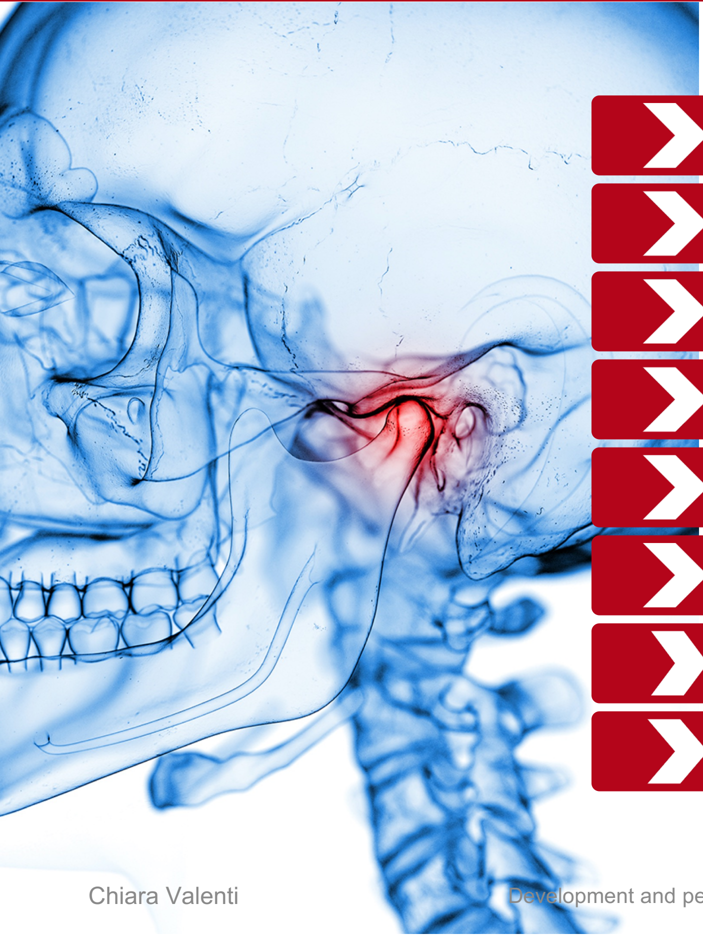
Università
degli Studi
di Padova

Development and performance analysis of techniques for mandibular movement measurement.

Chiara Valenti - 39th Cycle

Supervisor: Prof. Gianluca Rossi

admission to 2° year - 16 / 09 / 2024



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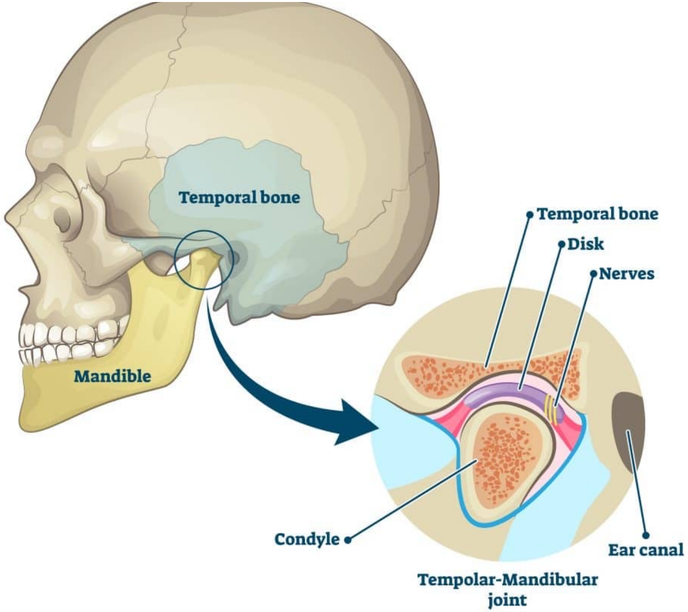
- Gantt Chart

Introduction

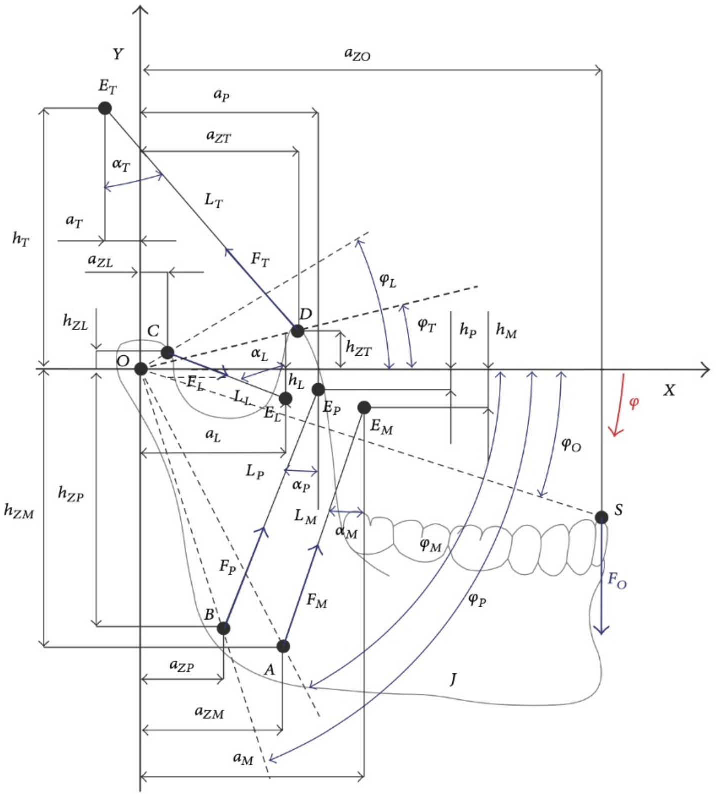
The measurement of the stomatognathic apparatus movements and masticatory tracings is a key element for the therapeutic approach of patients, to establish accurate diagnosis and effective treatment plans.

In particular for TMDs (temporomandibular disorders) characterization, as these pathologies include different conditions with complex etiology, therapeutic management, and differential diagnoses.



Schiffman E. et al. Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) for Clinical and Research Applications: recommendations of the International RDC/TMD Consortium Network and Orofacial Pain Special Interest Group†. J Oral Facial Pain Headache. 2014;28(1):6-27.*

Project



Jaw Tracking Systems (JTSs) have diagnostic and therapeutic purposes.

More approaches are needed to find a measurement method that meets realistic clinical needs.

This research is based on the development and analysis of a new accurate method for recording mandibular movements.

The aim is to design a novel, wearable device, resistant to motion artifacts, waterproof, unobtrusive for the patient, without ionizing radiation (CBCT), and with uncovered occlusal surface for mandibular movement measurement.

Kijak E. et al. Identification of mastication organ muscle forces in the biocybernetic perspective. Biomed Res Int. 2015;2015:436595.

Objectives

The objective of the research is to develop a prototype of jaw motion tracking system, and evaluate the measurement uncertainty both under in vitro and in vivo conditions.

Related expected benefits

- Realize accurate diagnoses of TMDs with effective treatment plans.
- Record data of physiological and pathological conditions for machine learning model training.
- Ensure a digital workflow, improving compliance, accuracy, efficiency, times, and costs of dental interventions.
- Personalize patient care with minimal post-production corrections of prosthetic or gnathological manufactures.

Working plan of the project

First Step	Bibliographic Research and Literature Review — Research Period in Company — Jaw Tracking Devices and Motion Simulation Analysis
Educational Activities	Courses and Seminars — Lectures and Conferences
Development and Analysis Phase	Innovative Jaw Tracking System — Laboratory Study and Measurement — In Vivo Application — Validation — Comparison
Machine Leargning Model	Data management and analysis — Supervised Algorithm — Training Phase — Clinical Comparison
Project Design	Research period Abroad — Project Applicability
Final Step	Publications — PhD Thesis

First step: bibliographic research

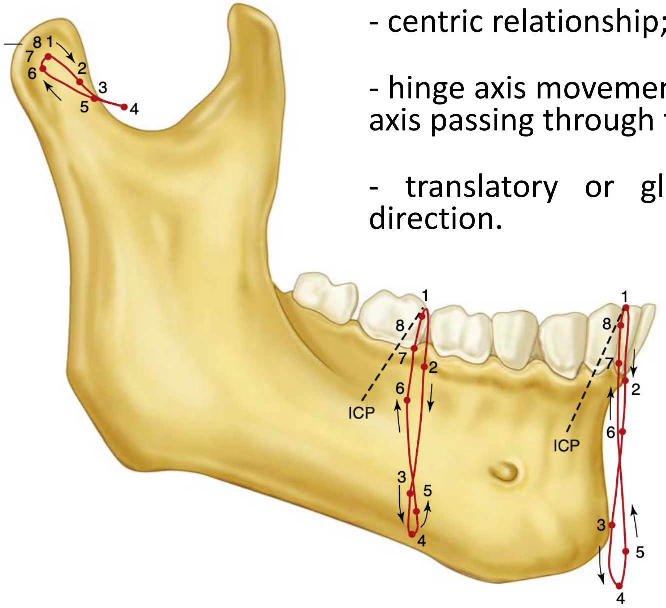
A review of the literature on the biomechanics was carried out, considering how mandibular movements are determined by an intricate kinematic system that includes different anatomical structures.

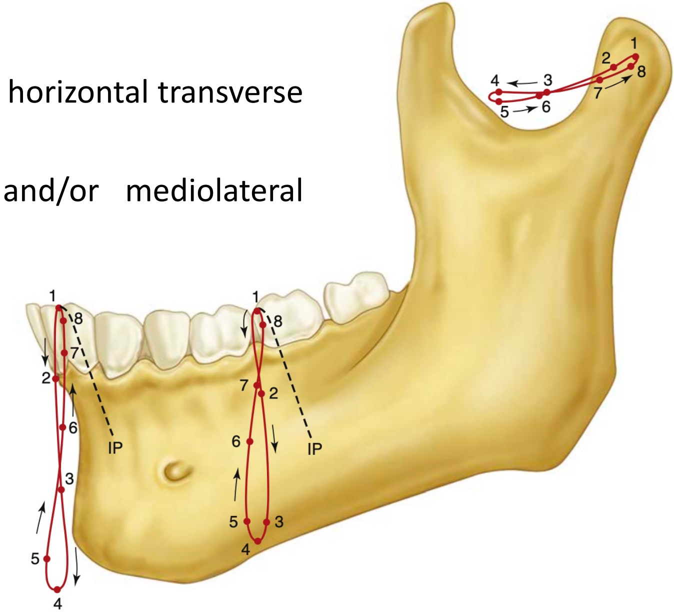
Key reference movements to be recorded:

- centric relationship;

- hinge axis movement, a rotation of the mandible around the horizontal transverse axis passing through the heads of the condyles;

- translatory or gliding movement, in anteroposterior and/or mediolateral direction.



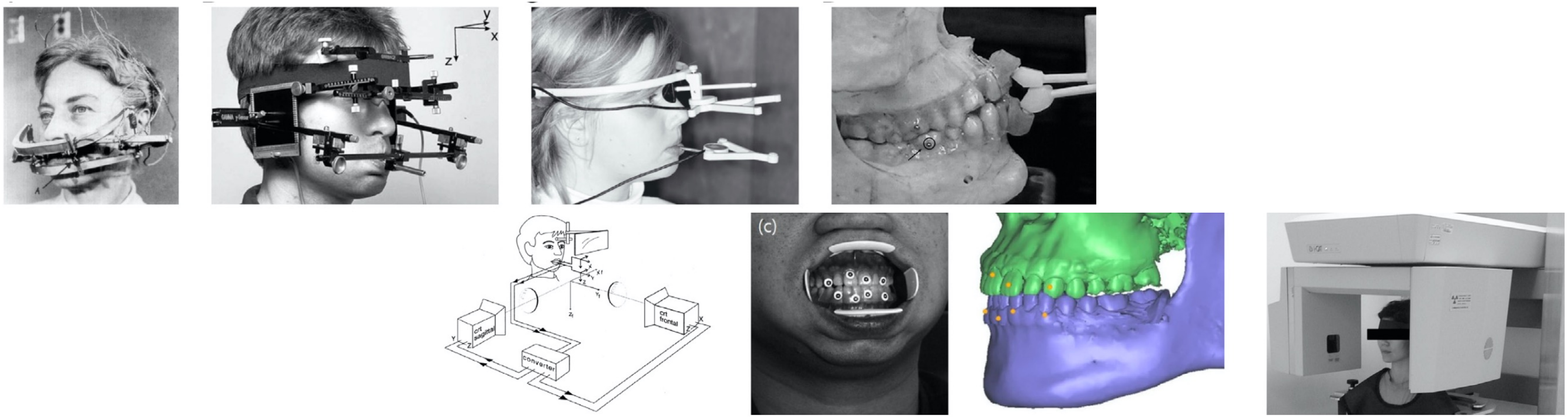


Jeffrey P. Okeson. Management of Temporomandibular Disorders and Occlusion. 8th Edition, 2019.,

First step: state of the art on JTS

The characteristics of different JTS types, mandibular dynamics, and how it affects the production of dental manufactures, were studied in depth during the 3-months period in the dental lab.

Commercially available and experimental devices were analyzed, considering both in vitro and in vivo studies on healthy and/or pathological subjects, paying particular attention to the alterations of the tracings as the pathophysiological conditions changed.



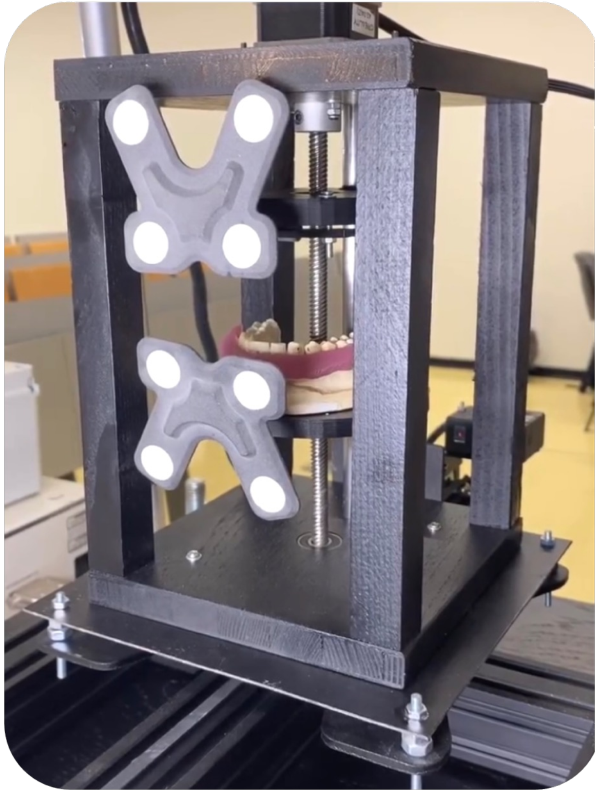
Woodford SC, et al. Measurement of normal and pathological mandibular and temporomandibular joint kinematics: A systematic review. J Biomech. 2020;111:109994.

First step: motion simulation analysis

To reproduce standardized linear motion along the y- and z-axes for the preliminary experimental setting, a simulation machine was built with parts of the structure and electronic components of an Ender 3 Pro 3D printer (Creality, Shenzhen, China).

The 3D printer's stepper motors, along with dedicated control drivers, were assembled to enable machine motion.

Linear movements were automatically defined using dedicated G-code motion functions stored on a microSD memory card, and repeated at a rate of 30 fps.



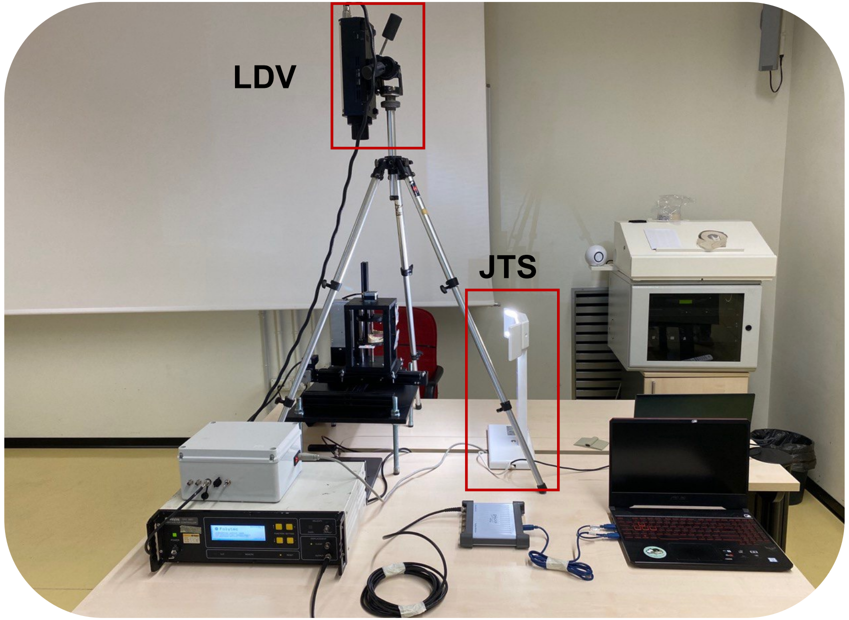
JTS analysis: preliminary results

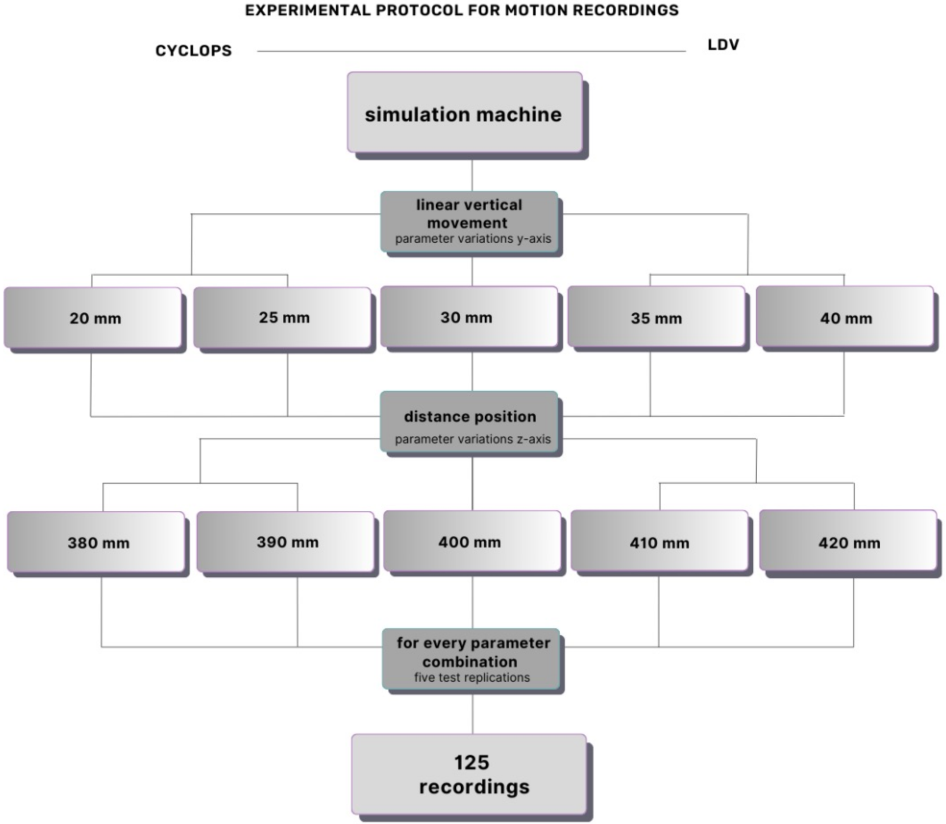
A new photometric JTS was selected to carry out preliminary measurement uncertainty analyses.

It was crucial to understand the accuracy of novel JTS in the market, to define its reliability and clinical utility, grasping any disadvantages, and making a comparison with the technique under development.

A Laser Doppler Vibrometer (LDV) was used as a reference to measure the vertical motion.

Laboratory Tests: preliminary results





Vibrometer Sensor Head

Polytec OFV-303

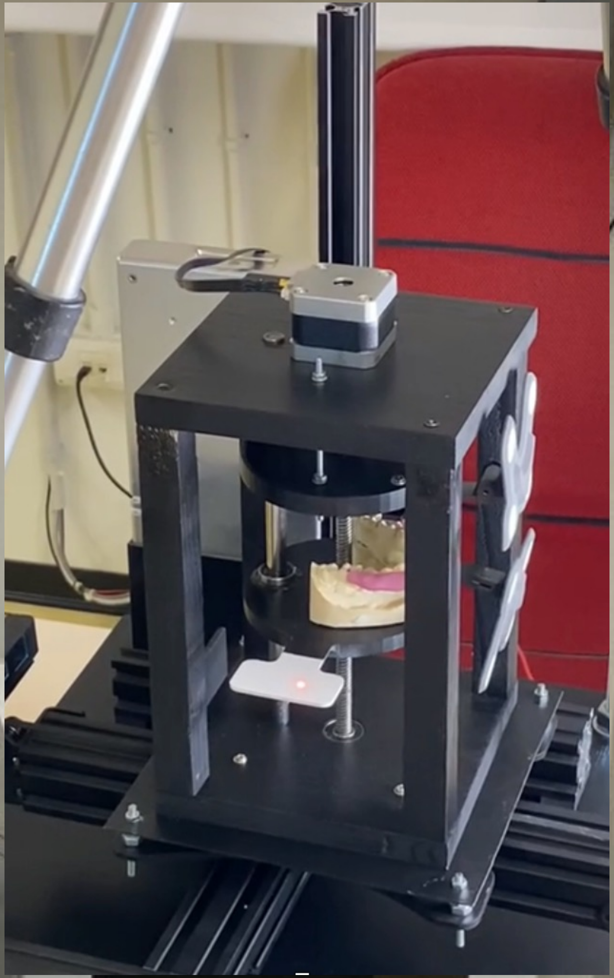
Laser type:	helium neon
Wavelength:	633 nm
Cavity length:	205 mm
Laser safety class:	II
Laser output power:	< 1 mW
Power consumption:	ca. 15 W
Output center frequency:	40 MHz
Operating temperature:	+0°C ... +40°C (32°F ... 104°F)
Storage temperature:	−15°C ... +65°C (5°F ... 149°F)
Relative humidity:	max. 80%, non-condensing

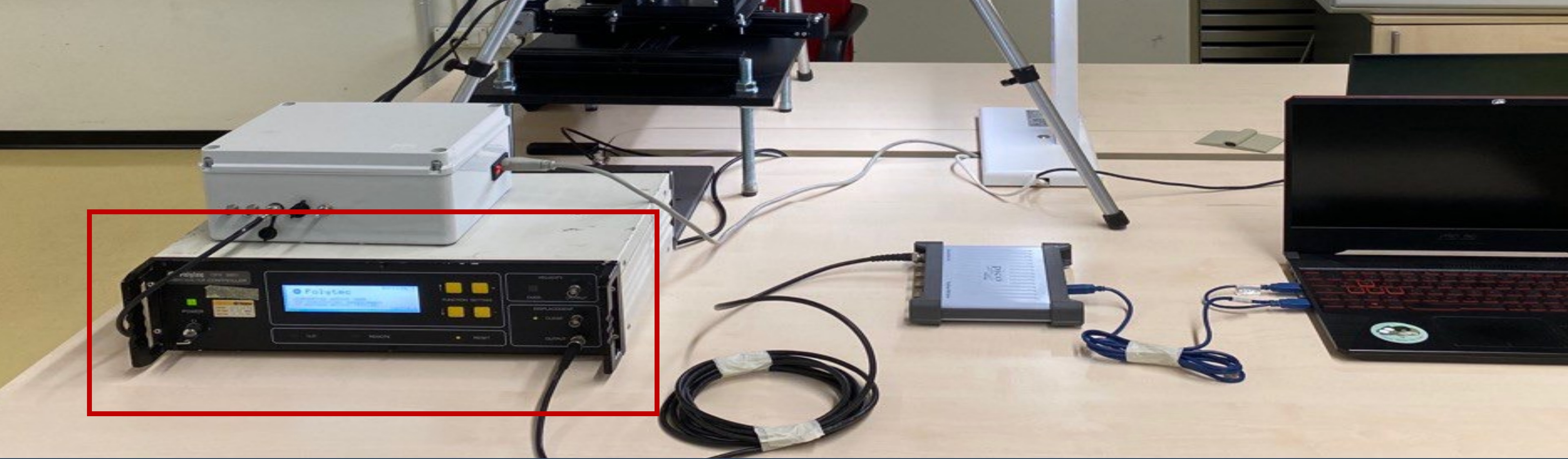
Front lens[1]		Long range (QR)	Mid range (MR)	Short range (SR)
Focal length	mm	100	60	30
Minimum stand-off distance[2]	mm	450	175	65
Aperture diameter ($1/e^2$)	mm	12	7	3.5
Spot size (typ.)	µm			
@ 175 mm		-	10	30
@ 450 mm		15	33	75
@ 1,000 mm		42	79	170
each additional meter		50	84	167
Maxima of visibility[3]		232 mm + n · 205 mm, n = 0; 1; 2; ...		

[1] A label on the side of the sensor head shows the front lens model which is fitted.

[2] The maximum stand-off distance depends on the back scattering properties of the object. It can range up to 250 m for the sensor head OFV-303 and a surface with reflective coating.

[3] Measured from the front panel of the sensor head.





Vibrometer Controller

Polytec OFV-3001

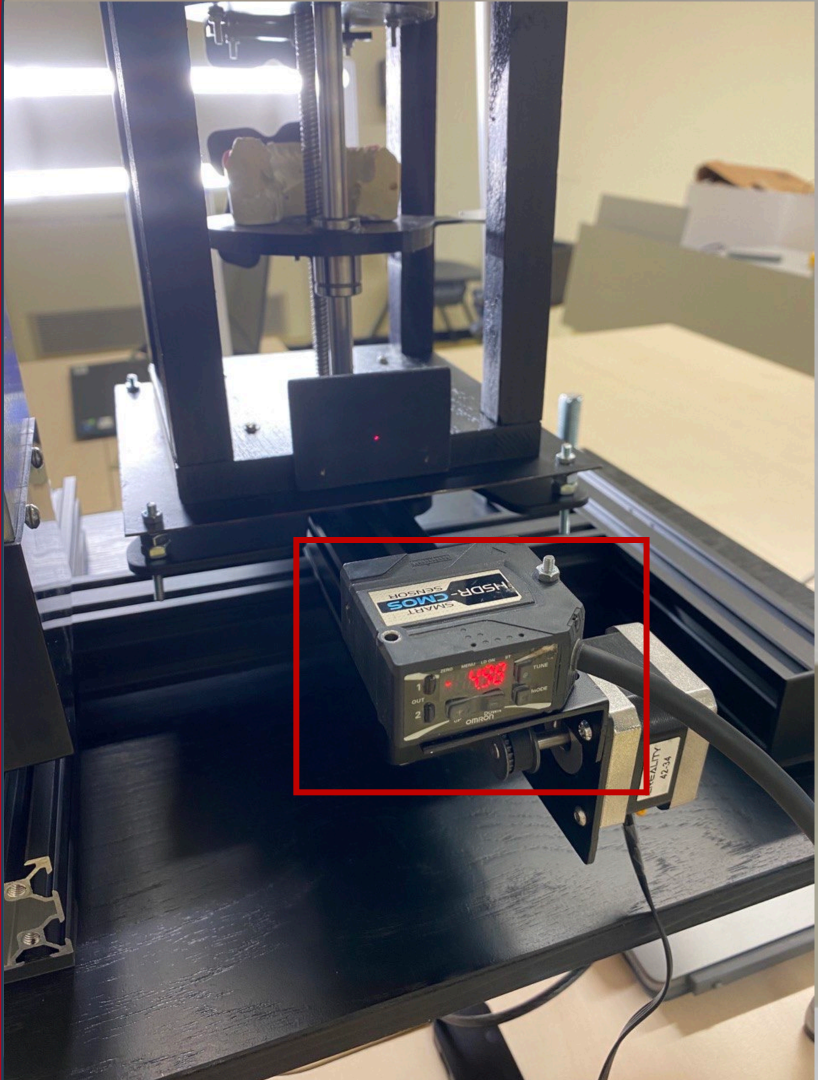
Mains voltage:	100/115/230 VAC ±10%, 50/60 Hz, adjustable at the back panel
Power consumption:	max. 150 VA
Fuses:	1.0 A/slow-blow for 230 V 2.0 A/slow-blow for 100/115 V
Protection class:	I (protective grounding)
Operating temperature:	+5°C...+40°C (41°F...104°F)
Storage temperature:	−15°C...+65°C (5°F...149°F)
Relative humidity:	max. 80%, non-condensing
Dimensions:	450 mm × 355 mm × 135 mm
Weight:	10.8 kg
Calibration recommended:	every 2 years

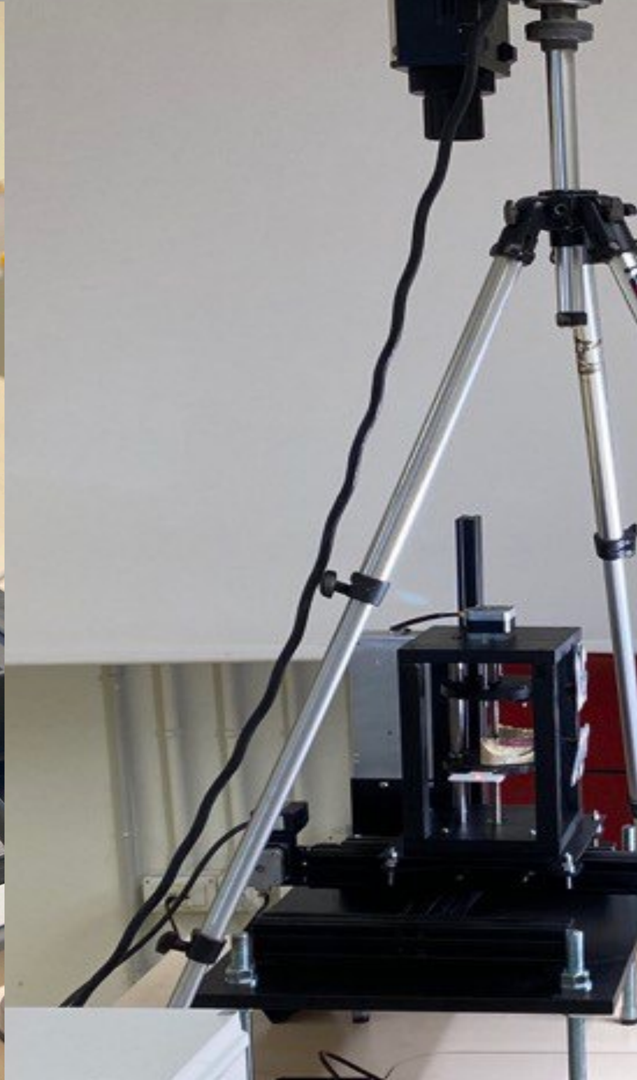
Displacement decoder	Measurement range (scaling factor) µm/V	Full scale output (peak-peak) µm	Resolution[1] µm	Maximum velocity m/s	Bandwidth kHz	Max. frequency for specified accuracy kHz
OVD-10	20	320	0.08	2.5	0...250	100
	80	1,280	0.32	10	0...250	100
	320	5,120	1.3	10	0...250	100
	1,280	20,480	5.0	10	0...250	100
	5,120	81,920	20	10	0...250	100
OVD-20 and OVD-40	0.5	8	0.002	0.06	0...25	10
	2	32	0.008	0.25	0...75	15
	8	128	0.032	1	0...75	25
	20	320	0.08	2.5	0...250	100
	80	1,280	0.32	10	0...250	100
	320	5,120	1.3	10	0...250	100
	1,280	20,480	5.0	10	0...250	100
	5,120	81,920	20	10	0...250	100

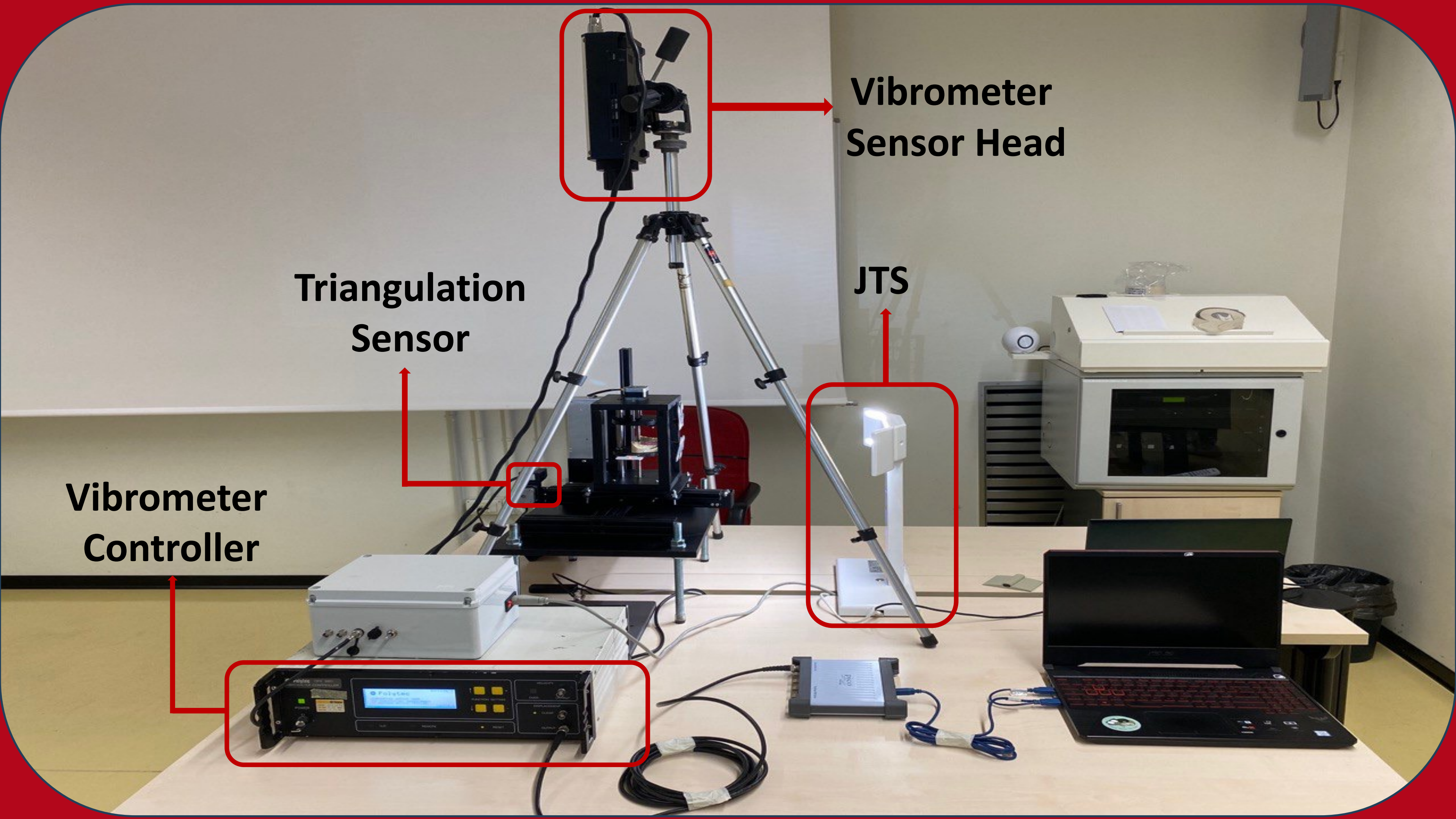
[1] The resolution is defined as 1 increment of the fringe counter output which is equivalent to a 4 mV output voltage step.

Triangulation Sensor

ZX2-LD100L	Line beam type	
ZX2-LD100	Spot beam type	
Measurement range	100mm±35mm	
Resolution	5 µm	
Linearity	Line beam	±0.05%F.S.*2
	Spot beam	±0.10%F.S.*2
Beam size	Line beam	Approx.110µm×2.7mm
	Spot beam	Approx.110µm dia.





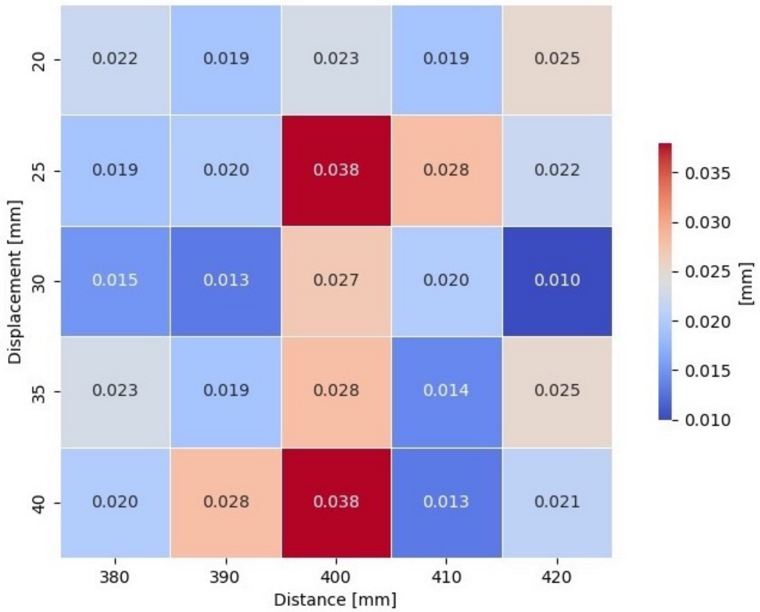

Vibrometer
Sensor Head
Triangulation
Sensor
JTS
Vibrometer
Controller

preliminary results

Through a statistical analysis of random errors, the measurement uncertainty was performed calculating the SD of the mean over N repeated measurements of the same physical measurement.

Data analysis was performed using Python with a p = 0.05 significance level.

Variations in linear vertical movement and distance positions did not significantly affect the accuracy of the instrument.



In Vivo Tests: preliminary results

Preliminary in vivo tests were also carried out to evaluate the variability of functional movements in protrusion and mediotrusion.

20 subjects were included in the study after gnathological examination, then each participant performed 5 different recordings within one-month.

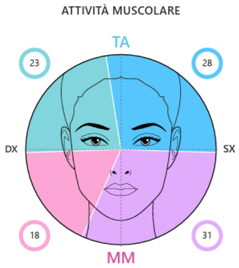






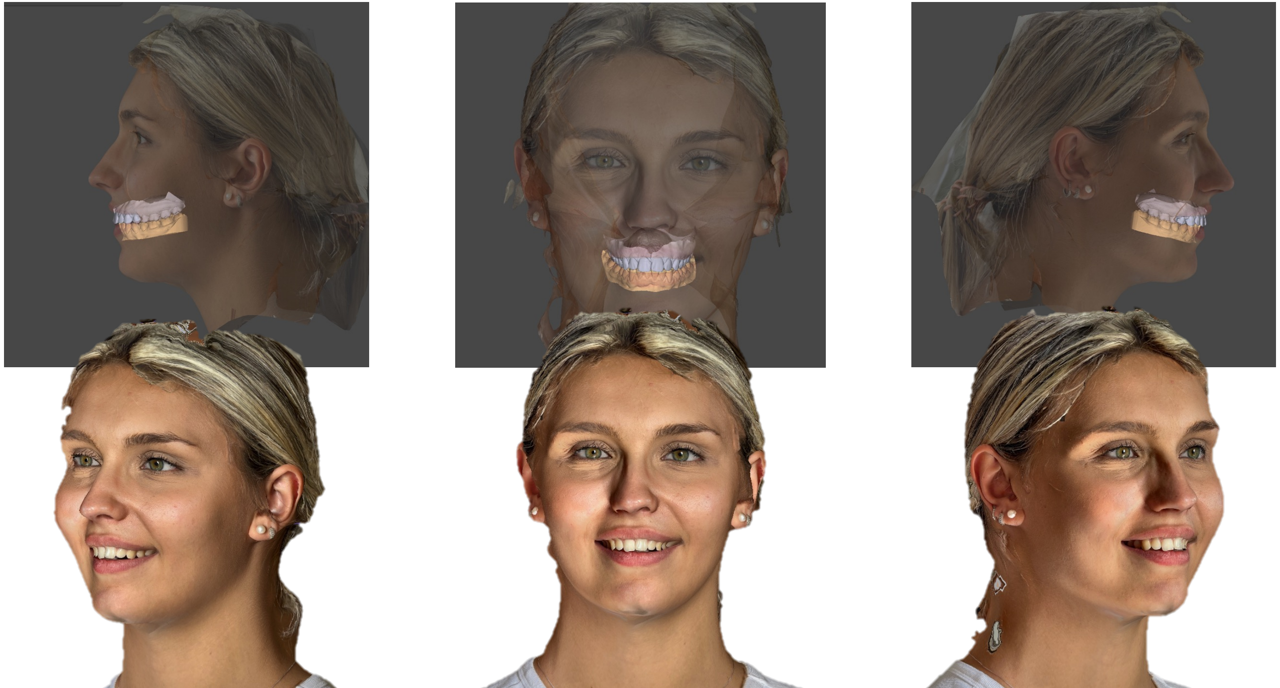




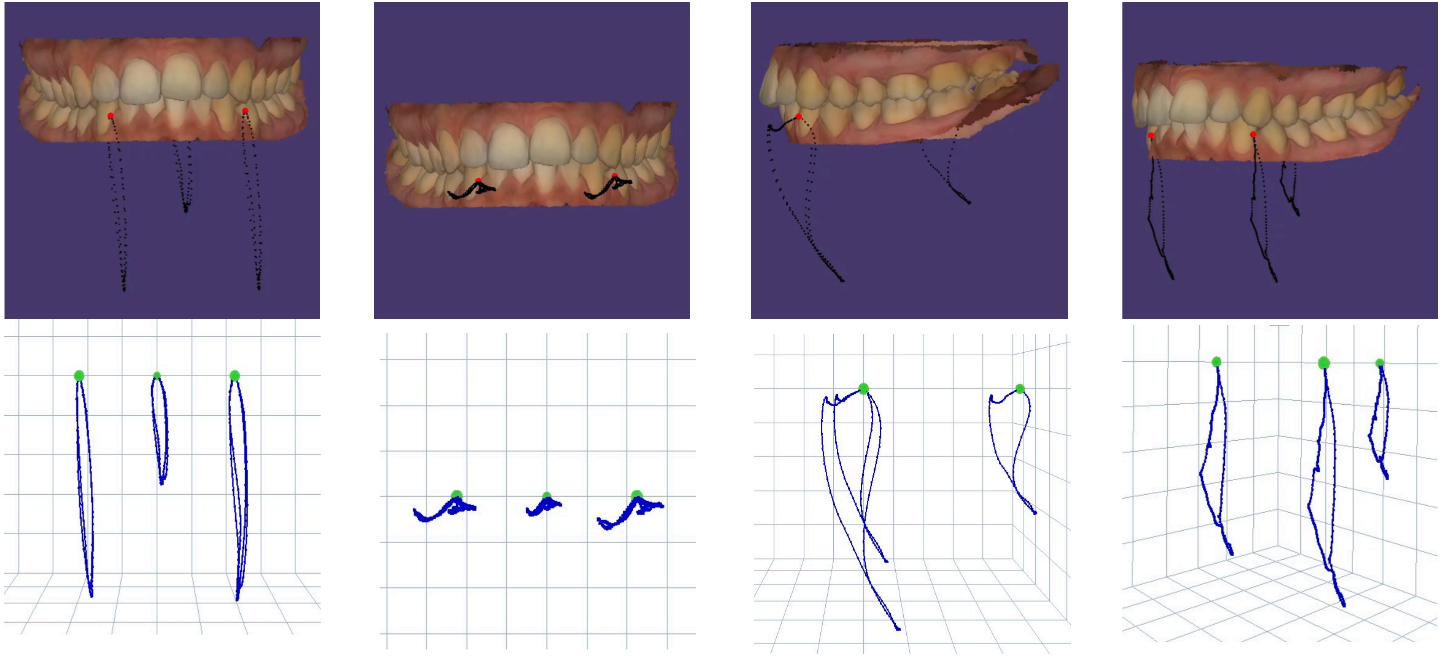


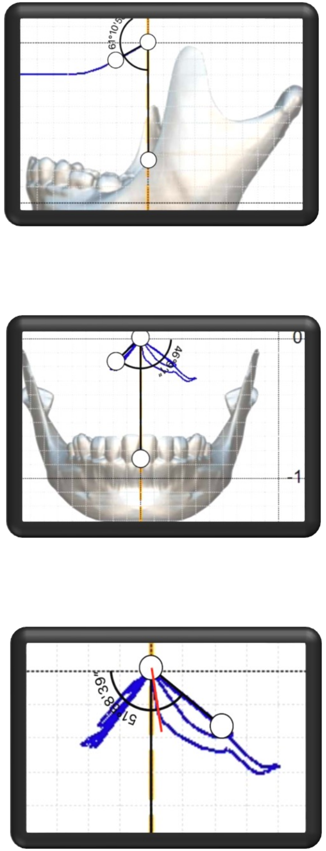
In Vivo Tests: preliminary results

JTS recordings, facescans (Metascan), and intraoral registrations were made to superimpose 3D static information, the relationship between perioral tissues and dental arches, and mandibular dynamics and excursions.



In Vivo Tests: preliminary results

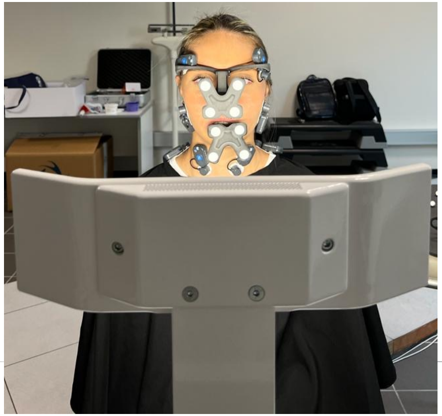


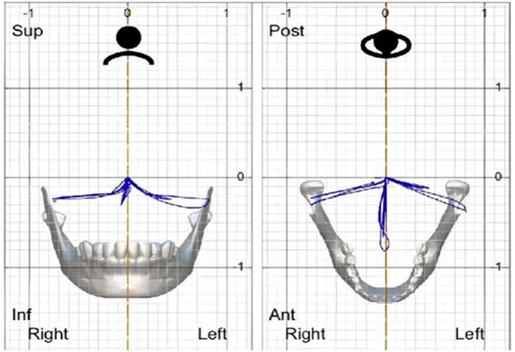


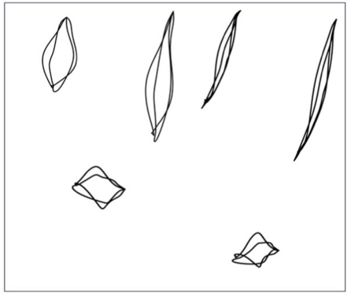
The variability of movements was evaluated with the angle of functional paths within the first 2 mm from the maximal intercuspal position.

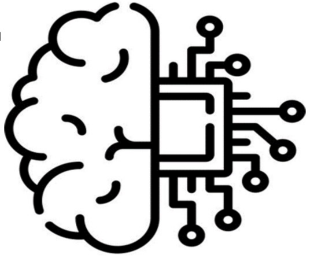
<u>significant variations</u> were reported between different patients, and *<u>non-negligible variations</u>* occurred even in the tracings of the same patient.

Machine Learning Models









Healthy patient

TMD patient

Recordings from 160 patients were converted from point clouds to 2D images to optimize the input.

80% of the dataset data were used for training,
the remaining 20% for testing phase.

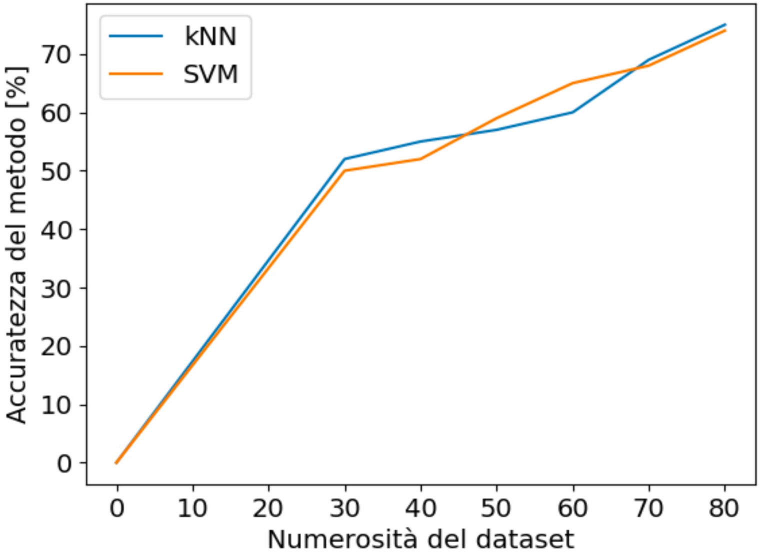
Machine Learning Models

Classification algorithms implemented in Python:

- k-NEAREST NEIGHBORSS (kNN) unsupervised algorithm determines the category of a new input comparing it with the features of the nearest neighbors in the dataset, and assigning the most common category among the selected neighbors.

- SUPPORT VECTOR MACHINE (SVM) supervised algorithm designed to identify the boundary that best separates image categories based on their distinctive features.

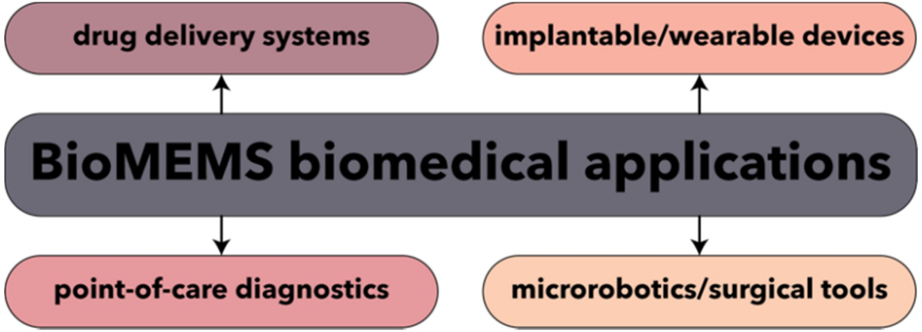
Future developments will consider to increase the database and explore convolutional neural networks (CNN).



MEMS application

Many options were evaluated for the development of a new JTS technique (ultrasound, optical, photometric, or magnetic systems).

The application of microelectromechanical systems (with integrated magnetometers, accelerometers, and gyroscopes), as in other biomedical fields, was identified as a potential system to record dental impacts through acceleration measurements, and jaw motion and dynamic closure, identifying pathological behavior that indicates the type of TMD dysfunction.



Chircov C, Grumezescu AM. Microelectromechanical Systems (MEMS) for Biomedical Applications. Micromachines. 2022; 13(2):164.

Publications

Journal of Dentistry 148 (2024) 105245

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.elsevier.com/locate/jdent

ELSEVIER

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Accuracy of a new photometric jaw tracking system in the frontal plane at different recording distances: An in-vitro study

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ARTICLE INFO

Keywords:
Kinesiography
Motion tracking analysis
Functional mandibular movement
Photometric jaw tracking system
Jaw movement recording

ABSTRACT

Objectives: To evaluate the accuracy of a new photometric jaw tracking system (JTS) in recording linear vertical movements in the frontal plane at different distances.
Methods: A mandibular plaster cast of a patient was placed on a simulation machine capable of linear movements along two spatial axes. Cyclops JTS (Itaka) was adapted to the plaster cast, while the head frame was attached to the simulation machine. The latter performed five linear movements from 20 to 40 mm in the y-axis; each movement was repeated five times at five different recording distance (380 to 420 mm). The recorded movements were measured and compared with those obtained with a laser Doppler vibrometer (LDV) for accuracy analysis. Data were statistically processed ($\alpha = 0.05$).
Results: No statistically significant differences were found between Cyclops and LDV measurements on the y- and z-axes ($p = 0.5$). Changes in linear vertical motion and distance positions did not affect the accuracy, which remained relatively constant with similar trends and values less than 1 % for each parameter variation. The best condition observed was linear vertical movement of 30 mm at 420 mm (0.010 ± 0.023 mm).
Conclusions: Cyclops has proven to be an accurate JTS in recording linear vertical movements in the frontal plane at different recording distances. For optimal recordings, the scanner should be placed as close as possible to the markers; excessive vertical movements decreased the accuracy. However, this study has limitations and requires in-vivo confirmations.
Clinical significance: The tested JTS proved accurate in recording linear vertical movements in the frontal plane. However, given the limitations of the study, further investigation under real conditions is needed to support prosthetic and gnathological rehabilitations.

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Contents lists available at ScienceDirect

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ELSEVIER

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Investigation of the precision of a novel jaw tracking system in recording mandibular movements: A preliminary clinical study

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ARTICLE INFO

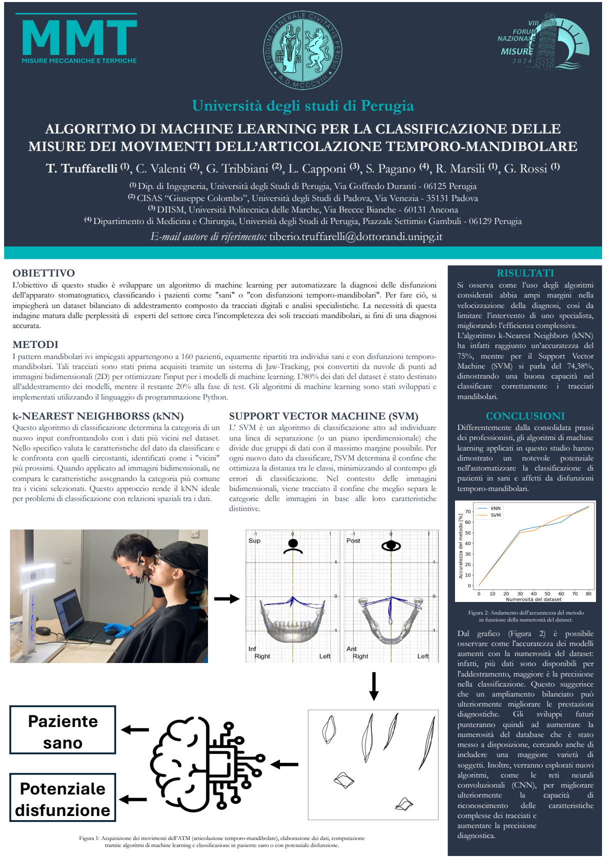
Keywords:
Functional mandibular movement
Jaw tracking system
Kinesiography
Jaw movement recording, Computer aided design
Dynamic technical modeling

ABSTRACT

Objectives: This preliminary study aimed to clinically assess the precision of a novel optical jaw tracking system (JTS) in registering mandibular movements (MMs) of protrusion and mediotrusion.
Methods: Twenty healthy participants underwent recordings using Cyclops JTS (Itaka Way Med) for functional MMs of protrusion and laterotrusion by two trained clinicians. Each subject performed five registrations at different times according to a standardized pattern within one-month period. The angulations of protrusive and mediotrusive functional paths within the first 2 mm from the maximal intercuspal position (MIP) were calculated for each trace, using a data software for angle measurements. Descriptive statistics were used to assess the repeatability of the recordings for each participant and MM. Additionally, inferential statistics were carried out on standard deviation values obtained (α=0.05).
Results: The overall precision for all the patients was 7.07±3.37° for the protrusion angle, 5.24±2.24° for right laterotrusion and 5.14±3.06° for left laterotrusion angles. The protrusion angle ranged from 3.08° to 13.57°, while the right and left laterotrusion ranged from 1.82° to 9.42° and from 1.58° to 10.59°, respectively. No statistically significant differences were observed between different functional MM types and gender ($p > 0.05$).
Conclusions: Recordings functional MMs of mediotrusion and protrusion using Cyclops JTS showed consistent repeatability, regardless of gender and functional MM type. The results revealed non-negligible variations that may be due to the patients' abilities to precisely reproduce jaw movements or to the operator's ability to consistently connect the kinesiograph.
Clinical significance: Capturing functional MMs digitally and importing the data into dental CAD software is essential for virtual waxing in prosthetic rehabilitations to design a functionalized adapted occlusion. Establishing the repeatability of MM recordings by a JTS is a crucial step in better understanding this novel JTS in the market. This process could facilitate the interpretation of cusp angles, aid in CAD dynamic technical modeling, and enhance clinical data communication between clinicians and technicians in a modern workflow.

Posters and Conferences

VIII FORUM NAZIONALE delle MISURE 2024



Posters and Conferences

EXPO DENTAL MEETING | 15-16-17 MAGGIO 2025 RIMINI - ITALIA

SIOCMF
SOCIETÀ ITALIANA DI ODONTOSTOMATOLOGIA E CHIRURGIA MAXILLO-FACCIALE

Nuovi sviluppi della registrazione occlusale e dimensione verticale, materiali e strumenti di supporto clinico

Gantt Chart

FIRST YEAR / SECOND YEAR / THIRD YEAR — T1 T2 T3 T4 — O N D J F M A M J J A S

WBS NUMBER	TASK TITLE	% OF TASK COMPLETE
1	Background and state of the art	
1.1	Bibliografic research and literature review	53%
2	Machinery study	
2.1	Research period in the selected company	50%
2.2	Jaw tracking device analysis	70%
2.2.1	Jaw motion simulation machine	60%
3	Educational activities	
3.1	Courses and seminars	30%
3.2	Lectures and conferences	30%
4	Development phase	
4.1	Innovative jaw tracking system	20%
4.1.1	Laboratory study	0%
4.1.2	In vivo application	0%
5	Analysis phase	
5.1	Validation of the device	0%
5.2	Comparison	0%
6	Machine learning model	
6.1	Classification of the recordings	30%
6.2	Supervised algorithm	40%
6.2.1	Training phase	0%
6.2.2	Clinical comparison	0%
7	Project design	
7.1	Research period abroad	0%
7.2	Project applicability	0%
8	Scientific publications	
8.1	Scientific articles writing	33%
9	PhD thesis	
9.1	Thesis writing	0%

Thanks for your attention

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