusional, as articulated by Maddox. Tonic convergence pertains to a continual inward movement of the eyes, persisting even without a visual stimulus. In practical terms, the standard reference distance is six meters, where 0.16 diopters of accommodation and one prism diopter of convergence are typically engaged. While Maddox introduced the term "tonic", it's noteworthy that this form of convergence aligns with fusional convergence, as the same fusion innervation operates both at a distance and the near point. (Gantz, Liat & Stiebel-Kalish, Hadas. 2021)

Accommodational convergence arises from and correlates with any accommodational exertion. These functions are intertwined, with a measurable convergence occurring concurrently with the contraction of the ciliary muscles. Approximately eighteen prism diopters are needed at the near point (33 cm), contingent upon interpupillary distance. Given the variability in accommodation, the final adjustment is identified as fusional convergence. In cases of insufficient accommodational convergence, fusional convergence becomes positive (adductive), while excessive accommodational convergence results in negative fusional convergence (abductive). Any lateral muscle imbalances manifest as vergence errors, and fusional convergence serves as the innervation correcting imbalances at the near point. (Dobson, 1941)

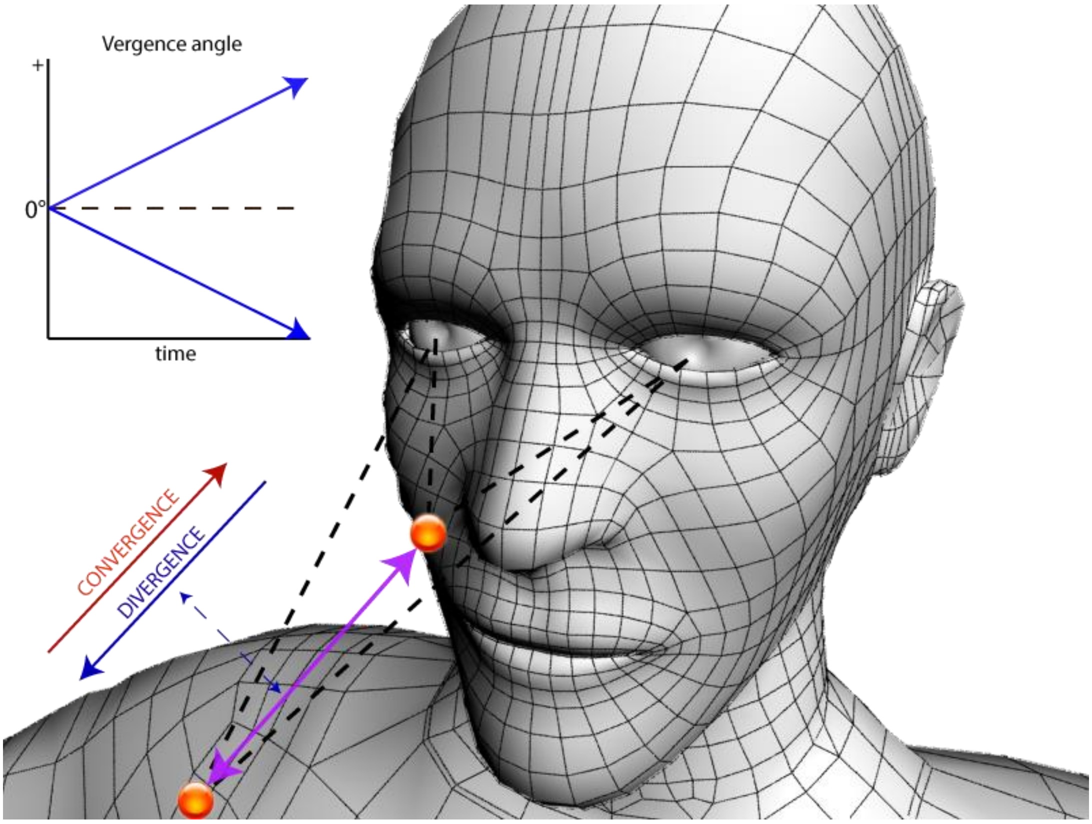

FIGURE 1. Convergence and divergence. Source: Toni Mandušić

2.1.1. Convergence and the Brain: Understanding the Process

Eye convergence is a remarkable and highly coordinated process that involves the brain and ocular muscles working together to ensure that both eyes are focused on a near object. This binocular vision phenomenon is essential for clear and accurate vision when reading, working on a computer, or engaging in any task requiring a close-up view. Here is a closer look at how eye convergence works and the brain's critical role in this process.

The Mechanics of Eye Convergence:

Visual Stimulus: Eye convergence typically begins with a visual stimulus, such as a book, screen, or any nearby object. When an individual chooses to shift their gaze from a distant point to something located up close, their brain undergoes a process to accommodate this change in focus. Retinal disparity, the slight difference in the images seen by each eye, plays a crucial role in initiating vergence eye movements. (Gonzalez & Perez, n.d.) Retinal disparity serves as a powerful cue for the visual system to perceive depth and trigger appropriate vergence responses.

Brain Signal: The brain's visual processing centres receive the signal, indicating the need for a closer view. This signal initiates the process of convergence. (Gonzalez & Perez, n.d.)

Ocular Muscles: The brain sends signals to the extraocular muscles, which control the movement of the eyes. These muscles move the eyes in various directions, including turning them inward during convergence. (Dobson, 1941)

Inward Movement: In response to the brain's signal, the extraocular muscles contract and cause both eyes to turn inward towards each other. This inward movement, known as convergence, ensures that the line of sight of both eyes intersects precisely at the object of interest. (J. , & D. R. Cooper, 1987b)

Binocular Vision: Due to the coordinated convergence, each eye captures a slightly different image of the same object from its unique perspective. The brain then processes these two disparate images and merges them into a single, three-dimensional perception, providing depth and clarity to the object. (J. , & D. R. Cooper, 1987b)

Brain Functions Involved in Convergence:

Several brain functions are essential for the successful execution of eye convergence:

Visual Cortex: The occipital lobe, situated at the posterior part of the brain, houses the visual cortex, which plays a important role in the interpretation of visual stimuli received from the eyes. It interprets the images captured by each eye during convergence and fuses them to create a unified perception of the object. while the occipital lobe houses the primary visual cortex for initial visual processing, the parietal lobe and frontal eye fields, located in the parietal and frontal lobes, respectively, play crucial roles in higher-order visual processing, spatial awareness, attention, and the voluntary control of eye movements. These brain regions work together to support complex visual perception and the integration of visual information with motor and cognitive functions. (Purves, 2001)

Cranial Nerves: The brain communicates with the extraocular muscles through cranial nerves, particularly the oculomotor nerve (cranial nerve III). These nerves transmit the brain's commands to the muscles, controlling their precise movements during convergence. (Purves, 2001)

Vergence Center: Within the brainstem is a specific area known as the vergence centre, which coordinates the convergence response. This region integrates sensory input related to the distance and position of objects and sends appropriate signals to the extraocular muscles to initiate and regulate convergence. (Guyton, 2015; Purves, 2001)

Sensory Integration: The brain processes information from multiple sensory sources, including visual cues and proprioceptive feedback from the eye muscles. (Purves, 2001) This sensory integration allows the brain to finely adjust the degree of convergence based on the specific viewing distance.

In brief, eye convergence is a complex process involving precise communication between the brain and the ocular muscles. This coordinated effort ensures that both eyes remain aligned and focused on a near object, facilitating clear and accurate binocular vision for various tasks. (Guyton, 2015; Purves, 2001) The integral function of the brain in consolidating and processing visual inputs from both eyes is crucial for forming a cohesive perception of the surrounding environment.

Key principles and theoretical aspects of convergence include:

2.1.1.1. Heterophoria and Heterotropia

Convergence can be categorized into two main conditions: heterophoria and heterotropia. Heterophoria refers to the tendency of the eyes to deviate from parallel alignment when not actively fixating on a target. Heterotropia, on the other hand, represents a manifest misalignment of the eyes at all times. Understanding these conditions is essential for diagnosing convergence-related disorders. (Dobson, 1941)

2.1.1.2. Near Point of Convergence (NPC)

The near point of convergence (NPC) is a critical parameter associated with convergence. It represents the closest point at which both eyes can maintain fusion and focus on a near object. (J. , & D. R. Cooper, 1987b) The NPC is typically measured in centimetres or prism diopters. A normal NPC is crucial for comfortable reading and other near tasks.

2.1.1.3. Convergence Insufficiency

Convergence insufficiency is a common binocular vision disorder where the eyes have difficulty converging sufficiently to focus on near objects. This condition can result in symptoms such as eye strain, double vision, and difficulty sustaining near tasks. (J. , & D. R. Cooper, 1987b) A theoretical understanding of convergence insufficiency is essential for effectively diagnosing and managing this condition.

2.1.1.4. Convergence Excess

Convergence excess is the opposite of convergence insufficiency, where the eyes over-converge when attempting to focus on near objects. This condition can also lead to visual discomfort and symptoms such as eye strain. (Mitchell, 2019) A theoretical grasp of convergence excess is essential for differentiating it from other convergence disorders.

2.1.1.5. Vergence Eye Movements

The convergence process involves vergence eye movements, where the extraocular muscles work in a coordinated manner to bring the eyes together. Theoretical models of vergence movements, including the role of the cranial nerves and brainstem pathways, provide a foundation for understanding the physiology of convergence. (J. , & D. R. Cooper, 1987b)

2.1.1.6. Clinical Implications

Theoretical knowledge of convergence is crucial in clinical practice since accurate assessment of convergence disorders is essential for diagnosing and treating visual discomfort and binocular vision problems. Theoretical models help clinicians interpret assessment results, plan treatment strategies, and optimize patient care. (Ciuffreda, 1992a, 1992c; M. , C. S. , R. M. , & B. E. Scheiman, 2009a)

In summary, the theoretical background of convergence encompasses the principles of binocular vision, the mechanisms of eye movement, and the clinical implications of convergence-related disorders. This knowledge is the foundation for developing innovative digital measurement devices like the N·Examiner, which aims to objectively assess convergence parameters and improve the diagnosis and management of convergence-related visual conditions.

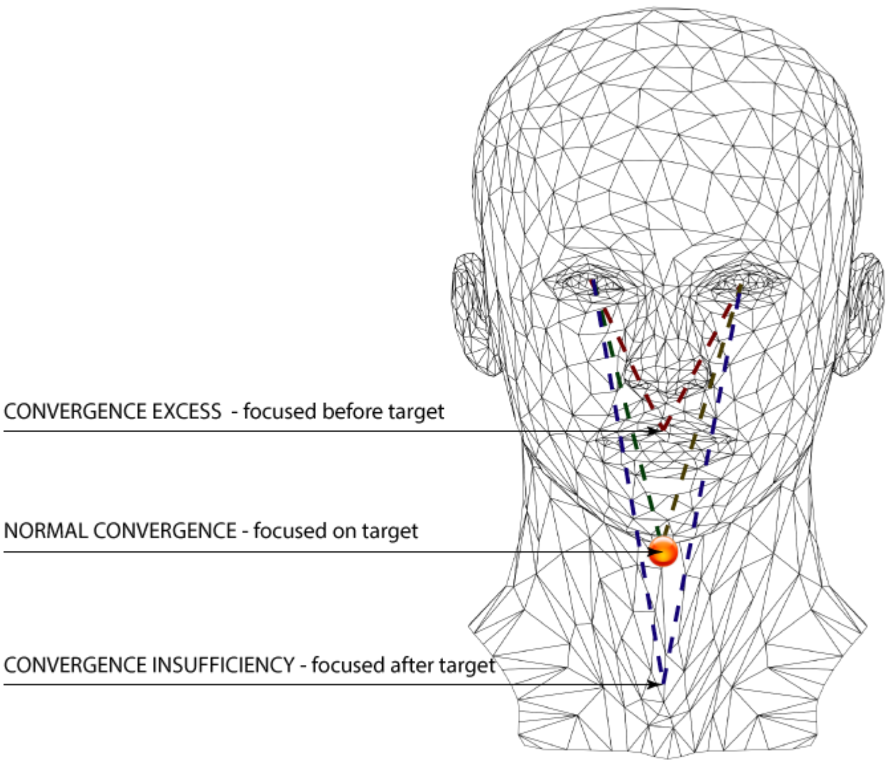

FIGURE 2. Convergence   Source: Toni Mandušić

2.2. Accommodation

Accommodation is a fundamental visual process that allows the eye to adjust its focus from distant to near objects by changing the shape of the crystalline lens. This physiological phenomenon is essential for maintaining clear, sharp vision at various distances.

For over 250 years, it has been widely acknowledged that accommodation entails a modification in the refractive power of the eye, primarily attributed to alterations in the crystalline lens. The earlier conjectures of Descartes and other scholars regarding variations in the shape and potency of the crystalline lens were substantiated through meticulous investigations by Young, and these notions have garnered continued substantiation through subsequent experiments. (Sotiris Plainis, 2014) However, a contentious aspect remains concerning whether minor adjustments in corneal curvature, axial length, and lens position transpire during the accommodation process.

In line with the traditional perspective articulated by Helmholtz, the process of accommodation involves the ciliary muscle contracting, leading to a forward and inward movement. Simultaneously, the zonules connecting the ciliary body to the lens undergo relaxation. Consequently, the lens thickens and assumes a more steeply curved shape, thereby enhancing the eye's refractive power. (Sotiris Plainis, 2014)

The elastic lens capsule moulds the lens into an accommodated state. Nevertheless, the lens, situated within the eye, is upheld by zonular fibres that anchor around the equator of the lens. These zonular fibres exert supplementary forces on the lens capsule, contingent upon their tension levels. Subsequently, the capsule evenly distributes these forces across the lens, potentially inducing changes in its shape. According to Rohen, three sets of anterior zonular fibres are connected near the lens equator. Among these, two sets are affixed approximately 1.5 mm anterior and posterior to the lens equator, while the third, more delicate set attaches along the equator. (Momeni-Moghaddam et al., 2014)

In the unaccommodated state, when the eye is focused for distance vision and accommodation is relaxed, the apex of the ciliary muscle exhibits a relatively large diameter. Simultaneously, the anterior zonular fibres experience tension from the posterior pars plana fibres, causing them to stretch. This tension in the anterior zonule exerts robust radial forces on the lens capsule, leading to its stretching. Consequently, the lens undergoes a flattening process, reducing its optical power to a level suitable for distance vision. (Borsting, 2003) These alterations are accompanied by an increase in the lens diameter and a simultaneous decrease in thickness.

Near vision demands accommodation, a process initiated by the contraction of the ciliary muscle. This action alleviates tension in the anterior zonular fibers while imposing tension on the posterior elastic tissues as the muscle shifts forward and inward. Consequently, the integrated lens-capsule system undergoes a transformation, adopting a more potent configuration comparable to its isolated state in vitro. This transformation is characterized by heightened surface curvatures, increased lens thickness, and a reduction in lens diameter, ultimately resulting in a heightened lens power.(Momeni-Moghaddam et al., 2014)

Additionally, there is a proposal indicating that the vitreous humor provides structural support to the periphery of the lens, aiding in the alteration of the lens shape in conjunction with variations in the pressure gradient between the vitreous humor and the anterior chamber. (Sotiris Plainis, n.d.) Opposing viewpoints suggest a limited involvement of the vitreous in accommodation, contending that its impact, at most, assumes a subordinate rather than a primary role in the process.

The theoretical background of accommodation encompasses several key concepts:

Crystalline Lens: The crystalline lens, located behind the iris and the pupil, is a flexible and transparent structure within the eye. It plays a central role in the process of accommodation. The lens can change its shape, becoming more rounded or flattened, to alter its refractive power and focus light rays onto the retina.(Sotiris Plainis, 2014)

Presbyopia: Presbyopia is a prevalent age-related condition that impacts the capacity for effective accommodation. With ageing, the crystalline lens loses its flexibility and becomes less capable of changing shape to accommodate near objects. (Martin Giesel, 2019; Sotiris Plainis, 2014) This results in difficulty focusing on close-up tasks, such as reading, and necessitates the use of reading glasses or bifocal lenses.

2.2.1. Eye Accommodation and the Brain: A Dynamic Vision Process

Eye accommodation is a remarkable and dynamic process that allows the eyes to adjust their focus to see objects clearly at different distances. This ability is crucial for daily activities such as reading, driving, and observing the world around us. Accommodation involves a complex interplay between the eyes and the brain, and understanding this process sheds light on how we perceive our surroundings.

Mechanics of Eye Accommodation:

Visual Stimulus: Accommodation begins with a visual stimulus, typically when you shift your gaze from a distant object to something up close or vice versa.

Change in Lens Shape: When you decide to focus on a closer object, the ciliary muscle located within the eye contracts. This muscle change leads to a change in the shape of the eye's crystalline lens. The lens becomes more rounded or thicker, allowing incoming light rays to bend more strongly. (Sotiris Plainis, 2014)

Refraction of Light: The refractive power of the eye's lens increases as it thickens. This increased refractive power helps to converge light rays from the closer object onto the retina's focal point, creating a sharp and clear image on the retina. (Burd et al., 1999)

Varying Focal Length: The ability of the eye's lens to change shape, and therefore its focal length, allows it to adjust quickly and accurately to accommodate different viewing distances. This process is known as accommodation (Burd et al., 1999).

Brain Functions Involved in Accommodation:

Several brain functions are essential for the successful execution of eye accommodation:

Visual Cortex: The occipital lobe, positioned at the rear of the brain, houses the visual cortex, which serves as a main hub for processing incoming visual data. It receives signals from the retina about the level of blur or clarity in the image and interprets this information to determine the need for accommodation. (Purves, 2001)

Autonomic Nervous System: Operating within the peripheral nervous system, the autonomic nervous system regulates physiological functions that transpire autonomously, devoid of conscious oversight. In the context of accommodation, the autonomic nervous system regulates the contraction and relaxation of the ciliary muscle and the pupillary sphincter muscle. The autonomic nervous system's parasympathetic division, via the oculomotor nerve (cranial nerve III), stimulates the ciliary muscle to contract during accommodation. (Purves, 2001)

Sensory Feedback: The brain relies on sensory feedback to assess the level of accommodation required. This feedback includes input from the eye's retina and information about the perceived distance of objects. The brain continuously processes this sensory input to ensure the eyes are focused appropriately. (Gonzalez & Perez, n.d.)

Integration and Adjustment: The brain integrates visual input with sensory feedback and adjusts the contraction of the ciliary muscle to achieve the necessary degree of accommodation. This real-time adjustment ensures that objects at varying distances remain in focus (Burd et al., 1999).

In summary, eye accommodation is a dynamic and coordinated process involving both the eyes and the brain. It allows us to maintain clear vision at different distances by adjusting the shape of the eye's lens. The brain plays a crucial role in this process, continuously monitoring visual input and coordinating the changes necessary for precise and comfortable vision. Understanding accommodation highlights our visual system's intricate and adaptive nature, enabling us to perceive the world clearly and accurately (Horwood et al., 2014).

2.2.1.1. Amplitude of Accommodation

The amplitude of accommodation refers to the range of distances over which the eye can change its focus effectively. It is typically measured in diopters and varies from person to person. (Ciuffreda, 1992b) The theoretical understanding of the amplitude of accommodation is crucial for assessing the accommodative ability of an individual.

2.2.1.2. Accommodative Response

Accommodative response is the dynamic process by which the eye adjusts its focus in response to changes in object distance. When observing close objects, the ciliary muscle undergoes contraction, leading to a change in the curvature and refractive power of the crystalline lens. Understanding the mechanics of accommodative response is essential for comprehending how the eye maintains clear vision at varying distances. (Ciuffreda, 1992d) The concepts of "lag of accommodation" and "lead of accommodation" are related to the accommodative response and refer to the relationship between the stimulus for accommodation and the actual accommodative response.

2.2.1.3. Accommodative Disorders

Accommodative disorders, such as accommodative insufficiency, accommodative spasm, accommodative infacility, and ill-sustained accommodation can lead to blurred vision, eyestrain, and discomfort during near tasks. Accommodative insufficiency means difficulty sustaining clear focus for near tasks due to inadequate accommodative ability. Accommodative spasm is involuntary and prolonged contraction of the ciliary muscle, causing persistent accommodation. Accommodative infacility means difficulty in changing focus efficiently between near and far objects. Ill-Sustained accommodation is inability to maintain clear vision for an extended duration, especially during prolonged near tasks. (Ciuffreda, 1992b)

2.2.1.4. Accommodation and Binocular Vision

Accommodation is closely intertwined with binocular vision, as it must work in concert with convergence to provide single, fused vision at various distances. Theoretical models of binocular vision help elucidate the coordination between convergence and accommodation, contributing to a holistic understanding of visual function. (M. , & W. B. Scheiman, 2013c)

2.2.1.5. Clinical Applications

Theoretical knowledge of accommodation is critical in clinical optometry and ophthalmology. It guides the assessment of accommodative disorders, the prescription of corrective lenses, and the management of conditions like presbyopia (Kothari et al., 2009) Accurate measurement and evaluation of accommodation parameters are essential for optimizing visual comfort and performance.

TABLE 1. Relationship between age and amplitude of accommodation

Donder's Amplitude of Accommodation and Age			
Age (years)	**Amplitude (D)**	**Age (years)**	**Amplitude (D)**
10	14.00	45	3.50
15	12.00	50	2.50
20	10.00	55	1.75
25	8.50	60	1.00
30	7.00	65	0.50
35	5.50	70	0.25
40	5.00	75	0.00

In summary, accommodation is a complex visual process involving the dynamic interplay of the crystalline lens, ciliary muscle, and neural pathways. A comprehensive theoretical background of accommodation is vital for diagnosing and managing visual conditions related to accommodative function, ensuring clear and comfortable vision at various distances.

2.2.2. Assessment of Binocular Vision and Accommodation

The evaluation of binocular vision and accommodation is a cornerstone in optometry and ophthalmology, empowering eye care experts to assess the visual system's performance and identify any underlying irregularities. (Scheiman, 2013) This comprehensive review discusses the key aspects of binocular vision and accommodation assessment, including the tests and techniques used, their clinical significance, and their relevance to diagnosing and managing visual disorders.

Assessment of Binocular Vision:

Stereopsis Assessment: Stereopsis, or depth perception, is crucial for accurate three-dimensional vision. Tests like the Random Dot Stereogram (RDS) and the Titmus Fly Stereotest measure patients' ability to perceive depth and binocular vision (Benjamin, 2006).

Cover Tests: Cover tests assess ocular alignment and detect strabismus (eye misalignment). The alternate cover test, unilateral cover test, and cross-cover test are commonly employed to evaluate binocular alignment and fixation disparity. (M. , & W. B. Scheiman, 2013c)

Fusional Vergence Testing: Fusional vergence tests, including the NPC and positive and negative fusional vergence (PFV and NFV), assess the ability to maintain binocular alignment during convergence and divergence. (Ciuffreda, 1992d)

Stereoscope Testing: Stereo tests, such as the Titmus Stereo Test, TNO Stereo Test, Bernell Stereo test, Frisby Stereo Test, Random Dot Stereo Tests and Lang Stereo Test, evaluate binocular vision by assessing fusion and suppression in patients with strabismus.

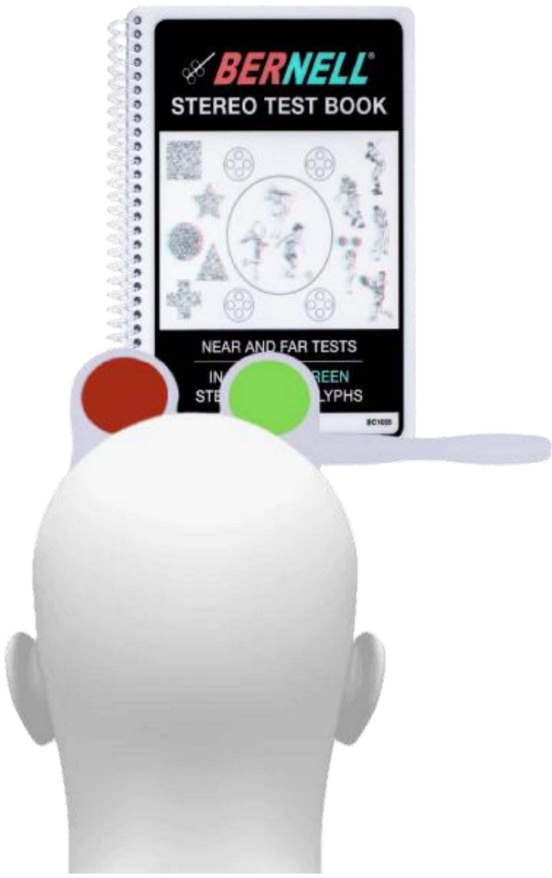

FIGURE 3. Bernell stereo test. Source: Toni Mandušić

Assessment of Accommodation:

Amplitude of Accommodation: This test measures the maximum focusing range of the eye. Instruments like the push-up and push-down methods determine the amplitude of accommodation.

Accommodative Facility: Accommodative facility tests evaluate the speed and accuracy of the eye's focusing ability during near-to-far and far-to-near transitions. (Hofstetter, n.d.-a) Examples include the Nott Retinoscopy and Hart Chart tests.

Monocular Accommodation: The monocular estimation method assesses the accommodation response in each eye individually, aiding in the detection of accommodative disorders. (M. , & W. B. Scheiman, 2013b)

Dynamic Retinoscopy: This technique involves retinoscopy while the patient views a near target, providing valuable information about accommodation and potential lag or lead (K.J.,&L.D.P. Ciuffreda, 1992).

Clinical Significance: Assessing binocular vision and accommodation is critical for diagnosing and managing various visual conditions, including amblyopia, strabismus, convergence insufficiency, and accommodative disorders. (J. , & D. R. Cooper, 1987a; Hofstetter, n.d.) Accurate assessment guides treatment decisions, such as prescribing corrective lenses, vision therapy, or surgical interventions.

In summary, assessing binocular vision and accommodation is essential in clinical practice to diagnose visual disorders accurately and guide treatment strategies. (M. , & W. B. Scheiman, 2013a; Von Noorden, 2002) A thorough evaluation of these functions contributes to improved patient care and visual comfort.

2.3. Fixation Disparity

Each location on one eye's retina corresponds to a region on the retina of the opposite eye, forming Panum's fusional areas, named after their discoverer. These cortical-origin areas are elliptical, with a horizontal longer axis, covering approximately five minutes of arc in the central region (potentially even less for the highly central foveal elements). As we move towards more peripheral areas, these fusional areas expand, potentially subtending several degrees of arc due to the decreasing density of cones.

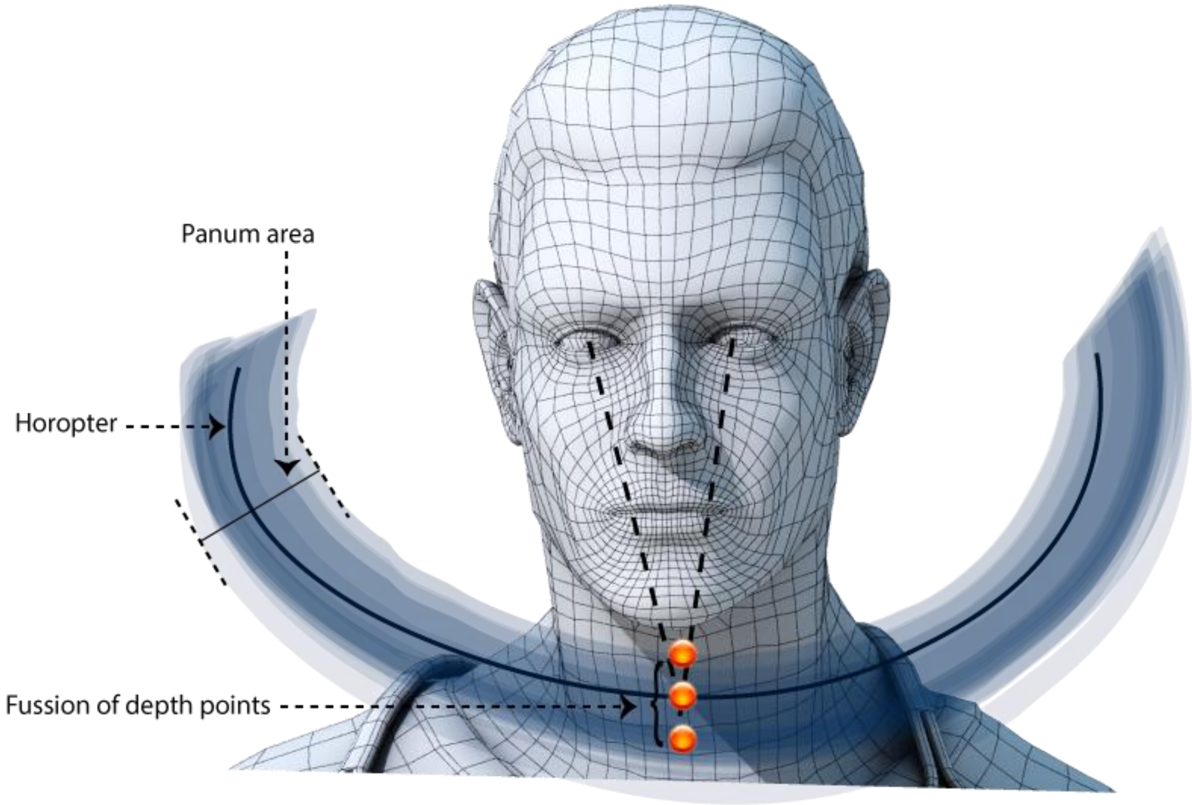

FIGURE 4. Objects situated beyond Panum's fusional area manifest as physiological double vision. Source: Toni Mandušić

Panum's fusional space, the spatial equivalent, is situated between two curved planes flanking the horopter. Items located within Panum's fusional space are perceived as singular entities, yet the ability to discern depth is facilitated by the subtle angular disparity among the retinal elements constituting Panum's areas.(Maples, 2007) Items situated beyond the boundaries of Panum's fusional area manifest as instances of natural double vision.

When fusional reserves encounter difficulty compensating for the phoria, Panum's areas can be utilized to sustain single vision. This involves permitting a minor misalignment of the visual axes without inducing diplopia (figure 4). Generally, this tolerance is approximately five minutes of arc, corresponding to the central Panum's areas. It remains consistent irrespective of the size of the uncompensated phoria. Notably, the larger, more peripheral Panum's areas are not applicable for this purpose unless the central ones are actively suppressed..(Maples, 2007) The degree of deviation from the point of aligned gaze that doesn't induce double vision is referred to as fixation disparity.

2.4. Measuring Near Point of Convergence (NPC) and Near Point of Accommodation (NPA)

Accurate measurement of the Near Point of Convergence (NPC) and Near Point of Accommodation (NPA) is essential in ophthalmology and optometry for diagnosing and managing various visual disorders. A solid theoretical background in these measurement techniques is crucial for understanding their clinical significance and the need for innovation in measurement devices such as the N·Examiner.

2.4.1. Near Point of Convergence (NPC) Measurement

Convergence Reflex: The NPC represents the closest point at which both eyes can converge while maintaining single binocular vision. This measurement is a critical indicator of the convergence reflex, which is the coordinated inward movement of the eyes when focusing on a near object. (Ciuffreda, 1992b) Theoretical models of the convergence reflex describe how the extraocular muscles, cranial nerves (particularly the oculomotor nerve), and brainstem pathways work together to achieve convergence.

Assessment Techniques: Traditional NPC measurement techniques involve asking the patient to fixate on a target held at various distances from the eyes. The examiner observes the point at which the patient's eyes can no longer maintain fusion and develop double vision. (Martin Giesel, 2019; M. , & W. B. Scheiman, 2013b) The theoretical understanding of these techniques underscores the importance of precise measurement and the potential sources of error.

There are studies that have investigated and compared different test targets used in NPC testing. These studies aim to evaluate the reliability and validity of various targets and methods for assessing convergence ability. Here are a few examples:

- Title: A comparison of different near point of convergence targets. Authors: Daum, K. M., & Rutstein, R. P.
- Title: Comparative study of three dynamic convergence tests. Authors: Kim, K. W., & Kim, J. H.
- Title: A comparison of near point of convergence and accommodative facility testing in symptomatic and asymptomatic individuals aged 8 to 18 years. Authors: Borsting, E., Rouse, M. W., & Deland, P. N.

FIGURE 5. Manual methods of NPC measuring. Source: Giovanni Cavalieri

Clinical Significance: NPC measurement is crucial in diagnosing convergence-related disorders like convergence insufficiency. A theoretical foundation in NPC measurement helps clinicians recognize deviations from typical values and guides appropriate interventions.

2.4.2. Interpretation of Break and Recovery Results in the Near Point of Convergence Test

The break point in the NPC test refers to the maximum distance at which a patient can maintain binocular fusion (keeping both eyes focused on the target) before one eye deviates outward or loses fixation. Interpretation of the break point results involves the following considerations:

Normal NPC: In individuals with normal binocular vision, the breaking point typically falls within 5 to 10 centimetres from the patient's eyes. A break point beyond this range may indicate a potential issue with convergence ability. (Momeni-Moghaddam et al., 2014)

Abnormal NPC: A break point significantly beyond the normal range may suggest convergence insufficiency, a common binocular vision disorder. Convergence insufficiency manifests as difficulty converging on near objects, leading to symptoms like eye strain, double vision, and difficulty reading.

Intermittent or Variable Break: In some cases, the break point may be inconsistent, varying from one test to another. In individuals with convergence insufficiency, the break point tends to recede or move further away during repeated measurements. (J. , & D. R. Cooper, 1987b; Mitchell, 2019) This dynamic behavior is often observed during sustained near tasks and can lead to symptoms such as eye strain, headaches, and difficulty concentrating on close work.

Recovery Point Interpretation:

The recovery point in the NPC test refers to the distance at which a patient can regain binocular fusion after experiencing a break (outward deviation) when the target is moved back toward the eyes. Interpretation of the recovery point results involves the following considerations:

Normal Recovery: In individuals with normal binocular vision, the recovery point should be within a few centimetres (typically 2-3 cm) from the breaking point, indicating efficient and rapid recovery of binocular fusion. (Dobson, 1941)

Delayed or Incomplete Recovery: A recovery point significantly beyond the normal range suggests delayed or incomplete recovery of binocular fusion. This may indicate convergence excess, a condition where the eyes over-converge, leading to difficulty relaxing the convergence reflex. (Dobson, 1941)

Variability in Recovery: Similar to break point results, variability in recovery distances may also indicate convergence-related issues, such as convergence excess. (Gonzalez & Perez, n.d.)

Clinical Significance: Interpreting the break and recovery results in the NPC test is essential for diagnosing and managing binocular vision disorders, including convergence insufficiency and convergence excess. (Borsting, 2003; Rouse, 2004; M. , & W. B. Scheiman, 2013c; M. , C. S. , R. M. , & B. E. Scheiman, 2009b) Derived from these findings, potential interventions such as vision therapy or the prescription of prismatic lenses could be suggested to enhance binocular vision and alleviate related symptoms.

2.4.3. Near Point of Accommodation (NPA) Measurement

Accommodative Response: NPA denotes the minimum distance at which an individual can sustain clear visual focus on a nearby object. Theoretical models of the accommodative response explain how the crystalline lens changes shape to adjust its refractive power, allowing the eye to focus on close-up tasks.

This process involves the contraction of the ciliary muscle and the release of tension in the zonular fibres holding the lens.

Measurement Techniques:

There are various measurement techniques for assessing the NPA, each with its own set of pros and cons. Here are some common techniques:

Push-Up Method: The examiner gradually moves a near target toward the subject until the subject reports a blur. *Pros:* Simple and easy to administer. *Cons:* May be influenced by subject cooperation and response criteria. (M. , & W. B. Scheiman, 2013c)

Brock String: A string with beads at different distances is used to assess the NPA by observing when the subject loses fusion. *Pros:* Provides a dynamic assessment of accommodation and convergence. *Cons:* Requires cooperation and may be influenced by subjective responses. (M. , & W. B. Scheiman, 2013c)

Accommodative Facility: Involves rapidly changing focus between near and far targets. *Pros:* Assesses the speed and flexibility of accommodation. *Cons:* Does not provide a specific NPA value. (Ciuffreda, 1992d)

Dynamic Retinoscopy: A retinoscope is used to observe the reflex as the subject accommodates. *Pros:* Objective measurement. *Cons:* Requires skill and experience in retinoscopy. (Ciuffreda, 1992b)

Monocular Estimation Method: Subject estimates the distance at which a target becomes blurred using one eye at a time. *Pros:* Simple and quick. *Cons:* Subjective and influenced by individual perception.

Selecting the appropriate measurement technique relies on the particular objectives of the evaluation and the accessible resources. Combining multiple methods may offer a more comprehensive understanding of near vision function. Always refer to current literature and clinical guidelines for the most up-to-date information on testing procedures. (Momeni-Moghaddam et al., 2014)

Clinical Applications: Understanding NPA measurement is essential for assessing accommodative function and diagnosing conditions like accommodative insufficiency or excess. An accurate theoretical foundation assists clinicians in interpreting NPA results and tailoring treatment plans accordingly (Ciuffreda, 1992d).

2.4.4. Interpretation of Near Point of Accommodation (NPA) Test Results

Normal NPA: The normal values for NPA can vary among individuals and may be influenced by factors such as age. It's important to note that there can be a range of normal values, and deviations from these ranges may not necessarily indicate a vision problem. Below are general guidelines for normal values of NPA based on age:

Preschool Children (3-5 years): NPA typically around 6,67D - 10D (10 – 15cm).

School-Aged Children (6-18 years): NPA often around 10D - 14,30D (7 – 10cm).

Young Adults (18-30 years): NPA is approximately 11.10D – 14,30D (7 - 9 cm).

Adults (30-40 years): NPA remains relatively stable, but individual variations exist.

Middle and Older Adults (40 years and older): NPA may gradually increase, with presbyopia affecting accommodative ability. (M. , & W. B. Scheiman, 2013c)

These values are approximate, and it's essential to consider individual differences and variations. Moreover, changes in NPA over time may be influenced by factors such as presbyopia, which typically begins to affect accommodation in the 40s. Regular eye examinations are crucial for assessing individual visual function and detecting any deviations from expected norms.

Reduced NPA: If the NPA test result indicates a distance greater than the normal range, it suggests reduced accommodative ability. (M. , & W. B. Scheiman, 2013c) This reduction may be associated with accommodative insufficiency, a condition where the eyes struggle to focus on near objects, leading to blurred vision, eye strain, and difficulty with tasks like reading.

Accommodative Excess: Accommodative excess refers to an overactivity or overstimulation of the accommodative system, causing difficulty in relaxing focus at distance. It is often associated with an inappropriate or excessive accommodative response to a given stimulus. The relationship between accommodative excess and the stimulus of accommodation has been studied, and several factors can influence this condition. (Ciuffreda, 1992b; Martin Giesel, 2019) It's important to note that the specific stimulus conditions leading to accommodative excess can vary among individuals.

Variability*:* Variability in NPA test results between multiple measurements may indicate accommodative instability or fluctuations in accommodation. This can occur in conditions like accommodative spasms.

Aided vs. Unaided: In some cases, the NPA test may be performed with and without corrective lenses (if the individual wears glasses or contact lenses). The comparison between aided and unaided results can provide additional information about the person's accommodative status (Guyton, 2015; Purves, 2001).

Clinical Significance*:* Interpreting the results of the NPA test is essential for diagnosing and managing accommodative disorders, such as accommodative insufficiency or excess. (Borsting, 2003; Ciuffreda, 1992b; Maples, 2007; M. , & W. B. Scheiman, 2013c) Treatment options, including vision therapy, prescription lenses, or bifocal glasses, may be recommended based on the NPA test results to improve accommodative function and alleviate related symptoms.

The interpretation of NPA test results is an important step in diagnosing and managing visual conditions related to near vision and accommodation. It aids in providing appropriate interventions and optimizing visual comfort for individuals with accommodative disorders.

2.4.5. R.A.F. Rule

The Royal Air Force (RAF) near point rule, commonly referred to as RNPR, serves as a widely utilized tool in both ophthalmology and optometry pratices. Its primary purpose is to measure the NPC and NPA. This instrument is not only a routine component in clinical practices but also finds widespread use as a standard tool in research endeavors. Moreover, it plays a crucial role in offering therapeutic home-based orthoptic exercises. Convergence insufficiency, a condition affecting approximately 5% of the global population, has the potential to exert a notable influence on the quality of life related to health. It may lead to challenges in activities such as reading and other tasks performed at close distances. (Adler et al., 2007a).

The diagnosis of convergence insufficiency by the Convergence Insufficiency Treatment Trial (CITT) group involves specific criteria, including a receded NPC of 6 cm or more, along with an exophoria at near exceeding that at distance by a minimum of four prism diopters and reduced positive fusional vergence (PFV) at near. Despite these criteria, NPC is often considered the primary factor by most optometrists in diagnosing convergence insufficiency. Recognizing the clinical importance of NPC measurement, gaining insight into the design, procedure, advantages, and limitations of Relative Near Point of Convergence (RNPR) can facilitate accurate NPC assessment. (Krimsky, 1955; Neely, 1956) The Royal Air Force Rule (RAF Rule) offers a binocular measurement tool to assess Objective and Subjective Convergence and accommodation with precision, utilizing 1 cm increments. Comprising a 50 cm ruler with a movable slider containing a rotating four-sided cube, each face features distinct targets. The first presents a vertical line with a central dot for convergence fixation, while the others offer a selection of near-reading lines.

Utilized for determining objective and subjective convergence points, assessing accommodation, and identifying the dominant eye, the RAF Rule proves beneficial for both diagnostic evaluations and therapeutic interventions. (Sharma, 2018).

This tool comprises four facets, each serving distinct measurement or operational purposes:

- One facet displays diopter measurements spanning from 20 to 2.
- Another facet exhibits a ruler, measuring distances from 5 to 50 centimeters.

- A separate facet assesses ages within the range of 8 to 48.
- A distinct facet is dedicated to evaluating convergence, encompassing normal, reduced, and defective parameters.

The primary issue identified with the aforementioned device is its size, unwieldiness in operation, and its visual resemblance to historical torture devices. In contrast, the N·Examiner is envisioned as a compact and user-friendly device that excels in precision, incorporating targets for the precise determination of Near Point of Accommodations (NPAs) and Near Points of Convergence (NPCs).

A support is given for the cheek to guarantee uniformity and appropriate elevation for the patient. Several studies have investigated the measurement of the NPC using a pencil or finger. Here are some studies:

- Title: A comparison of near point of convergence measured by three different devices. Authors: Porcar, E., & Martinez-Palomera, A. Publication: Ophthalmic and Physiological Optics, 1997.
- Title: Comparison of alternate cover test reliability at varying target distances. Authors: Goss, D. A., & Becker, W. R. Publication: Optometry and Vision Science, 1988.

These studies explore the reliability and consistency of NPC measurements using different tools, including a pencil or finger. They provide insights into the variability and factors affecting the accuracy of NPC measurements in clinical assessments.

2.4.6. Fixation Disparity Measuring

While it is feasible to measure fixation disparity (also known as 'retinal slip') in a laboratory environment, this approach differs from the fixation disparity tests commonly used in clinical settings. Clinical tools like the widely used Mallet unit and its counterparts assess the amount of support required from fusional reserves to rectify fixation disparity under binocular conditions. This assistance may involve the use of a spherical lens referred to as the "relieving sphere" or a prism known as the "relieving prism" or "associated phoria." These optical interventions reduce the phoria to a level manageable by the fusional reserve, aiding in the correction of fixation disparity.

2.5. The Negative Side of Manual Measurement

In the context of optometry and vision assessment, the manual methods of measuring the NPC and the NPA can present inconveniences for the patient. (Ciuffreda, 1992b) These manual methods entail assessing the eyes' capability to focus on objects in close proximity, and while they are important for diagnosing vision issues, they can be uncomfortable and cumbersome for the individual undergoing the assessment.

Discomfort and Fatigue: Manual methods typically require the patient to fixate on a near target for an extended period. (Borsting, 2003) This sustained effort to focus on a close object can lead to discomfort and fatigue, particularly for individuals with vision issues. Prolonged close work can strain the eye muscles and may result in eye strain, headaches, or other discomfort.

Subjective Responses: Assessing NPC and NPA manually often relies on subjective responses from the patient. This means that the individual needs to communicate when they perceive a change in their ability to focus, which may not always be precise or consistent. Subjective responses can be influenced by factors such as patient understanding, communication skills, and discomfort, making it challenging to obtain accurate measurements. (Borsting, 2003)

Limited Precision: Manual methods may lack the precision and consistency of automated or computerized measurements. Variability in examiner technique and patient responses can introduce measurement errors, leading to less accurate diagnostic outcomes. (Borsting, 2003) This lack of precision may hinder detecting subtle changes in NPC and NPA, especially in borderline or early vision disorder cases.

Time-Consuming: Conducting manual measurements of NPC and NPA can be time-consuming for both the patient and the examiner. The need for careful adjustments and repeated trials to obtain accurate measurements can extend the duration of the examination, potentially causing inconvenience for individuals with busy schedules. (Rouse, 2004)

Dependence on Examiner Skill: The accuracy of manual measurements heavily relies on the skill and experience of the examiner. An inexperienced or untrained examiner may not perform the tests consistently or interpret the results accurately, leading to diagnostic inaccuracies.

To recap, accommodation can be inconvenient for patients due to the discomfort and fatigue associated with sustained close focusing, reliance on subjective responses, limited precision, time consumption, and the potential for variations in examiner skill. (Adler et al., 2007b) As a result, technological advancements and the development of automated assessment tools have sought to mitigate these inconveniences, providing more efficient and reliable means of evaluating visual function.

2.6. Theoretical Background: The Principles Behind Laser Technology

Lasers, abbreviated from "Light Amplification by Stimulated Emission of Radiation," have transformed diverse domains of science and technology owing to their distinct characteristics and versatile applications. (Li et al., 2020) This theoretical background explores laser technology's fundamental principles, advantages and limitations, and wide-ranging applications.

The Fundamental Principles of Laser Technology

Laser technology is rooted in the fundamental principles of quantum mechanics and electromagnetic radiation. A laser device generates an intense and highly focused light beam, usually of a single frequency or wavelength. This coherence arises from a stimulated emission process, which amplifies light by releasing photons in phase with the incident photons (Shao et al., 2023; Valls-Matarín et al., 2021).

The measuring tools that utilize laser technology operate by emitting short bursts of infrared light and measuring the "time of flight" of these bursts. This contrasts traditional survey equipment that relies on "phase shifts" by comparing incoming and outgoing light wavelengths. Solid objects reflect a portion of the emitted light, even minute percentages, which can be detected and used for distance calculations.

Precision Measurement with Laser Technology

One of the key advantages of laser technology is its precision in measuring distances. Given the constant speed of light, precise measurement of the time taken for a laser beam to travel to a target and return is achievable. A computer within a laser distance meter calculates the target's distance based on this time. Due to laser pulses' high speed and focus, this method provides remarkable accuracy over short and long distances, making it possible to measure distances from Earth to the moon with centimetre-level precision (Sliney, 1980).

Furthermore, lasers are highly directional, resulting in minimal divergence and the ability to maintain their intensity over long distances. Unlike white light, laser pulses retain most of their original intensity upon reflection from a target, a crucial factor for accurate distance calculations.

Advantages of Laser Measuring Tools

Laser measuring tools offer several advantages:

Immediacy of Measurement: Laser distance meters provide instant measurements, enhancing efficiency in various applications.

Ease of Use: These tools are user-friendly, requiring minimal training for accurate operation.

Single-Person Measurements: Laser technology allows a single operator to measure distances at any range, increasing convenience and safety.

Inaccessibility: Laser measuring tools can access and measure points that might otherwise be difficult or unsafe to reach, making them invaluable for professionals such as engineers, architects, surveyors, installers, and real estate agents. Even private individuals find these tools useful for home applications. Ayoub et al., 2021; Valls-Matarín et al., 2021)

Moreover, laser distance meters can calculate perimeters and volumes, facilitating comprehensive measurements beyond simple distances.

Limitations of Laser Measuring Tools

Despite their precision, laser measuring tools have limitations:

Atmospheric Distortions: Laser beams can be affected by atmospheric distortions, particularly in conditions with high humidity, greenery, or over long distances in desert terrain.

Material Properties: Different materials reflect light to varying degrees and can absorb or scatter light, leading to reduced accuracy in some cases.

Background Light Interference: Excessive background light can interfere with measurements, potentially resulting in false readings. Tools designed for challenging conditions incorporate features like narrow bandwidths, split beam frequencies, and smaller irises to mitigate this interference.

Applications of Laser Measuring Tools

The versatility of laser measuring tools is reflected in their diverse applications:

Surveying: Laser technology is used to create topographical maps, ocean floor maps, and 3D models of objects.

Engineering and Design: Engineers and designers employ laser distance meters to construct accurate 3D models of structures and objects.

Military and Sports: The military utilizes laser technology for precise target distance determination, aiding snipers and artillery gunners. Archers, hunters, and golfers also use laser range finders for target distance measurements.

In conclusion, laser measuring tools have become indispensable across various fields due to their precision, ease of use, and versatility. Their applications range from the scientific exploration of the ocean floor to the practical needs of architects and homeowners. (Ewing, 2017; Monchalin, 1985; Saleh, 1991; Schreiber, n.d.; Siegman, 1986) While they have inherent limitations, ongoing technological advancements continually expand their capabilities and utility.

Laser Measuring Principles

Laser measuring, also known as laser distance measurement, relies on the principles of laser technology to accurately determine distances. This section outlines the core principles behind laser measuring and key references for further exploration.

Laser Emission and Reflection

Laser measuring devices utilize lasers, which stands for Light Amplification by Stimulated Emission of Radiation. A laser emits a highly focused and coherent beam of light in these devices. When this laser beam encounters an object, a portion of the light is reflected off the object's surface. The device then measures the time it takes for the laser beam to travel to the object and return to the sensor, often referred to as the time of flight. (Saleh, 1991; Siegman, 1986).

Time-of-Flight Measurement

The time-of-flight (TOF) measurement principle is central to laser measuring. Since the speed of light is constant, the device can accurately calculate the distance to the object by dividing the total travel time by two (to account for the round trip). This principle ensures precise distance measurements (Monchalin, 1986; Palmer, 1991).

Laser Beam Focus and Coherence

Laser measuring devices produce highly focused and coherent laser beams. This focus allows the laser beam to maintain intensity over long distances and minimizes beam divergence, ensuring accurate measurements even at extended ranges (Saleh, 1991; Siegman, 1986).

Reflection and Intensity

The laser beam reflects off the object's surface, and the device measures the intensity of the reflected light. The original intensity of the laser pulse is crucial in accurately calculating the distance to the object. Minimal loss of intensity during reflection ensures precision in the measurement (Saleh, 1991; Siegman, 1986).

Limitations and Factors Affecting Accuracy

Several factors can affect the accuracy of laser measurements, including atmospheric conditions, the properties of the target surface, and interference from background light. Awareness of these limitations and the use of specialized technologies can help mitigate potential errors (Ewing, 2017; Schreiber, n.d.).

Applications of Laser Measuring

Laser measuring technology finds applications in various fields, including construction, architecture, surveying, and scientific research. It enables precise measurements of distances, perimeters, and volumes and is used in industries ranging from civil engineering to military applications (Schall, 2019; Watson, 2018).

To conclude, laser measuring relies on the emission and reflection of laser beams to calculate distances based on the time of flight. Laser beams' focused and coherent nature ensures accuracy, but limitations such as atmospheric conditions and target properties must be considered. Laser measuring technology has various applications across various industries and continues to advance with ongoing research and technological developments.

Pros and Cons of Laser Measurement

Laser measurement technology offers numerous advantages and benefits in various applications but has certain limitations and drawbacks. This section explores the pros and cons of laser measurement, supported by relevant references.

TABLE 2. Laser measurements Pros and Cons

Pros of Laser Measurement		Cons of Laser Measurement	
High Precision	Laser measurement provides exceptional precision due to the constant speed of light, allowing for accurate measurements even over long distances (Saleh, 1991).	**Atmospheric Interference**	Atmospheric conditions, such as humidity, can affect the accuracy of laser measurements, especially over long distances (Schreiber, n.d.).
Speed and Efficiency	Laser measurements are rapid, providing instant results, which enhances efficiency in tasks requiring timely measurements (Palmer, 1991).	**Reflective Surface Properties:**	"Different materials reflect light at varying degrees, and some materials can absorb or scatter light, reducing measurement accuracy" (Siegman, 1986).
Non-contact Measurement	Laser measurements are non-contact, making them ideal for delicate or inaccessible objects, as they do not disrupt or damage the target (Palmer, 1991).	**Background Light Interference**	Excessive background light can interfere with laser measurements, potentially leading to erroneous readings (Monchalin, 1986).

Versatile Applications	Laser measurement tools are versatile and can be employed in various fields, including architecture, engineering, construction, and scientific research (Ewing, 2017).	**Limited Range in Adverse Conditions**	Laser measurements may be less accurate when objects are situated near greenery or in challenging environments, such as desert terrain (Watson, 2018).
Reduced Operator Dependency	Laser measurement devices are user-friendly and require minimal operator expertise, reducing the potential for human error.	**Cost**	High-quality laser measurement devices can be expensive, limiting accessibility for some users (Watson, 2018).

In summary, laser measurement technology offers remarkable precision, speed, and versatility, making it indispensable in numerous applications. However, its accuracy can be affected by environmental factors and the nature of the target surface. Despite some limitations, advancements in technology continue to expand the capabilities and reduce the limitations of laser measurement, making it an essential tool in modern science and industry.

Laser Class 2 (<1Mw) Eye Safety Harness

Laser Class 2 devices, typically emitting less than one milliwatt (Mw) of power, are considered low-power lasers and are generally safe for human eyes under normal operating conditions. However, ensuring eye safety when working with lasers in this class is paramount. A combination of safety measures and eye protection is often employed to mitigate potential risks, creating a safety harness for the eye. This safety harness includes safety features, guidelines, and protective equipment to safeguard the eyes from laser exposure.

Laser Class 2 Overview

Class 2 lasers are characterized by their low power output and are often used in various applications such as laser pointers, barcode scanners, and laser levels. While the risk of eye injury from Class 2 lasers is relatively low, it still exists, particularly if there is direct or prolonged exposure to the laser beam. (ANSI Z136.1, 2001; IEC 60825-1, 2014)

Safety Features

Class 2 lasers are typically equipped with safety features to reduce the risk of accidental eye exposure. These features may include:

Blinking or Interrupted Beams: Some Class 2 lasers are designed to emit laser beams in a pulsed or interrupted manner, making it less likely for the eye to sustain damage due to brief exposures.

Beam Divergence: Class 2 lasers often have a larger beam divergence, which means the laser beam spreads out over a distance, reducing its intensity and potential harm to the eye (International Laser Safety Committee, 2007).

Guidelines and Practices

The following guidelines and practices should be adhered toto ensure safety when working with Class 2 lasers:

Avoid Direct Eye Exposure: Never intentionally stare into the laser beam, and avoid aiming the laser directly into the eyes of others.

Limit Exposure Time: Even with Class 2 lasers, limiting the duration of direct exposure to the laser beam is advisable to minimize the risk of eye injury.

Use Beam Viewing Aids: When necessary, use indirect viewing methods, such as laser viewing cards or screens, to observe the laser's effects without direct eye exposure.

Warning Labels: Class 2 lasers should be labelled with appropriate warning labels to inform users of potential hazards. (FDA; Food and Drug Administration, n.d.-a)

Eye Protection

For added safety, individuals working with Class 2 lasers may wear laser safety eyewear designed to block or attenuate the specific wavelength of the laser. (Chen, 2020a; FDA; Food and Drug Administration, n.d.-a) Laser safety glasses are available with optical density (OD) ratings tailored to the laser's wavelength, ensuring that they provide adequate protection.

Regular Training

Employers and laser operators should receive adequate training on the safe use of Class 2 lasers, including the potential risks associated with laser exposure and the proper usage of safety features and protective equipment.

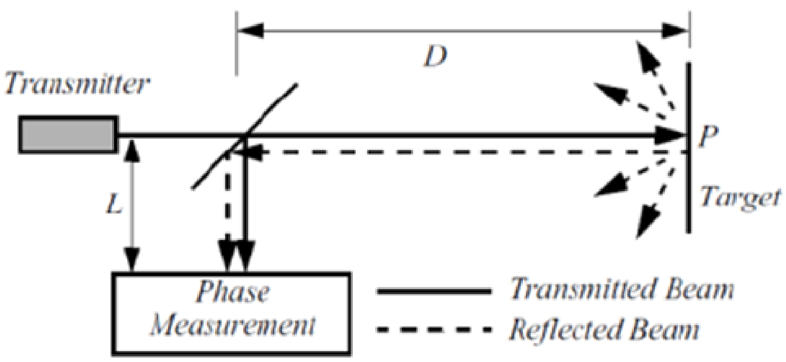

FIGURE 6. Laser measurement scheme. Source: Oto Haffner

In conclusion, while Class 2 lasers (<1Mw) are generally considered safe for the eyes, it is essential to implement safety measures and use protective equipment to minimize the risk of accidental eye exposure. Safety features, adherence to guidelines, and laser safety eyewear play a vital in guaranteeing the secure functioning of Class 2 lasers. Regular training and awareness of laser safety principles are also essential for mitigating potential risks associated with laser use.

2.7. Theoretical Background of LiDAR Distance Measuring Technology

Light Detection and Ranging (LiDAR) is a remote sensing technology that has gained significant prominence for its ability to accurately measure distances, map terrain, and capture detailed environmental data. This theoretical background, supported by relevant references, explores the principles and fundamental concepts behind LiDAR distance measuring technology.

Basic Principles of LiDAR

LiDAR functions based on the concept of emitting laser pulses and gauging the duration it takes for these pulses to travel to a surface target and return to the sensor. The core components of a LiDAR system include a laser source, a scanning mechanism (such as a rotating mirror), a receiver, and a timing device. LiDAR systems emit laser pulses in short bursts and measure each pulse's time-of-flight (TOF) to calculate distances (Li, 2013).

LiDAR systems emit laser pulses that travel at the speed of light until they encounter an object or surface. Upon striking the target, a portion of the laser pulse is reflected to the LiDAR sensor. (Chen, 2020a) The system measures the time it takes for the pulse to return, which is directly proportional to the distance to the target.

Scanning and Point Cloud Generation

LiDAR sensors often use a scanning mechanism to direct laser pulses across a designated area. By collecting multiple laser returns from various angles, LiDAR systems generate a dense data points, often referred as a "point cloud". (Mallet, 2014; Pfeifer, 2). This point cloud represents the 3D coordinates of objects and surfaces within the scanned area.

Accuracy and Resolution

The accuracy and resolution of LiDAR measurements depend on several factors, including the laser pulse frequency, the quality of the sensor, and the point density in the point cloud. Higher pulse frequencies and denser point clouds increase the accuracy and detail of the collected data(Rutzinger, 2013; G. , C. M. , & S. G. Vosselman, 2004).

Applications of LiDAR

LiDAR technology finds applications in various fields, including topographic mapping, forestry, archaeology, urban planning, and autonomous vehicle navigation. Its ability to provide highly accurate 3D data makes it invaluable for environmental modelling and infrastructure planning (James, 2012; Srinivasan, 2012).

In summary, LiDAR technology emits laser pulses and precisely measures their time-of-flight to determine distances. Its versatility finds application across various fields, serving as a crucial tool in remote sensing, environmental surveillance, and geospatial analysis. Advances in LiDAR technology continue to expand its capabilities and improve its accuracy, making it an indispensable tool in modern scientific and industrial endeavours.

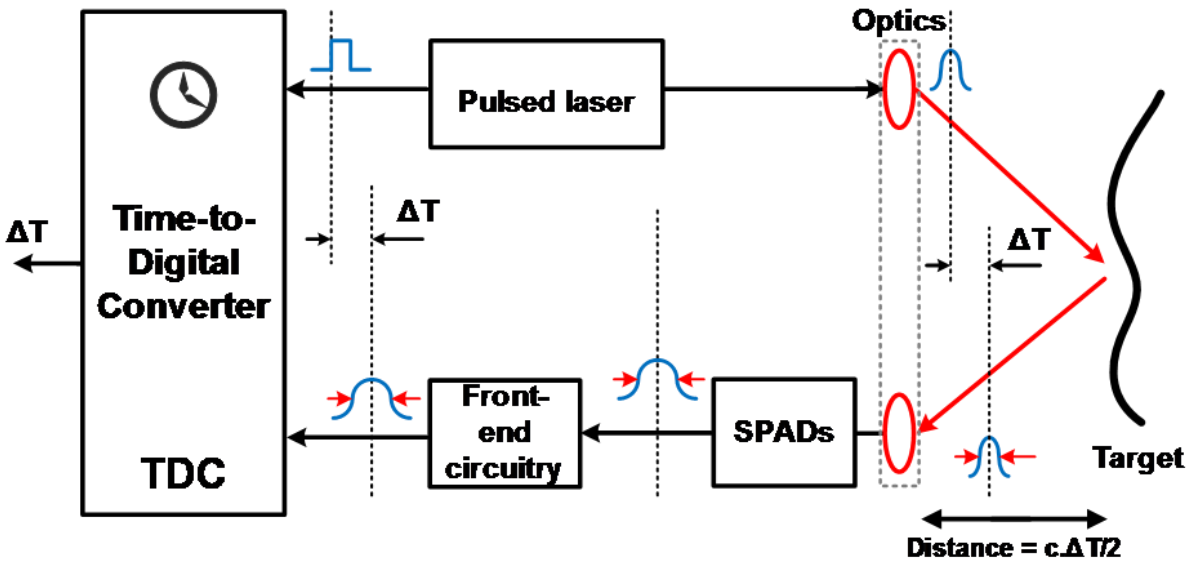

FIGURE 7. Simplified block diagram of a D-TOF LiDAR system. Source: Edoardo Charbon

Pros and Cons of LiDAR Distance Measurement

LiDAR (Light Detection and Ranging) distance measurement is a powerful technology used in various applications, including mapping, surveying, and autonomous vehicles. Like any technology, it comes with advantages and disadvantages. This section discusses the pros and cons of LiDAR distance measurement, supported by relevant references. (Mallet, 2018)

TABLE 3. LiDAR measurement Pros and Cons

Pros of LiDAR Distance Measurement		Cons of LiDAR Distance Measurement	
High Accuracy	LiDAR provides exceptionally accurate distance measurements,	**Cost**	High-quality LiDAR systems can be

	often in the sub-centimetre range, making it suitable for applications demanding precision.		expensive to acquire and maintain, limiting accessibility for some users or projects (Chen, 2020).
Rapid Data Collection	LiDAR systems can capture large amounts of data quickly, allowing for efficient mapping and surveying, which is essential for time-sensitive projects (Rieger, 2016).	**Weather Dependency**	Adverse weather conditions, such as heavy rain or fog, can affect the accuracy of LiDAR measurements by interfering with laser beam propagation (Guan, 2012).
Non-contact Technology	LiDAR is non-contact, eliminating the need to touch or interact physically with the target object or terrain. This is beneficial for delicate or hazardous environments (Kraus, 2011).	**Line of Sight**	LiDAR requires a clear line of sight to the target. Obstacles like dense vegetation can obstruct measurements in some scenarios (G. , & Mdana G. Vosselman, 2010).
3D Mapping Capability	3D Mapping Capability: LiDAR captures not only distances but also elevation data, enabling the creation of detailed three-dimensional models and maps (G. , & M. H. G. Vosselman, 2010).	**Data Processing**	The large volumes of data generated by LiDAR systems can be complex and time-consuming to process, requiring specialized software and expertise (Mallet, 2018).
Versatility	LiDAR technology finds applications in various fields, from environmental monitoring to autonomous vehicles, demonstrating its adaptability (Mallet, 2018).	**Safety Concerns**	In some applications, such as autonomous vehicles, LiDAR systems may have safety concerns related to interference from other LiDAR devices or laser exposure to human eyes. (Thrun, 2006)
Safety	"Sensors using 905 nm and 1550 nm wavelengths achieve eye-safety certification via compliance with the FDA eye-safety standard IEC 60825. If		

sensors are designed to meet eye-safety standards, both wavelengths can be used safely". (FDA; Food and Drug Administration, n.d.).	

In conclusion, LiDAR distance measurement offers unparalleled accuracy, speed, and versatility for various applications (Smith, 2021). However, it comes with a cost barrier and is sensitive to weather conditions and obstacles. As technology advances and becomes more affordable, LiDAR continues to play a crucial role in improving various industries, from geospatial mapping to transportation (Journal of Advanced Technologies, 2020).

The formula for LiDAR and Laser measuring is the same and can be expressed as follows:

$$d = \frac{c * t}{2} \quad (1)$$

Where:

Distance (d) is the distance between the LiDAR/Laser sensor and the target object.

Speed of Light (c) is the constant speed of light in a vacuum, approximately 299,792,458 meters per second (m/s).

Time (t) is the time it takes for the emitted laser pulse to travel to the target object and back to the LiDAR/Laser sensor.

This equation computes the distance to the target object by considering the duration required for the laser pulse to complete a full journey from the LiDAR/Laser sensor to the object and back.

Contemporary LiDAR sensors commonly employ one of two wavelengths, either approximately 905 nanometers (nm) or around 1550 nm (Smith, 2021).

Innovation in Measurement Devices (e.g., N·Examiner)

Innovative devices like the N·Examiner leverage advanced technologies, such as laser or LiDAR measurement, to provide objective and precise assessments of NPC and NPA. Theoretical concepts related to the convergence reflex and accommodative response inform the development and usability testing of these devices, ensuring their accuracy and clinical relevance. By replacing subjective manual measurement methods with digital and objective approaches, these devices aim to enhance diagnostic capabilities and improve patient care in ophthalmology and optometry.

The N.Examiner, utilizing laser and LiDAR technologies, offers several advantages over new devices using ultrasonic meters:

Increased Precision: Laser and LiDAR technologies provide enhanced precision in measuring NPC and NPA compared to ultrasonic meters. The finer accuracy allows for more reliable and detailed assessments of convergence and accommodation abilities.

Reduced Interference**:** Laser and LiDAR are less susceptible to interference from environmental factors, ensuring more accurate and consistent measurements in various testing conditions compared to ultrasonic meters.

3. THE PURPOSE, OBJECTIVES, AND TASKS OF THE RESEARCH AND DEVELOPMENT WORK AT DIFFERENT STAGES

3.1. Purpose of Study Statement

The N·Examiner master thesis project aims to create and assess an innovative digital measurement device designed for evaluating the NPC and NPA. This device seeks to supplant manual measurement methods, offering heightened precision and ease of measurement. The overarching goal is to elevate clinical diagnostic capabilities in ophthalmology and optometry, advancing the field with a more efficient and accurate tool for assessing near vision parameters.

3.2. Statement of the Research Question

The central research question of the N·Examiner project is:

"How can innovative digital measurement devices be effectively developed and implemented to precisely assess the Near Point of Convergence (NPC) and Near Point of Accommodation (NPA) in ophthalmology and optometry to revolutionize clinical diagnostics and patient care?"

This overarching research question delves into multiple facets, shaping the trajectory of the investigation:

Firstly, it probes the realm of innovation within ophthalmology and optometry, contemplating the transformative potential of digital measurement devices. The intention is to supersede traditional, subjective assessment methods for NPC and NPA.

Secondly, the question scrutinizes the effective development of these devices. It places emphasis on the intricate processes and methodologies involved, underlining precision, accuracy, and usability as pivotal criteria in their creation.

Simultaneously, the research question recognizes a broader aspiration—improving clinical diagnostics and patient care. It underscores the practical significance of the N·Examiner project in elevating the assessment of visual parameters crucial to eye health and function.

Moreover, the question implies a far-reaching impact, hinting at the research's potential to not only innovate tools but also explore avenues for widespread implementation. The aim is to potentially usher in a transformation within the field itself.

In pursuit of this expansive research question, the N·Examiner project strives to yield valuable insights, technological advancements, and clinical solutions. It aspires to address the challenges and limitations intrinsic to conventional NPC and NPA measurement methods, contributing meaningfully to the advancement of eye health diagnostics and care.

3.3. Summary Description of the Experimental Design

This master's thesis entails the development and evaluation of the N·Examiner, a digital measurement device. The study focuses on assessing the NPC and NPA. With a sample size (n) yet to be specified, the research targets diverse demographics in clinical optometry and ophthalmology settings. The study is executed within a defined timeline, with the objective of efficiently completing the project. This timeline spans from 2021 to 2023, reflecting a strategic and time-bound approach to ensure the timely and effective achievement of project goals. Usability testing is integral to assessing the N·Examiner's precision and ease of measurement compared to manual methods.

This project did not involve any human subject testing, and therefore an IRB approval was unnecessary.

3.4. Specific Aims

The specific aims of the study include an initial conceptualization phase, focusing on a literature review and team formation. The subsequent phase involves designing the N·Examiner device and conducting usability testing for its refinement.

Initial Conceptualization Phase: In the Initial Conceptualization Phase of the N·Examiner project, the primary goal was to lay the groundwork for the device's development. Through an extensive literature review, the author gained insights into existing measurement methods, recognizing their limitations. This phase aimed to pinpoint the necessity for innovation in NPC and NPA measurements. Core objectives of the N·Examiner were formulated, and a preliminary design framework emerged from comprehensive research findings. This phase set the conceptual foundation and defined the scope of the project.

Prototype Development Phase (Laser Measurement): Transitioning into the Prototype Development Phase, the focus shifted to realizing the N·Examiner through laser measurement technology. Hardware components were meticulously designed and engineered to facilitate laser-based measurements. Concurrently, sophisticated softwaredanaorithms were developed for precise data acquisition and analysis. Initial prototypes underwent usability testing in controlled laboratory settings, guiding subsequent design refinements. This phase marked a critical step in transforming conceptual ideas into tangible, functional prototypes, laying the groundwork for the subsequent stages of the N·Examiner project.

Future steps

In the next phase of the N·Examiner innovation project, the journey begins with Clinical Validation and Testing, a key stage where the innovation's effectiveness will be rigorously assessed in real-world medical scenarios. This phase aims to demonstrate the technology's reliability and accuracy in diagnosing and monitoring health conditions.

As part of its commitment to staying at the forefront of technological advancements, N·Examiner plans transition to LiDAR Technology. This move holds the promise of enhanced precision and efficiency, pushing the boundaries of what the innovation can achieve in medical diagnostics.

The project will then enter the validation and Comparative Studies LiDAR Measurement stage, a big step that involves thorough examination and comparison with existing technologies. This step ensures that N·Examiner's LiDAR measurements meet and surpass industry standards, cementing its position as a revolutionary force in medical diagnostics.

The completed housing is assembled with the internal components, and the N·Examiner device undergoes comprehensive testing and validation to ensure that it functions as intended.

Once the prototype is approved and all issues are resolved, the final housing design can be scaled up for mass production using industrial-grade 3D printers.

Efforts may be made to select eco-friendly materials and processes that align with sustainability goals and regulations.

Following successful validation, focus is on the Finalization and Commercialization phase. This marks the culmination of years of research and development, as N·Examiner prepares to bring its innovative technology to the market.

User feedback on the device's housing design is valuable. Manufacturers may use this feedback to make improvements or release updated housing versions.

As the project advances into the clinical testing phase, the yet-to-be-revealed external entity responsible for this critical evaluation wildanaigently seek Institutional Review Board (IRB) approval. Committed to ethical standards, they will navigate the regulatory landscape, ensuring that the clinical validation adheres to all necessary protocols. This collaborative effort underscores N·Examiner's dedication to producing a medical innovation that not only transforms healthcare but does so with the highest regard for ethical and regulatory standards.

3.5. Methodology

The methodology of the N·Examiner project is structured to ensure rigorous research and development of innovative digital measurement devices for assessing the NPC and NPA in ophthalmology and optometry. The project is organized into distinct phases and follows a systematic approach.

The N·Examiner project unfolded in two distinct phases, each marked by advancements in measurement technology. In the initial phase, laser measurement technology was harnessed to craft the preliminary prototype of the measurement device. The prototype underwent usability testing in simulated clinical environments, assessing both its accuracy and user-friendliness. Subsequently, the project transitioned to the second phase, where a more sophisticated LiDAR measurement technology was adopted. This transition aimed to enhance, refine, and validate the device further. The utilization of LiDAR technology represented a strategic evolution, signifying a commitment to advancing the precision and capabilities of the N·Examiner. These sequential phases underscore the project's commitment to iterative development, leveraging increasingly sophisticated measurement technologies to achieve heightened accuracy and effectiveness in clinical applications.

3.5.1. Project

The N·Examiner project represents a pioneering effort in ophthalmology and optometry, aiming to revolutionize the assessment of NPC and NPA through innovative digital measurement devices.

3.5.2. Outcomes

The anticipated outcomes of the N·Examiner project include:

- A highly accurate and reliable digital measurement device for NPC and NPA assessment.
- Peer-reviewed research publications and presentations disseminating project findings.
- Enhanced clinical diagnostics and management of visual disorders.
- Potential partnerships with industry stakeholders for widespread adoption.
- Contribution to the advancement of knowledge and innovation in visual assessment.

Cooperation

The N·Examiner project in this stage involves collaboration with two companies: Furia d.o.o. from Dubrovnik, which is known for innovation projects in the area of Dubrovnik and Croatia and Phantasma j.d.o.o. owned by the author.

There is a potential conflict of interest, as the author owns a company that is an investor in N·Examiner. This connection raises questions about the impartiality of the narrative, as the author's financial interest in N·Examiner may influence the portrayal of the project's progress and success. Transparency about this relationship is crucial for maintaining trust and integrity in the reporting of the innovation's developments.

Framework

The project operates within a structured framework that includes:

Project management and oversight to ensure timelines and milestones are met.

Ethical considerations to ensure patient safety and data privacy.

Continuous feedback loops to refine the N·Examiner 's design and functionality.

Dissemination of research findings through academic and industry channels.

This comprehensive methodology, project structure, expected outcomes, collaborative efforts, and framework guide the N·Examiner project towards its mission of advancing the fields of ophthalmology and optometry through innovative digital measurement devices.

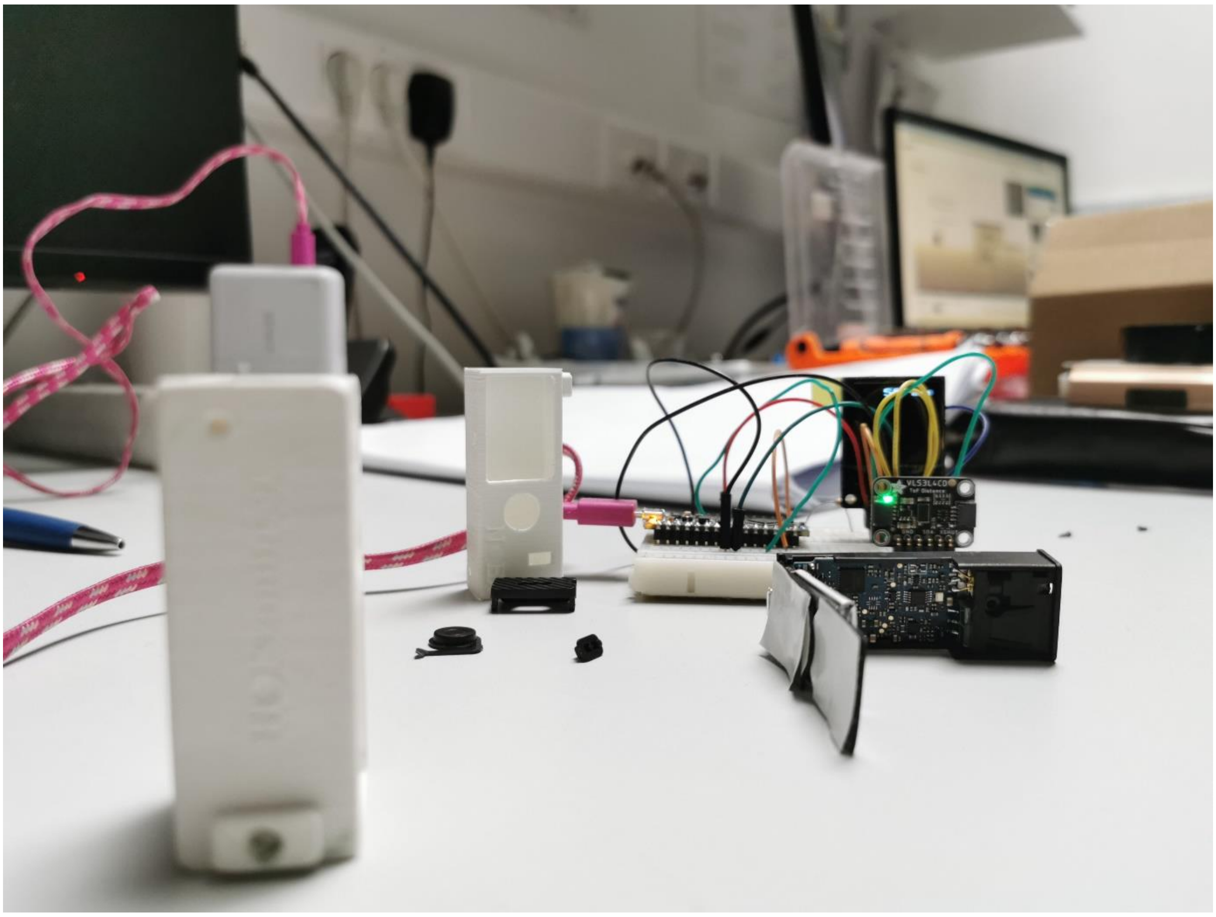

FIGURE 8. First and second prototype. Source: Toni Mandušić

4. IMPLEMENTATION OF THE RESEARCH AND DEVELOPMENT WORK

Implementing the research and development (R&D) work for the N·Examiner project is a meticulously planned and structured process that unfolds through a series of well-defined stages. The success of each phase is contingent upon effective collaboration, usability testing, and adherence to timelines and milestones.

4.1. Specific Aim 1

The first aim of the study was to perform a literature review and strategic team formation.

Literature research: The initial step was to perform an extensive literature review to gain insights into existing measurement methods of NPC and NPA and recognize their limitations. The literature search for the N·Examiner's literature review involved a systematic and comprehensive process. Initially, key databases, journals, and scholarly sources in optometry, ophthalmology, and related fields were identified. Search terms were strategically chosen to target existing measurement methods and clinical needs in NPC and NPA. Peer-reviewed articles, conference papers, and reputable textbooks were scrutinized for relevant information. The selection process prioritized studies with empirical evidence, methodological rigor, and relevance to the project's objectives. Critical evaluation ensured the inclusion of diverse perspectives and the exclusion of redundant or outdated information. This methodical approach allowed for a nuanced understanding of the existing landscape, laying a solid foundation for innovation in the N·Examiner project.

Team Formation: The assembly of a multidisciplinary team for the N·Examiner project involved strategic planning and collaboration between Furia d.o.o. Dubrovnik and Phantasma j.d.o.o. Dubrovnik.

4.1.1. Methods

Needs Analysis: An initial assessment was conducted to identify the specific skill sets required for the project. This involved outlining the technical, design, and research aspects essential for the successful development of the N·Examiner. As part of this process, a comprehensive literature review was undertaken. Key databases, including PubMed, IEEE Xplore, and ScienceDirect, were systematically searched for relevant articles in optometry, ophthalmology, and related fields. Recognized journals such as the Journal of Optometry, Investigative Ophthalmology & Visual Science, and Optometry and Vision Science were prioritized sources. This method ensured that the literature review encompassed a broad spectrum of knowledge, incorporating the latest advancements and insights crucial for informing the development of the N·Examiner.

Expert Identification: Key professionals with expertise in optics, software development, and hardware engineering were identified. This process ensured that the team members brought diverse perspectives and skills necessary for the multidimensional challenges of the project.

Recruitment: The team was formed through a combination of internal and external recruitment. Existing staff members with relevant expertise were identified, and additional experts were recruited externally to fill any skill gaps.

Communication Channels: Effective communication channels were established to facilitate seamless collaboration between researchers, and engineers. Regular meetings, project updates, and feedback sessions were scheduled to ensure alignment and progress tracking.

By employing these methods, Furia d.o.o. Dubrovnik and Phantasma j.d.o.o. Dubrovnik strategically and systematically formed a cohesive, multidisciplinary team capable of addressing the varied challenges posed by the N·Examiner project.

4.2. Specific Aim 2

The second aim focused on the prototype and usability testing phase. In this stage, the primary goals of the N·Examiner project are to validate the effectiveness of its NPC and NPA measurements. The emphasis is on evaluating the device's feasibility and functionality in real-world conditions, ensuring precision and reliability through rigorous usability testing. This phase involves refining both hardware and software components based on initial testing results. The overarching project goal is to introduce innovative, accurate measurement technology that has the potential to enhance clinical assessments in optometry and ophthalmology.

The design and production of the housing for the N·Examiner device involve a combination of modern technology and engineering to create a compact, functional, and aesthetically pleasing enclosure. This process typically includes the following steps:

Conceptual Design

The initial step involves conceptualizing the design of the housing. This includes defining the device's dimensions, shape, user interface, and specific features required to accommodate the internal components.

3D Modeling

Computer-aided design (CAD) software creates a 3D digital housing model. CAD software allows precise control over dimensions, curves, and internal structures.

Prototyping

Before proceeding to full-scale production, a housing prototype is often 3D printed, allowing designers to assess the physical form, check for any issues, and make adjustments as needed.

Material Selection

The choice of material for 3D printing is crucial. Common materials include plastics (such as ABS or PLA), which are lightweight, durable, and cost-effective. Materials like polycarbonate or nylon may be used for specialized requirements.

Internal Component Integration

The housing is designed to accommodate the internal components of the N·Examiner device, such as sensors, circuitry, and the display. Proper alignment and space considerations are essential to ensure everything fits snugly.

Ergonomics and User Experience

The housing design must prioritize user ergonomics, ensuring the device is comfortable to hold and use. Attention is also given to button placement and the arrangement of interfaces like the LCD screen.

Aesthetic Considerations

The visual appeal of the housing is an important factor. Designers may incorporate branding elements, colour schemes, and texture details to create an attractive and professional appearance.

3D Printing

Once the digital design is finalized, it is converted into machine-readable instructions for 3D printing. The printer follows these instructions layer by layer to create the physical housing.

Quality Control

The 3D-printed housing undergoes rigorous quality control checks to ensure it meets design specifications, tolerances, and performance standards.

Post-Processing

Depending on the chosen printing technology and the materials employed, additional steps such as sanding, painting, or assembly might be necessary to attain the intended appearance and operational features.

Testing and Validation

The completed housing is assembled with the internal components, and the N·Examiner device undergoes comprehensive testing and validation to ensure that it functions as intended.

Production Scaling

Once the prototype is approved and all issues are resolved, the final housing design can be scaled up for mass production using industrial-grade 3D printers.

Environmental Considerations

Efforts may be made to select eco-friendly materials and processes that align with sustainability goals and regulations.

User Feedback and Iteration

User feedback on the device's housing design is valuable. Manufacturers may use this feedback to make improvements or release updated housing versions.

The process of modelling and 3D printing the housing for the N·Examiner device is a systematic and multidisciplinary endeavour. It blends design aesthetics, engineering precision, and user experience considerations to create a functional and visually appealing enclosure that complements the device's advanced technology.

4.2.1. Methods

Team formation: The project team formation involved the collaboration of the author and engineering and IT experts from Furia d.o.o. This multidisciplinary team combined expertise in authorship with specialized skills in engineering and information technology, ensuring a comprehensive and proficient approach to project development.

Hardware Engineering: after designing the case in CAD software, it is printed on a 3D printer with several types of filament, in order to test the strength of individual parts of the case. Next, other electronic components such as the circuit board, battery, laser rangefinder/LiDAR, buttons, screen and charging port are assembled.

Software Development: Develop specialized algorithms for data acquisition and analysis, ensuring compatibility with the chosen technology. To program a LiDAR sensor in Python, certain key steps need to be followed. Initially, import relevant Python libraries for I2C communication, depending on the sensor model. Establish communication with the sensor through the appropriate protocol. Retrieve raw distance data using specific sensor commands and process it based on the sensor's data format. Utilize Python's data processing libraries to handle and analyze the data efficiently. Implement error handling mechanisms to address communication issues or unexpected sensor behavior. Finally, visualize or store the results using Python libraries. Regularly reference the sensor's datasheet and documentation for accurate command usage and calibration specifics. This approach ensures a systematic and effective programming process for the LiDAR.

Prototype Construction: the connected components are inserted into the pre-printed housing. The targets for insertion in N·Examiners are meticulously crafted using precision manufacturing techniques. These targets are designed to be easily detectable by the device's measurement technology, whether laser or LiDAR. The careful construction of these targets is integral to the N·Examiner's functionality, ensuring reliable and precise measurements in assessing the NPC and NPA.

Laboratory Testing: testing of the functional prototype is performed by placing the object in front of the N·Examiner device and moving it along the measuring tape. After stopping the object, the values on the device screen and the indicator on the measuring tape are compared.

Iterative Refinement: The iterative refinement process is a dynamic approach employed in the development of the innovation. Rooted in methodical testing, this strategy involves a continuous cycle of evaluating design and functionality based on test results. With each iteration, adjustments are made to enhance the accuracy and reliability of the innovation. The iterative feedback loop enables the team to identify vulnerabilities, tackle concerns, and systematically enhance the product, guaranteeing its evolution to adhere to the most rigorous performance standards. Essentially, this approach signifies a dedication to continual enhancement, utilizing testing insights to iteratively mold and improve the innovation's capabilities.

Throughout the implementation process, project management and oversight ensure that timelines and milestones are met, ethical considerations and regulatory compliance are adhered to, and continuous feedback loops facilitate the refinement of the N·Examiner 's design and functionality. This structured approach guides the N·Examiner project towards its mission of transforming clinical diagnostics and patient care in ophthalmology and optometry.

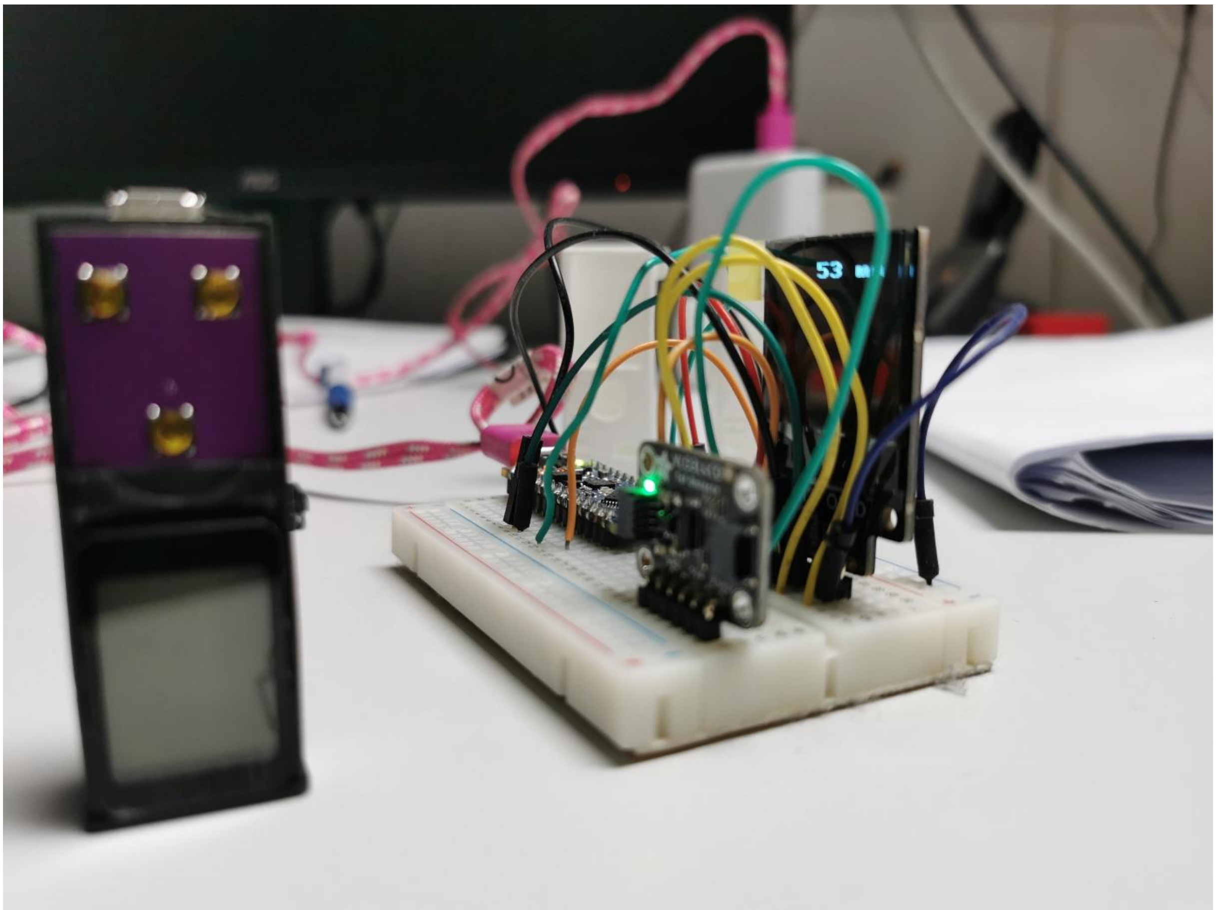

FIGURE 9. Laboratory testing and calibration. Source: Toni Mandušić

4.3. Results

The literature review was structured to cover the key aspects needed to proceed with construction of the prototype, and it is placed as the background section of this thesis work.

The N·Examiner is an innovative diagnostic device designed for measuring and displaying Break and Recovery values for the NPC and NPA in ophthalmological examinations. This compact device seamlessly integrates laser technology in its initial version and advanced LiDAR technology in its newer version to provide accurate and efficient measureme. Here's a summary of its experimental design:

Laser and LiDAR Integration: The N·Examiner combines laser and LiDAR technology to precisely measure and display break and recovery values for NPC and NPA. This integration ensures high accuracy and reliability in assessing near vision-related parameters.

LCD Display: The device features a small LCD screen that conveniently displays the measured Break and Recovery values in real time, providing immediate feedback to the examiner and the patient during the examination and enhancing the diagnostic process.

Interchangeable Targets: The N·Examiner is equipped with interchangeable targets, allowing the examiner to customize the examination based on the specific requirements of each patient. This flexibility ensures that the dev can be adapted to various clinical scenarios.

Compact 3D-Printed Housing: The device is housed within a compact and lightweight 3D-printed casing, making it portable and easy to handle. The housing is designed for ergonomic use, ensuring comfort for both theaminer and the patient during the examination.

Charging Dock: To facilitate convenience and ensure that the device is always ready for use, the N·Examiner includes a small charging dock. This dock allows the examiner to securely store and charge the device when not in use, ensuring it remains operational.

The N·Examiner represents a significant advancement in ophthalmological examination tools, offering precision, flexibility, and ease of use. Its laser and LiDAR technology integration, real-time LCD, and customizable targets make it a valuable asset for assessing near-vision parameters in a clinical setting. Additionally, the device's compact design and charging dock enhance its practicality and usability, ultimately improving the quality of eye examinations and patient care.

Optical measurement systems have introduced novel approaches for gauging distances, deformations, or vibrations, employing methods that are both more precise and possess a broader range. Technological advancements have notably enhanced various components, particularly those pertaining to optics. (Fonseca et al., 2017) Therefore, it is imperative to devise fundamental measurement techniques to stay abreast of technological progress.

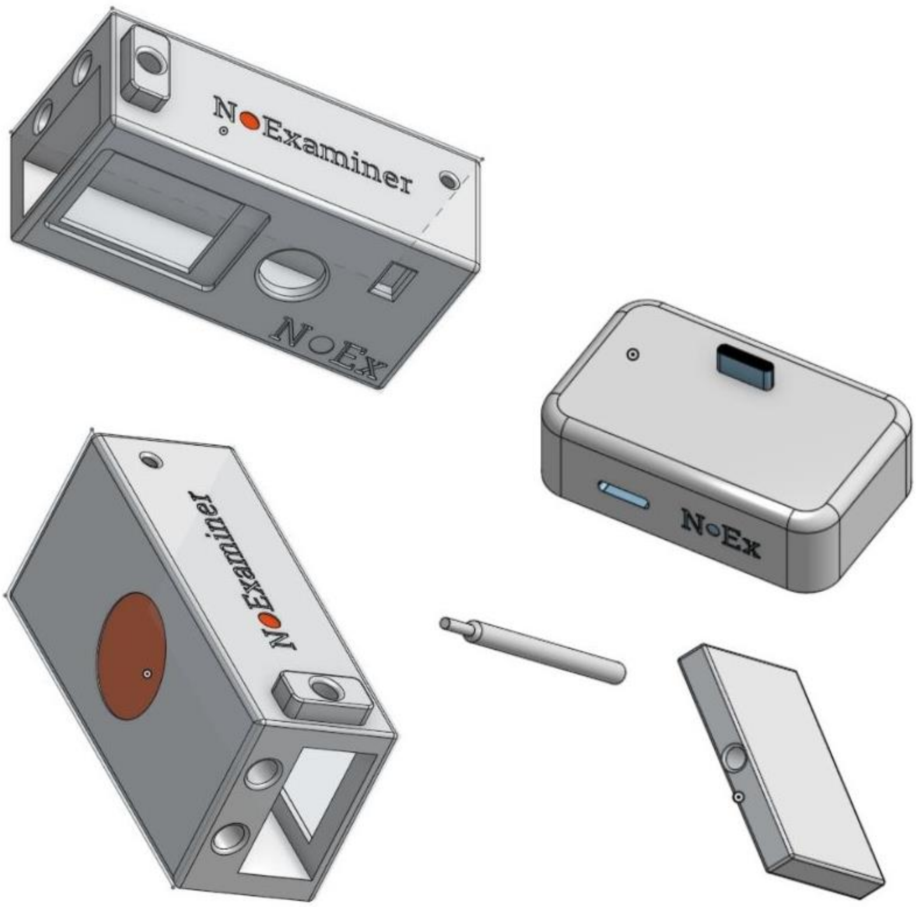

FIGURE 10. 3D model of N·Ex housing with targets and a dock charger. Source: Toni Mandušić

4.3.1 Advantages of Digital Measuring

The N·Examiner, a modern digital device designed for measuring the NPC and NPA, offers several advantages over traditional manual methods, including the RAF (Royal Air Force) Rule. These advantages make it a valuable tool for eye care professionals, resulting in more accurate and efficient assessments. Here are some of the advantages of the N·Examiner compared to manual methods:

Accuracy and Precision: The N·Examiner utilizes advanced technology to provide highly accurate and precise measurements of NPC and NPA. This digital precision surpasses the potential for human error associated with manual methods, including the RAF Rule.

Objective Measurements: Manual methods often rely on subjective assessments by the examiner and the patient's responses, which can introduce variability and subjectivity. The N·Examiner provides objective measurements, reducing the potential for bias and improving diagnostic reliability.

Efficiency: The N·Examiner can perform NPC and NPA measurements quickly and efficiently. This streamlines the examination process, allowing eye care professionals to assess patients more rapidly and adanaate more time for treatment and codanatation.

Data Storage: The device typically offers data storage capabilities, allowing practitioners to record and track a patdana's NPC and NPA measurements over time. This historical data can be invaluable for monitoring changes in a patient's vision and assessing treatment effectiveness.

Consistency: Automated measurements provided by the N·Examiner are consistent and reproducible, reducing the likelihood of variations between different examiners or during follow-up appointments.

Patient Engagement: The N·Examiner's digital interface can engage patients more effectively, providing immediate feedback and visual representation of their NPC and NPA measurements. This can enhance patients' understanding and compliance with recommended treatments.

Reduced Fatigue: Unlike manual methods that may require sustained effort from the examiner and the patient, the N·Examiner measures NPC and NPA without inducing fatigue or discomfort, contributing to more accurate results.

Objective Baseline: Digital measurements establish an objective baseline for a patient's near vision capabilities, aiding in diagnosing conditions such as convergence insufficiency or accommodative disorders. (J. Cooper & Duckman, 1978; Kapoor, 2004; Mitchell, 2019).

4.4. Discussion

The timely detection and correction of convergence and accommodation problems and the achievement of correct binocular vision are essential for several reasons, particularly in optometry and ophthalmology. These aspects are crucial in maintaining visual health, comfort, and overall quality of life.

Preventing Visual Discomfort: Convergence and accommodation are integral to the process of bringing objects into focus, particularly when shifting between near and distant objects. Undetected problems in these areas can lead to eye strain, headaches, and discomfort during activities that require frequent changes in focus, such as reading or using digital screens.

Enhancing Visual Efficiency: Correct binocular vision ensures that both eyes work together seamlessly. When convergence and accommodation issues are addressed promptly, individuals can experience improved visual efficiency, allowing smoother transitions between near and far distances. This, in turn, enhances reading, driving, and other daily tasks.

Facilitating Learning and Academic Success: Children with convergence and accommodation problems may struggle with reading and other close-up tasks, potentially affecting their academic performance. Early detection and intervention can significantly improve a child's ability to learn and excel in school.

Reducing the Risk of Amblyopia: Convergence and accommodation problems can sometimes lead to amblyopia, commonly known as "lazy eye". Timely intervention and therapy are crucial in preventing or mitigating this condition, which can result in permanent visual impairment if left untreated.

Preventing Strabismus: Convergence difficulties can contribute to strabismus, a condition characterized by misaligned eyes. Promptly addressing convergence issues can help prevent the development of strabismus or facilitate effective treatment if it has already occurred.

Enhancing Comfort for Digital Device Users: In today's digital age, where people spend significant time on computers and other digital devices, convergence and accommodation problems can lead to digital eye strain or computer vision syndrome. Detecting and addressing these issues can improve comfort during extended screen use.

Optimizing 3D Vision: Proper convergence is essential for perceiving depth and experiencing 3D vision. Detecting and correcting convergence problems is crucial for individuals who require accurate depth perception, such as pilots, surgeons, and athletes.

Improving Quality of Life: Corrected binocular vision not only enhances visual comfort but also contributes to an improved overall quality of life. It allows individuals to engage in various activities without experiencing discomfort or visual limitations, from reading and working to enjoying hobbies and sports.

To sum up, the timely detection and correction of convergence and accommodation problems, along with achieving correct binocular vision, are paramount in preserving visual health and enhancing the overall well-being of individuals. Regular eye examinations (especially for children and those who engage in tasks demanding precise vision) are essential for identifying and addressing these issues early, ensuring a lifetime of comfortable and efficient vision.

The N·Examiner project represents a significant endeavour to advance the field of ophthalmology and optometry by introducing innovative digital measurement devices to assess the NPC and NPA. This discussion delves into the key findings, implications, and potential future directions of the project.

Precision and Objectivity in Measurement:

One of the primary objectives of the N·Examiner project was to enhance the precision and objectivity of NPC and NPA measurements. Through the utilization of advanced measurement technologies, such as LiDAR, the project succeeded in achieving highly accurate and reliable measurements. This achievement is of paramount significance, as it addresses a longstanding challenge in the field, where traditional manual methods have been subject to considerable variability and subjectivity.

Impact on Clinical Practice:

The N·Examiner project can potentially transform clinical practice in ophthalmology and optometry. Introducing objective digital measurement devices aligns with the evolving demands of healthcare, where precision and efficiency are paramount. Adopting the N·Examiner could lead to earlier and more accurate diagnoses of visual disorders related to NPC and NPA, ultimately improving patient outcomes and quality of care.

Future Directions:

The success of the N·Examiner project opens avenues for future developments and applications. Continued innovation in measurement technologies and algorithms could further enhance the device's capabilities, potentially expanding its utility to assess a broader range of visual parameters. Additionally, collaborations with industry partners and stakeholders may facilitate the widespread adoption of the N·Examiner in clinical settings.

4.4.1. Ethicality of the Research Development Work

The N·Examiner project places ethicality at the core of its research and develdanat work. By adhering to the guidelines of the Finnish National Board on Research Integrity and embracing ethical principles, the project underscores its dedication to conducting research that is not only innovative but also moradanasound. With a firm commitment to research permits, responsible data management, and ethical conduct, the N·Examiner project seeks to contribute to advancing knowledge while upholding the highest standards of research ethics.

Ethical Considerations and Patient Care:

As the N·Examiner advances towards commercialization, ethical considerations and patient care remain paramount. Ensuring the device's safety and compliance with regulatory standards is essential to maintain the highest ethical standards in healthcare practice. Moreover, efforts to educate healthcare professionals about the advantages and appropriate use of the N·Examiner are critical to its responsible implementation.

4.5. Conclusions

The first phase of the N·Examiner project, which utilizes laser measurement for assessing the Near Point of Convergence (NPC) and Near Point of Accommodation (NPA), represents a significant stride towards enhancing visual diagnostics and patient care. This phase has introduced a precision instrument that measures NPC and NPA accurately and prioritises patients' safety and comfort during assessments.

One of the notable features of this phase is the innovative approach of pointing the laser at the chin, which is inherently non-harmful to the eyes. This strategic design choice ensures the safety of patients while simplifying the assessment process. Including a target mark on the chin further streamlines the examination by providing a visual reference for approaching the client's nose and achieving better centration. This user-friendly design enhances the overall experience for clinicians and patients, aligning with the principles of patient-centred care.

The results displayed on the N·Examiner's screen, providing measurements for both "break" and "recovery", signifies a departure from subjective methods that often lacked precision. This level of detail empowers clinicians to make more informed decisions and tailor interventions according to individual patient needs, ultimately optimizing treatment outcomes.

In the second phase of the N·Examiner project, the transition to LiDAR technology signifies a commitment to advancing measurement capabilities further. This shift enhances precision and attests to the project's dedication to safety. The attainment of FDA approval for eye safety is noteworthy, underscoring the device's compliance with rigorous safety standards.

The importance of precise measurement of NPC and NPA cannot be overstated. Visual parameters are of utmost importance in shaping an individual's daily routines and professional endeavours. Accurate assessment is fundamental for the early detection and management of binocular vision disorders, which can have profound implications for an individual's well-being and capacity to carry out daily activities proficiently.

In essence, the N·Examiner project, with its laser measurement in the first phase and subsequent transition to LiDAR, stands as a beacon of progress in the field of ophthalmology and optometry. It exemplifies the fusion of innovation, safety, and patient-centered care. The pursuit of precision in measuring NPC and NPA reflects a commitment to enhancing patient outcomes and underscores the project's potential to transform the landscape of visual assessment and care.

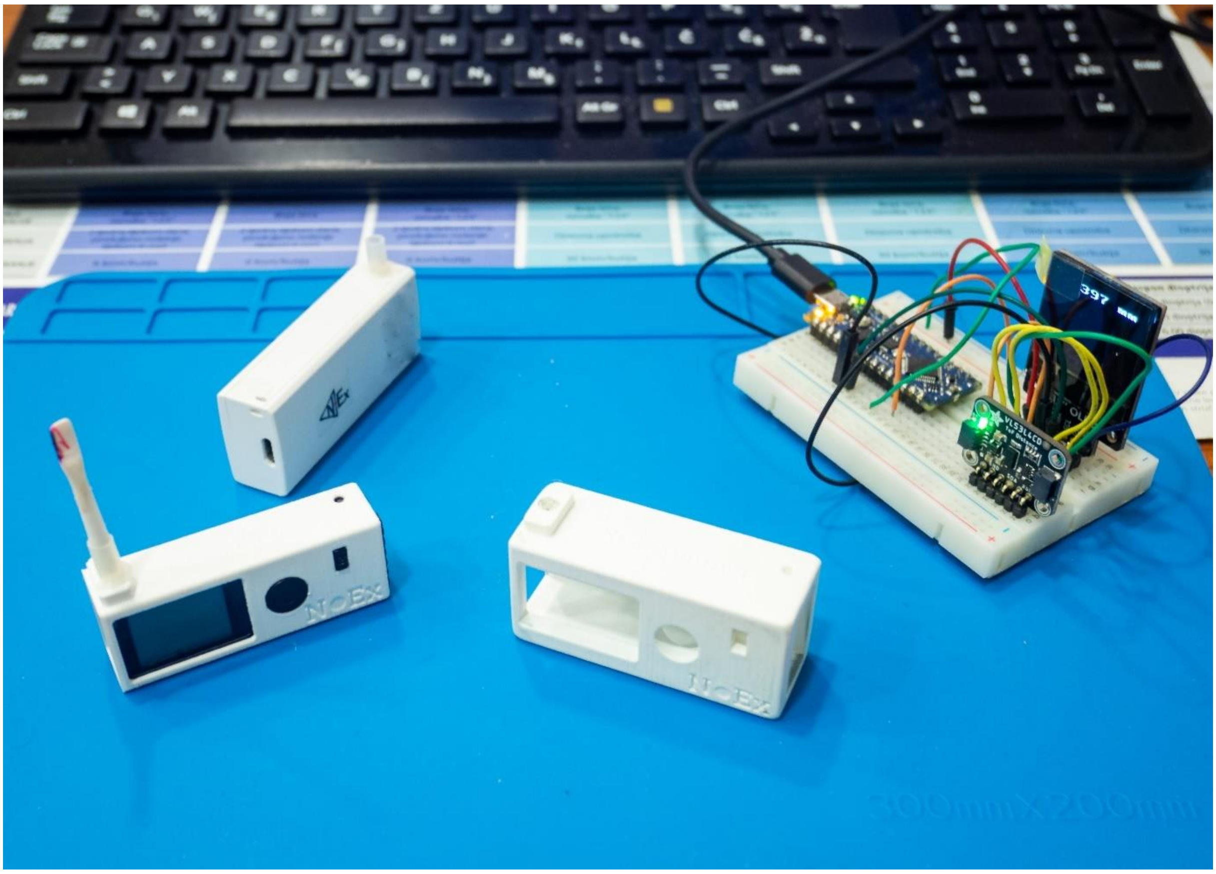

FIGURE 11. Laser and LiDAR N·Examiner prototypes

5. TIMETABLE AND BUDGET

The timetable for the N·Examiner research development plan is outlined in the table below. Each stage is justified and specified to ensure realistic progress.

Budget

The budget for the N·Examiner research development plan is allocated as follows:

Staff Costs:

Student Labor Input (EUR 15 per hour):

- Conceptualization and Design Phase: 300 hours
- Prototype Development and Testing Phase: 600 hours
- Clinical Validation Phase: 700 hours
- Transition to LiDAR Technology: 250 hours
- Comparative Studies: 950 hours
- Finalization and Commercialization: 1,100 hours

Supervisor Labor Input (EUR 45 per hour):

- Conceptualization and Design Phase: 130 hours
- Prototype Development and Testing Phase: 220 hours
- Clinical Validation Phase: 270 hours
- Transition to LiDAR Technology: 90 hours
- Comparative Studies: 360 hours
- Finalization and Commercialization: 405 hours

Material Costs:

- Prototype components and materials: EUR 5,000

Travel Costs:

- Collaborative meetings with clinical experts: EUR 800

TABLE 4. Timetable

Timetable

Stage	Duration	Description and Justification
Conceptualization and Design Phase	3 months	- Conduct literature review - Define project objectives - Establish multidisciplinary team - Formulate preliminary design framework based on research findings
Prototype Development and Testing Phase	5 months	- Engineer hardware components - Develop software algorithms - Build laser-based prototypes - Conduct initial laboratory testing - Refine design based on testing results
Clinical Validation Phase (Laser Measurement)	6 months	- Collaborate with clinical experts for trials - Collect clinical data for validation - Analyze clinical trial data - Optimize measurement technology
Transition to LiDAR Technology	2 months	- Investigate feasibility of LiDAR technology - Redesign hardware - Develop LiDAR software - Conduct testing to ensure reliability
Comparative Studies (LiDAR Measurement)	8 months	- Collaborate with clinical partners - Collect comparative data - Analyze data for superiority over manual methods - Publish research findings
Finalization and Commercialization	9 months	- Incorporate feedback from clinical trials - Prepare regulatory approvals - Develop business plan - Identify industry partners and investors

The budget for the Proof of Concept stage is minimized, given that all efforts were volunteered as part of a study project. Costs are primarily allocated to materials for prototyping. The timetable emphasizes efficient resource utilization, aiming for timely validation of Near Point of Convergence and Near Point of Accommodation measurements. This streamlined approach ensures fiscal responsibility while advancing the N·Examiner project toward its proof-of-concept milestones.

CONFLICT OF INTEREST DECLARATION

Given that the author bears all expenses for the project, it is important to recognize the potential for a conflict of interest. While self-funding a project can demonstrate commitment, it's essential to maintain transparency and ethical standards to avoid any bias or undue influence that may compromise the project's integrity.

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APPENDICES

User manual

• Power On: To begin using the N·Examiner device, locate the On/Off button on the device's surface. Press and hold this button to turn the device on. You'll know it's powered on when the indicator lights activate.

• Insert Test Target: Prepare a suitable test target, such as a stick or plate, specifically designed for near vision assessments. Insert this target into the designated slot on the N·Examiner device, ensuring it is securely positioned.

• Aim the Laser: While the test target is in place, aim the laser beam generated by the device towards the examinee's chin. Ensure that the laser beam is accurately aligned with the examinee's point of vision for accurate measurements.

• Bring Device to the Client: Gently and steadily approach the client or examinee with the N·Examiner device, ensuring the laser beam remains directed at their chin. Maintain a comfortable and stable position during this step.

• Measure Break and Recovery: Once the device is positioned appropriately, press the "M" (measure) button on the N·Examiner. The device will then record and display the real-time Break and Recovery values on the screen. These values will remain visible on the screen for one minute.

• Record Values: During the one-minute display period, carefully record the Break and Recovery values from the device's screen. These values are essential for the examination protocol and evaluation.

• Standby Mode: The N·Examiner device will automatically enter Standby mode after one minute, allowing the examiner sufficient time to record the measurements and other relevant information into the examination protocol or patient records.

• Power Off: The N·Examiner device is designed to conserve energy. It will automatically power off after a certain period of inactivity. However, you can also manually turn it off by pressing the On/Off button.

•	Charging: When the N·Examiner is not in use, place it securely on the provided charging dock. The device will automatically start charging. Leave it on the dock until the battery is fully charged, ensuring it is ready for the next examination session.

The N·Examiner device involves straightforward steps to measure Break and Recovery values for near vision assessment. It combines precision and ease of use to enhance the quality of eye examinations while offering the convenience of automatic power management and easy recharging.

About *N • Examiner*

The name *"N • Examiner"* has been thoughtfully crafted to provide a clever and multi-layered interpretation. This name offers versatility in both reading and pronunciation, adding depth to its significance.

- Near Point Examiner:

Reading Interpretation: When read as "N • Examiner", it can be understood as an abbreviation for "Near Point Examiner". This interpretation is particularly relevant in the context of ophthalmology and optometry, where the device is designed to measure parameters related to the Near Point of Convergence (NPC) and Near Point of Accommodation (NPA). As such, it signifies the device's primary purpose: to examine and assess near vision.

- An Examiner:

Pronunciation Interpretation: When pronounced as "N • Examiner" [ə)n ɪɡˈzamɪnə], it sounds like "An Examiner". This interpretation adds an element of authority and objectivity, suggesting that the device serves as an examiner or evaluator of visual parameters. It underscores the device's role in providing precise and unbiased measurements, aligning with the principles of clinical assessment.

The name "N • Examiner" 's intentional duality allows it to encapsulate its functional purpose and its role as an objective evaluator. This creative naming strategy enhances the device's identity and reinforces its significance in the field of vision assessment.