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VOICE STRING THROAT VIBRATION VOICE RECOGNITION SYSTEM FOR ELECTRIC ROTORCRAFT NAVIGATION

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Abstract: Over the last five decades, researchers have devoted efforts to improve voice recognition technology and improve accessibility for people with disabilities. Significant frameworks since the 1950s, such as Amazon's pioneering work in voice-controlled remote systems, have shaped the field. This paper proposes a speech recognition system designed for speech recognition through voice string vibrations to navigate on electric wheel tracks. The system uses a digital signal processor (DSP) and a laryngophone to capture throat vibrations. The prototype was tested and its reliability validated, mainly in environments with high noise levels. The system ensures accuracy in the interpretation of voice commands, focusing on throat vibrations. In addition, an algorithm was developed to link voice commands to the corresponding actions for the electric motor. Our results indicate that this system has higher noise immunity compared to the microphone system, improves the quality of life and autonomy of people with disabilities, while offering wider application opportunities.
Keywords: Digital Signal Processing, Electric Wheelchair, Tetraplegics, Laryngophone, Urban Mobility.

INTRODUCTION

Approximately one billion people in the world face some form of disability [1]. In Brazil, according to the 2010 Census, 17.3 million individuals over 2 years of age have some kind of disability [2]. Among these impairments, there are injuries that affect the spinal cord at the cervical level, resulting in different degrees of motor and sensory compromise and culminating in the need for mechanical assistance for locomotion. Tetraplegia, for example, affects approximately 300 thousand Brazilians, standing out as a complex challenge, characterized by paralysis of the upper and lower limbs, as well as other motor and sensory functions, imposing significant limitations on the independence and quality of life of the affected people [2].

To overcome these challenges, some relevant work is taking place in the field of biomedical and rehabilitation devices, such as electric wheelchairs, exoskeletons, thought-controlled prostheses, intelligent orthotics, brain-machine interfaces, wearables, as well as accessibility applications and voice and speech recognition assistants.

This article presents the sequential results of the work that culminated in the granting of the patent by INPI [3], entitled "Motorization of wheelchairs by three-phase induction motors with vector control and joystick control and support/suction", granted on 03/03/2022.

The work on the control of wheel loaders began in 2000 [4], [5], at the Advanced Control and Biomedical Engineering Laboratory of the State University of Londrina (UEL) and published in [6], also resulting in another patent granted in 2022 [7], entitled "Wheel loader moved by support and suction", on 11/29/2022.

Subsequently, a new control system was developed based on the vibrations of the vocal cords to actuate the movements of the wheelchair. This advance is a consequence of the work of [8].

As a result, a new patent application was filed, number BR1020230185096, with the title "Cadeira de rodas elétrica comandada pelas vibrações das cordas vocais na garganta", which was registered on 09/13/2023.

In the ISI Web of Science database, only two articles related to vibrations of vocal cords in the throat were found and none of them used a laryngophone.

In [9], the vibrations of the vocal cords are acquired considering the fundamental frequency of the user's vibrations and the acquisition occurs through an accelerometer that measures the vibration of the vocal cords. Thus, many problems are reported in the article itself in the acquisition and treatment of signals.

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In [10], not all the steps of the procedure for effective operation are explained. The paper uses only a microphone close to the throat and also does not explain the proper functioning in noisy environments, making only an analysis of the signals [10].

In [8], a work with laryngophone and tests in different environments on the operation of the wheelchair commands are presented. In our work, the laryngophone proved to be more robust, easily adaptable to the throat and versatile, prepared to treat and respond better to noise in different environments, reducing the complexity in the treatment of signals shown in the works found in the ISI database [9],[10], reducing sensitivity to external noise. The result was a less expensive implementation with a low-cost commercial microcontroller.

The authors have published several related works in the area of biomedical engineering involving electrostimulation control of paraplegic patients [11], [12], [13], [14], [15], joystick-operated wheelchair control [16], control of the wheelchair controlled by support and suction [6], [17], [18], [19], interface for decoding of the voice for surdocegics [20] and control of the robotic arm [21], [22], [23], [24].

The electric wheelchairs are generally controlled by the user by means of a joystick [16], but there are other possibilities of operation, such as: ocular [25], facial expressions [26], electromyography, eletroencephalography, suction and suction [27] and by voice. In the state of the art of voice-commanded wheelchair different strategies were performed. In [28], the authors performed microphone capture and feature extraction processing using Multi-Layer Perceptron (MLP) neural networks. In [29], a decision method using the Euclidean distance concept was proposed for voice recognition for round-robin camera. In [30], a scooter was adapted to a wheelchair and by means of three voice commands performed alterations in the course. However, the authors reported problems in environments with high noise intensity.

The main contribution of this work to the state of the art consists in the development of a prototype that captures throat vibrations by laryngophone and processes voice commands to operate the electric motors of the scooter. A wide mobility is achieved by the user who controls by voice the direction of the trolley with options of forward, return, left and right. An on-board algorithm performs the information processing and voice recognition, as well as performs the operation of the electric motors. The novelty of this work consists in the fact that for the first time a system with laryngophone is proposed to capture vibrations of the vocal cords through the throat. The advantage of this approach in relation to the conventional method is due to its greater reliability and immunity to external noises.

Within the scientific and technological context, this research is extremely important because it aims to improve voice recognition technologies to control devices, with special focus on wheelchairs for quadriplegics. In addition, this work contributes to improve the quality of life of people with severe disabilities, providing them with greater autonomy and independence. The results achieved may not only benefit directly the users of wheelchairs, but also pave the way for the development of other assistive technologies based on voice recognition, promoting a more inclusive and accessible society.

THEORETICAL FOUNDATION

TETRAPLEGIA

The focus of application of this work is on people with motor deficiency, specifically people with severe restricted mobility, tetraplegics. Tetraplegia is a medical condition characterized by paralysis of the upper and lower limbs (arms and legs) and, in many cases, of the trunk. Tetraplegia is particularly the result of a spinal cord injury in the cervical region of the vertebral column [31].

Generally, the causes of tetraplegia are: a) traumas, such as car accidents, accidents, firearm injuries, among others; b) diseases, medical conditions such as multiple sclerosis, poliomyelitis, spinal muscular atrophy and infections in the spinal cord; c) congenital conditions , that is, anomalies present at birth that affect the spinal cord.

The symptoms of tetraplegia may vary depending on the level and severity of the lesion, but generally include: loss of movement of the arms and legs; loss of sensation in areas below the lesion; respiratory problems; dysfunction of internal organs such as bladder, bowel and sexual organs; muscle spasms; neuropathic pain.

Thus, the inclusion of people with disabilities (PwD's) is a challenge for the whole society and governments through the strengthening of public policies. Among the challenges is the need to promote a more supportive and equal environment for PWDs, ensuring accessibility, mobility, social integration, school inclusion, employment opportunities, access to specialized medical services, as well as reducing stigmas and social preconceptions.

PHONATOR APPARATUS

The human voice is a complex phenomenon that involves the interaction of several anatomical and physiological systems [32]. The voice sound is produced mainly by the movement of the vocal cords, located in the larynx.

The vocal pregas are muscular and ligament structures that vibrate when the air passes through them, creating sound waves. This process is controlled by the air pressure in the lungs and by the movement of the diaphragm and intercostatic muscles [33]. The voice is influenced by the shape and function of the resonance cavities, including the pharynx, oral cavity, and nasal cavity. The pharynx serves as a resonance tube, which amplifies and modulates the sound produced by the vocal cords.

HUMAN VOICE PROCESSING

Since the 1950s, the use of speech as a command has been a constantly evolving area of research, driven by advances in audio signal processing and pattern recognition technology. The first speech recognition systems emerged at that time, using rudimentary techniques of signal processing to identify speech patterns. Among these systems, the IBM SHOEBOX® (1962) stands out, which recognized approximately 16 words, representing an important milestone at the time.

In the following decades, with the advancement of computer technology, more sophisticated systems, such as hidden Markov models, emerged. In the 1990s and 2000s, with the Internet and greater processing capacity, systems were integrated into consumer electronic devices. In 2014, Amazon launched a cloud-based voice assistant, which uses advanced natural language processing and speech recognition technologies to perform various tasks.

Since then, voice assistants, such as Alexa®, have become increasingly integrated into a variety of devices and systems, including smartphones, smart speakers, televisions and automotive vehicles.

Currently, these systems continue to evolve, offering an ever-increasing range of voice--based resources and functionalities for users. Especially in the field of Biomedical Engineering there is a special focus on the area of assistive technologies, seeking voice actions to assist people with disabilities.

The processing of the human voice involves time and frequency domain signal analysis techniques. One technique widely used to represent the frequency intensity variation of a voice signal over time is the spectrogram. There are two types of spectrograms: long band and narrow band.

The long-band spectrogram is useful to observe the temporal structure of voice signals, such as the duration of vowels and consonants, as well as the detection of rapid transitions between sounds. While the narrow band spectrogram is suitable for analyzing tonality and presence of specific frequencies. The frequency bands are narrower and the temporal resolution is lower, which makes it possible to evaluate harmonic frequencies in more detail [34].

METHODOLOGY

PROPOSED SYSTEM

To validate the strategy proposed in this work, some modifications were made to a commercial rover that has a joystick for navigation. Figure 1 shows the main hardware elements used in the approach of navigating the rover by voice commands from the throat.

The system is basically composed of: joystick and laryngophone; anticollision module; signal processing and control module; voice recognition module; signal conversion module; direct current (DC) voltage source; direct current to alternating current (AC) converter; three-phase inverter and three-phase induction motors, of the stator rotor-gear type.

The anticollision module uses HC-SR04 ultrasonic sensors. The laryngophone is Baofeng's UV-5R BF-A5 BF-888S model, which is connected to the Elechouse V3 DSP voice recognition module. This, in turn, is connected to the Arduino UNO microcontroller, which is responsible for signal processing and control. The power source of the rotor caddy is 12V automotive batteries. Considering that the trolley is powered by alternating current motors, a 24VDC direct current to alternating current converter for 220VRMS and a WEG frequency inverter, model CFW 010, parameterized in vector mode, were used. The integration between the signal processing and control modules with the frequency inverter was by means of a 4-channel relay shield. More details can be found in [8].

METHODOLOGY

The system is able to operate both by means of joystick commands and voice commands coming from the laryngophone. Before using the system it is necessary to perform a calibration step of the voice recognition module.

As described in [8], a software and the use of DSP (Digital Signal Processor) hardware were developed to evaluate signals captured via laryngophone, detecting command intentions to control a treadmill. The recognition of command patterns and their association with a reference bit for motor operation are described in [8] and accessed at https://x.gd/xVS9z.

According to [8], the recognition of command patterns and their association with a reference bit for motor operation are described by functional blocks, which are represented in Figure 1. The sensitivity of full speech is not prioritized, allowing users with speech pathologies to emit intentional sounds, since the algorithm prioritizes the throat vibrations over the finalized voice. The algorithm was developed in C language, a standard for the DSP's used.

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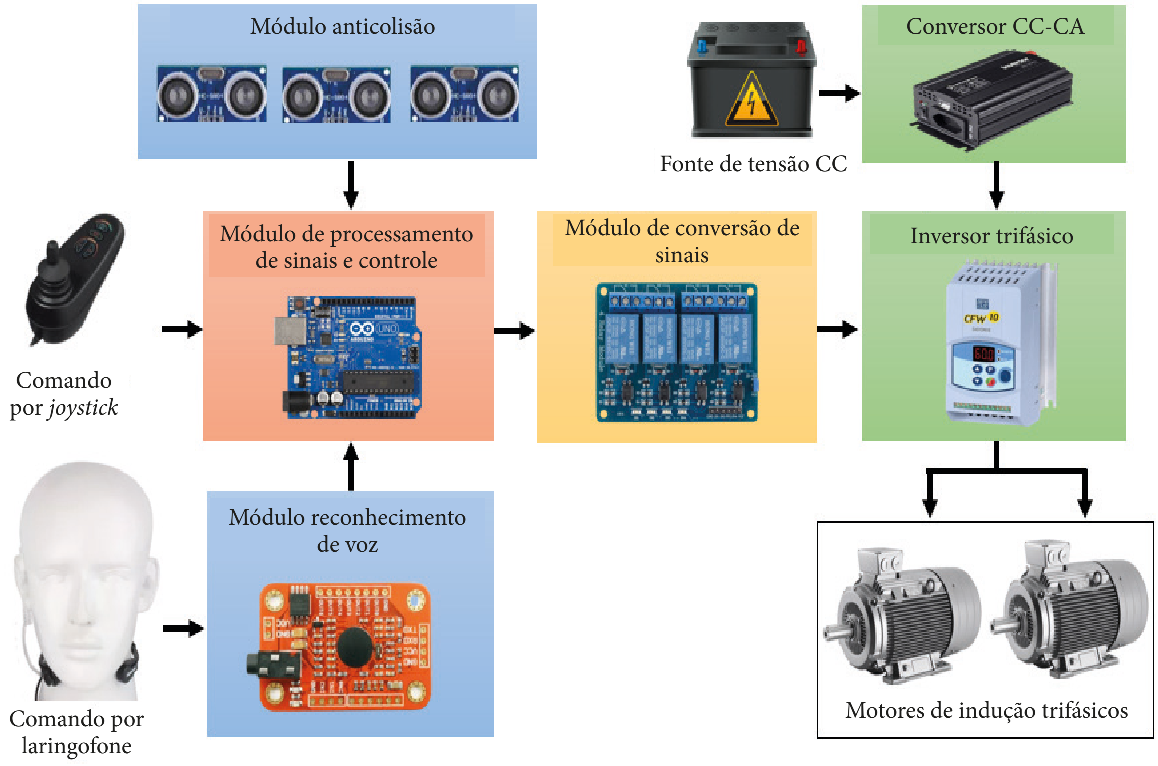

Figure 1 - Block diagram of the proposed system for wheelchair operation by voice commands from the throat. Source: [8].

In the procedure of education of the command voice, which were educated, training the algorithm in the recognition of the faults of the candidate in question, the faults were in points in 3 different environments and, for a broad view of the gain of the strategy of the throat vibration signals captured by the laryngophone, a comparison of the laryngophone with the eletretto microphone was performed, in the capture of the command voices to be educated in the system. In both situations, a non-pathological volunteer participated in the following environments: (a) silence, at 22 dB, (b) medium noise, at 38 dB, and (c) high noise, at 68 dB.

The command words that were educated and here applied to the two capture elements (Laringofone and Microfone) are: Advance, Return, Left and Right.

The speech analysis software used is WASP (Web Assisted Structure Prediction), a free program for speech recording, display and analysis, with which you can record and playback speech signals, save and reload them from disk, edit annotations and display spectrograms and a fundamental frequency plot.

WASP is a simple and complete application, but also designed to be compatible with the Speech Filing System (SFS) tools for speech research, owned by SOFTWARE.INFORMER.

Figure 2 illustrates a non-pathological volunteer, who is with the laryngophone raised to the level of the larynx, more specifically the glottis, which is the portion located between the vestibular and vocal cords on each side, the exact point of vibrations of the vocal cords.

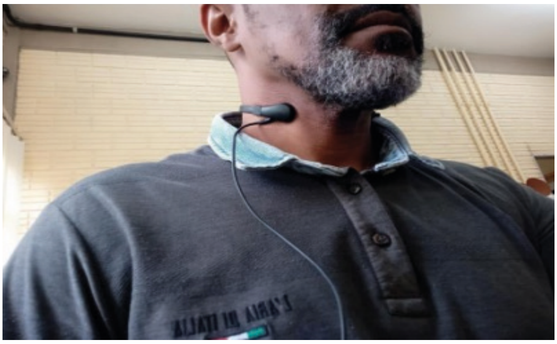

Figure 2 -Non-pathologic lung with laryngophone installed in the throat. Source: Author.

In the monitoring of speech education by WASP (WASP - University College London, open source), it is possible to adjust the recording quality by modifying the sample rate, being the standard rate of 16000 samples per second with a resolution of 16 bits, ideal for the production of speech spectrograms. However, not all computers support this rate, being necessary, in some situations, to record at 11025 (or 22050) samples per second, depending on the case.

RESULTS AND DISCUSSIONS

EXPERIMENTAL VALIDATION

Figures 3 and 4 show the waveforms, broadband and narrowband spectrograms, fundamental frequency trajectory and the height marker display, indicating the estimated times of the glottal stop. The recording for analysis was performed in two situations: with voice signal recorded by means of an eletretto microphone and with a laryngophone.

The comparison between ambient conditions at 22 dB showed a clearly better capture by the laryngophone, with less background loading in the long and narrow bands compared to the narrowband microphone, as seen in Figure 3.

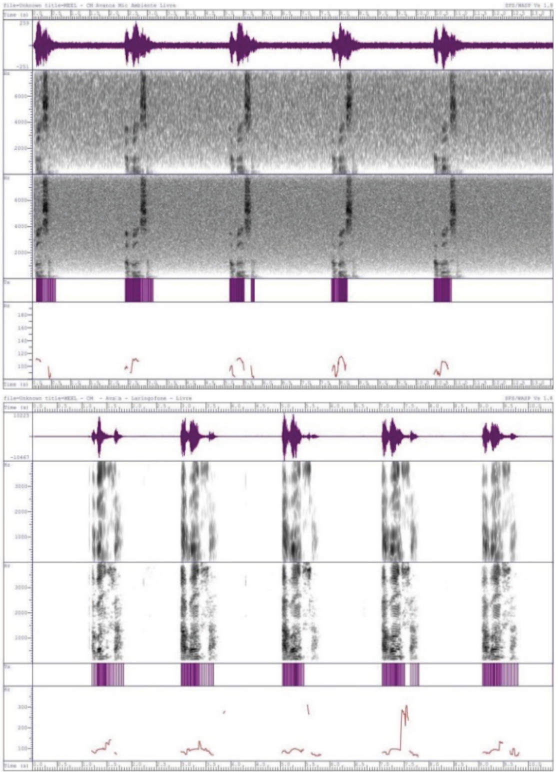

Figure 3 - Microphone (above) and Laringofone (below) **graphs**, related to the Avança command in environment at 22 dB. Source: Author.

In the most extreme condition of the speech education commands, Figure 4 illustrates the results for an environment presented with a noise level of 68 dB, with three volunteers talking randomly in a medium-high volume at a distance of 3 meters from the measurement point, in addition to a musical sound of equal intensity at the bottom. In Figure 4 (a), the Microphone is used and in Figure 4 (b), the Laryngophone is used.

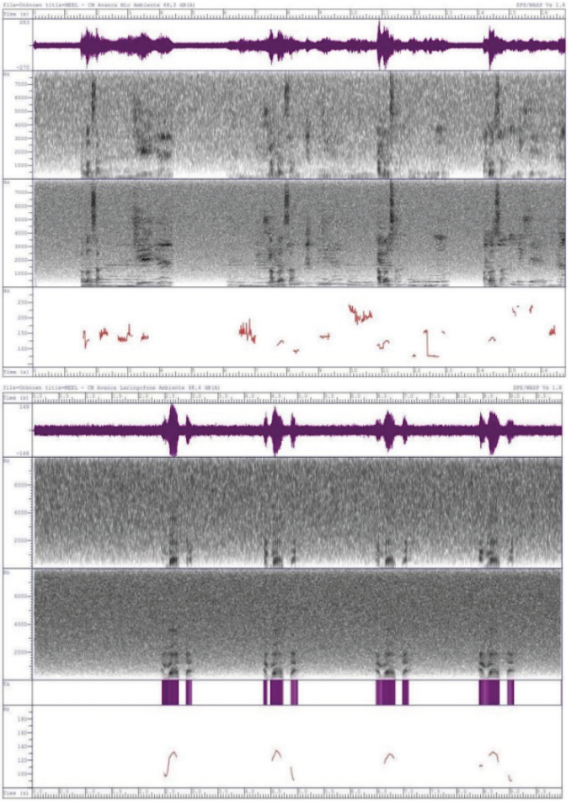

Figure 4 - Microphone (above) and Laringofone (below) **graphs**, related to the Avança command in environment at 68 dB. Source: Author.

The results indicate that the electret microphone is highly sensitive to ambient noise. This makes it extremely difficult for the speech recognizer to interpret the emitted sound, as evidenced by the Long Band and Narrow Band spectrograms, whose noise is clearly perceived, impairing the analysis.

In contrast, the laryngophone, despite the background vibration present in spectrograms, does not interfere with voice recognition, requiring only occasional repetition requests during education. The glottic facts present identical repetitions, facilitating the identification of the repetition frequency.

It was concluded that the laryngophone shows robustness when operating in environments with different noise levels, thanks to its unique ability to capture throat vibrations in the strategic region of the volunteer's larynx, as shown in Table 1.

Sound intensity of the noise in the medium	Conventional system	Proposed system
22 dB	93,0 %	99,5 %
38 dB	32,5 %	99,5 %
68 dB	1,5 %	98,8 %
Position error (22 dB)	57,8 %	78,3 %

Table 1 - Comparative Performance Values between the Conventional Technique and the Proposed System. Source: Adapted from [8].

The formula used to calculate the percentage of hits is the equation (1), where TA(%) represents the hit rate, Q_REC is the number of words recognized and Q_FAL is the number of words missed.

$$TA\% = \frac{Q_{REC}}{Q_{FAL}}.100\%. \quad (1)$$

An increase in the margin of error of recognition of 21.7% is observed, that is, a reduction in the hit rate to 78.3% when the device is positioned below the larynx of the volunteer, as seen in Table 1, in the item "Positioning error". Even under these conditions, the application of the laryngophone remains interesting. On the other hand, the microphone proves to be unfeasible for practical application in environments with noise above 30 dB.

Its effectiveness is noted only in quieter environments, especially at 22 dB, when positioned outside the ideal position in the direction of the volunteer's mouth. However, even in this environment, the feasibility of application of the microphone is limited, as indicated in Table 1.

These results emphasize the distinctive ability of the laryngophone to operate in challenging conditions, becoming a viable and effective option in lower noise contexts, while the microphone is more restricted in noisy environments.

PERSPECTIVA PARA TRABALHOS FUTUROS

The prototype roller conveyor is equipped with frequency inverter-driven induction motors, optimized for better efficiency [35].

FINAL CONSIDERATIONS

The inclusion of the voice command system represents a significant increase without generating excessive costs, since the components involved are economically accessible. This system is also indicated for users with speech difficulties, but who still manage to whisper, since the system is capable of recognizing throat vibration patterns and educated for the respective actions.

This not only allows the control of the wheelchair, but also the operation of other equipment, such as television and ambient lighting, facilitating the daily life of People with Disabilities (PwD's).

This initiative represents a significant contribution to research in biomedical engineering and assistive technologies, offering a practical and accessible solution for a wide range of users, including quadriplegic patients.

In addition to meeting the specific mobility and communication needs of PWD, this innovation drives the advancement of technological solutions for inclusion and accessibility, promoting greater independence, control and quality of life for all its users.

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