# As engenharias agregando conhecimento em setores emergentes de pesquisa e desenvolvimento 2


Henrique Ajuz Holzmann
(Organizador)



Atena Editora
Ano 2022

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# As engenharias agregando conhecimento em setores emergentes de pesquisa e desenvolvimento 2


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# APRESENTAÇÃO

Na sociedade atual, onde cada vez mais se necessita de informações rápidas e eficientes, o repasse de tecnologias é uma das formas mais eficazes de se obter novas tendências mundiais. Neste cenário destaca-se as engenharias, as quais são um dos principais pilares para o setor empresarial. Analisar os campos de atuação, bem como pontos de inserção e melhoria dessa desta área é de grande importância, buscando desenvolver novos métodos e ferramentas para melhoria continua de processos.

Estudar temas relacionados a engenharia é de grande importância, pois desta maneira pode-se aprimorar os conceitos e aplicar os mesmos de maneira mais eficaz. O aumento no interesse se dá principalmente pela escassez de matérias primas, a necessidade de novos materiais que possuam melhores características físicas e químicas e a necessidade de reaproveitamento dos resíduos em geral. Além disso a busca pela otimização no desenvolvimento de projetos, leva cada vez mais a simulação de processos, buscando uma redução de custos e de tempo.

Neste livro são apresentados trabalho teóricos e práticos, relacionados a área de engenharia, dando um panorama dos assuntos em pesquisa atualmente. De abordagem objetiva, a obra se mostra de grande relevância para graduandos, alunos de pós-graduação, docentes e profissionais, apresentando temáticas e metodologias diversificadas, em situações reais. Sendo hoje que utilizar dos conhecimentos científicos de uma maneira eficaz e eficiente é um dos desafios dos novos engenheiros.

Boa leitura

Henrique Ajuz Holzmann

## SUMÁRIO


**CAPÍTULO 1 ........................................................................................................ 1**

MINIATURIZAÇÃO DE UM ARRANJO LOG-PERIÓDICO QUASE-FRACTAL DE ANTENAS DE MICROFITA PARA APLICAÇÕES EM REDES DE COMUNICAÇÃO SEM FIO NA FAIXA DE 2,44 GHZ

Elder Eldervitch Carneiro de Oliveira
Pedro Carlos de Assis Júnior
Vinícius Nunes de Queiroz
Marcos Lucena Rodrigues

**https://doi.org/10.22533/at.ed.4142221041**

**CAPÍTULO 2 ........................................................................................................ 14**

A NORMATIZAÇÃO COMO MEIO DE INCENTIVO A DISSEMINAÇÃO DAS MICRORREDES ATRAVÉS DE POLÍTICA DE IMPOSTO E TARIFAÇÃO

Kelda Aparecida Godói dos Santos
Pedro André Zago Nunes de Souza
André Nunes de Souza
Haroldo Luiz Moretti do Amaral
Fábio de Oliveira Carvalho
Pedro da Costa Junior

**https://doi.org/10.22533/at.ed.4142221042**

**CAPÍTULO 3 ........................................................................................................ 27**

ESTUDO DO CONSUMO RESIDENCIAL DE ÁGUA VIA IOT EM RESERVATÓRIO COM CONTROLE DE NÍVEL AUTOMATIZADO

Eduardo Manprin Silva
Luís Miguel Amâncio Ribeiro
Selton de Jesus Silva da Hora
Rogério Luis Spagnolo da Silva

**https://doi.org/10.22533/at.ed.4142221043**

**CAPÍTULO 4 ........................................................................................................ 34**

SISTEMA SUPERVISÓRIO E CONTROLE MIMO ATRAVÉS DE LÓGICA

Márcio Mendonça
Gilberto Mitsuo Suzuki Trancolin
Marta Rúbia Pereira dos Santos
Carlos Alberto Paschoalino
Marco Antônio Ferreira Finocchio
Francisco de Assis Scannavino Junior
José Augusto Fabri
Edson Hideki Koroishi
André Luís Shiguemoto
Celso Alves Corrêa
Kazuyochi Ota Junior
Odair Aquino Campos

**https://doi.org/10.22533/at.ed.4142221044**

**CAPÍTULO 5........................................................................................................50**

EMPILHADEIRA AUTOMÁTICA

Camila Baleiro Okado Tamashiro
Edison Hernandes Belon
Gabriel Pucharelli Molina
Filipe Cortez
Joao Victor de Elmos da Silva
Joao Vitor da Silva Santana

**https://doi.org/10.22533/at.ed.4142221045**

**CAPÍTULO 6........................................................................................................53**

INTENSIVE RAINFALLS AND IONIZING RADIATION MEASUREMENTS IN FEBRUARY 2020 IN SÃO JOSÉ DOS CAMPOS BRAZIL REGION

Inacio Malmonge Martin

**https://doi.org/10.22533/at.ed.4142221046**

**CAPÍTULO 7........................................................................................................62**

ANÁLISE DE FALHA DE QUEBRA DE MANCAL SNH517 EM FERRO FUNDIDO CINZENTO EN GJL-200 (EN 1561) EM REGIME DE TRABALHO

Cristofer Vila Nova Fontes
Marcelo Bergamini de Carvalho
João Mauricio Godoy
Sérgio Roberto Montoro
Amir Rivaroli Junior

**https://doi.org/10.22533/at.ed.4142221047**

**CAPÍTULO 8........................................................................................................71**

PULSE TRANSIT TIME DETECTS CHANGES IN BLOOD PRESSURE IN RESPONSE TO GALVANIC VESTIBULAR STIMULATION AND POSTURE

Adriana Pliego Carrillo
Rosario Vega
Daniel Enrique Fernández García
Claudia Ivette Ledesma Ramírez
Enrique Soto

**https://doi.org/10.22533/at.ed.4142221048**

**CAPÍTULO 9........................................................................................................78**

EVIDENCIA INICIAL DE LAS ACCIONES DE ADAPTACIÓN DE EMPRESAS COLOMBIANAS A LA PANDEMIA CAUSADA POR EL SARS-COV2

Lucas Adolfo Giraldo-Ríos
Jenny Marcela Sanchez-Torres
Diana Marcela Cardona Román

**https://doi.org/10.22533/at.ed.4142221049**

**CAPÍTULO 10......................................................................................................85**

AVALIAÇÃO DO CONFORTO HUMANO DE PISOS MISTOS (AÇO-CONCRETO)

SUBMETIDOS A CARGAS DINÂMICAS RÍTMICAS

Elisângela Arêas Richter dos Santos
Karina Macedo Carvalho
Miguel Henrique de Oliveira Costa
José Guilherme Santos da Silva

**https://doi.org/10.22533/at.ed.41422210410**

**CAPÍTULO 11 ..... 100**

PANORAMA DAS POLÍTICAS DE PARCERIAS PÚBLICO-PRIVADAS (PPP'S) EM AEROPORTOS BRASILEIROS

Débora Comin Dal Pozzo
Caroline Miola
Humberto Anselmo da Silva Fayal

**https://doi.org/10.22533/at.ed.41422210411**

**CAPÍTULO 12 ..... 112**

ENCERRAMENTO DE ATIVIDADE INDUSTRIAL: DIRETRIZES PARA DESENVOLVIMENTO DE PLANOS DE DESATIVAÇÃO

Loiva Zukovski
Marlene Guevara dos Santos

**https://doi.org/10.22533/at.ed.41422210412**

**CAPÍTULO 13 ..... 125**

USO DE INDICADORES SOCIOAMBIENTAIS PARA ANÁLISE DOS IMPACTOS DO USO PÚBLICO NO PARQUE NACIONAL DO PAU BRASIL, PORTO SEGURO - BA

Bianca Rocha Martins
Michele Barros de Deus Chuquel da Silva
Gabriela Narezi
Valter Antonio Becegato

**https://doi.org/10.22533/at.ed.41422210413**

**CAPÍTULO 14 ..... 138**

AVALIAÇÃO DE NÍVEL DE MATURIDADE DE CULTURA DE SEGURANÇA EM ORGANIZAÇÃO DO TERCEIRO SETOR

Rodrigo Ferreira de Azevedo
Gilson Brito Alves de Lima
Licinio Esmeraldo da Silva

**https://doi.org/10.22533/at.ed.41422210414**

**CAPÍTULO 15 ..... 152**

THE EVOLUTION OF REGULATION OF THE AIR NAVIGATION ACTIVITY IN BRAZIL

Marcus Vinicius do Amaral Gurgel
Jefferson Luis Ferreira Martins

**https://doi.org/10.22533/at.ed.41422210415**

**CAPÍTULO 16......................................................................................................169**

ESTUDO DE *BACKGROUND* GEOQUÍMICO ambiental em ÁREA DE INFLUÊNCIA DIRETA (aid) DA MINERAÇÃO

Flávio de Morais Vasconcelos
Gabriel Melzer Aquino
Nathália Augusta Ferreira Sales Coutinho
João Santiago Reis

**https://doi.org/10.22533/at.ed.41422210416**

**CAPÍTULO 17......................................................................................................183**

AVALIAÇÃO DO POTENCIAL DE DRENAGEM ÁCIDA E LIXIVIAÇÃO DE METAIS EM PILHAS DE ESTÉRIL E BARRAGEM DE REJEITOS DE MINERAÇÃO

Nathália Augusta Ferreira Sales Coutinho
Flávio de Morais Vasconcelos
Hairton Costa Ferreira
Marcos Rogério Palma
Denner Dias Ribeiro

**https://doi.org/10.22533/at.ed.41422210417**

**CAPÍTULO 18......................................................................................................197**

ESTUDO DE TRATABILIDADE DA ÁGUA DA CAVA DA MINERAÇÃO RIACHO DOS MACHADOS PARA DESCARTE DO EFLUENTE

Flávio de Morais Vasconcelos
Nathália Augusta Ferreira Sales Coutinho
Igo de Souza Tavares
Ernesto Machado Coelho Filho
Luiz Lourenço Fregadolli

**https://doi.org/10.22533/at.ed.41422210418**

**CAPÍTULO 19......................................................................................................204**

MEDIÇÃO DE DESCARGA LÍQUIDA: MÉTODO DO MOLINETE NA BACIA DO RIO JI-PARANÁ (RONDÔNIA)

Renato Billia de Miranda
Frederico Fábio Mauad
Denise Parizotto

**https://doi.org/10.22533/at.ed.41422210419**

**CAPÍTULO 20......................................................................................................218**

APLICAÇÃO DE MATRIZ FILTRANTE DESFLUORETADORA, COMPOSTA POR SISTEMA CÉRIA/CARVÃO ATIVADO DE COCO *(Coccus nucifera L.),* EM ÁGUAS COMPLEXAS DO SEMIÁRIDO PARAIBANO

Carlos Christiano Lima dos Santos
Poliana Sousa Epaminondas Lima
João Jarllys Nóbrega de Souza
Tainá Souza Silva
Rodrigo Lira de Oliveira
Carlo Reillen Lima Martins

Ilauro de Souza Lima
Ana Sabrina Barbosa Machado
Maria Soraya Pereira Franco Adriano
Alexandre Almeida Júnior
Isabela Albuquerque Passos Farias
Fabio Correia Sampaio

**https://doi.org/10.22533/at.ed.41422210420**

**CAPÍTULO 21 ........................................................................................................ 233**

RESPONSIBLE MANAGEMENT OF XANTHATES TO ENSURE THE SUSTAINABILITY OF MINING INDUSTRIES IN LATIN AMERICA

Maria Andrea Atusparia Cierto
Fredy Castillejo
Gloria Valdivia
María Atusparia

**https://doi.org/10.22533/at.ed.41422210421**

**CAPÍTULO 22 ........................................................................................................ 251**

COBERTURA DE PILHA DE ESTÉRIL EM CLIMAS SEMI-ÁRIDOS

Flávio de Morais Vasconcelos
Nathália Augusta Ferreira Sales Coutinho
Michael Milczarek
Rodrigo Dhryell Santos
Luiz Lourenço Fregadolli

**https://doi.org/10.22533/at.ed.41422210422**

**CAPÍTULO 23 ........................................................................................................ 258**

SÍNTESE E QUEBRA DE EMULSÃO ÓLEO EM ÁGUA (O/A) VIA AQUECIMENTO E ADITIVAÇÃO COM NONILFENOL POLIETOXILADO

Heithor Syro Anacleto de Almeida
Geraldine Angélica Silva da Nóbrega
Diego Ângelo de Araújo Gomes
Rafael Stefano Costa Mallak,
Francisco Klebson Gomes dos Santos
Alyane Nataska Fontes Viana

**https://doi.org/10.22533/at.ed.41422210423**

**CAPÍTULO 24 ........................................................................................................ 268**

DESESTABILIZAÇÃO DE EMULSÃO (O/A) DO PETRÓLEO BRUTO UTILIZANDO ÁLCOOL LAURÍLICO ETOXILADO ALIADO A VARIAÇÃO DA TEMPERATURA

Rafael Stefano Costa Mallak
Heithor Syro Anacleto de Almeida,
Geraldine Angélica Silva da Nóbrega
Francisco Klebson Gomes dos Santos
Alyane Nataska Fontes Viana
Diego Angelo de Araujo Gomes

**https://doi.org/10.22533/at.ed.41422210424**

**CAPÍTULO 25..........................................................................................................280**

ESTUDIO PARA EVITAR LA CONTAMINACIÓN POR MEDIO DELA COMBUSTIÓN DEL GAS METANOS IN REALIZAR UNA RECUPERACIÓN ENERGÉTICA

Vilma Del Mar Amaya Gutiérrez

**https://doi.org/10.22533/at.ed.41422210425**

**SOBRE O ORGANIZADOR............................................................................285**

**ÍNDICE REMISSIVO...................................................................................286**

# CAPÍTULO 8

# PULSE TRANSIT TIME DETECTS CHANGES IN BLOOD PRESSURE IN RESPONSE TO GALVANIC VESTIBULAR STIMULATION AND POSTURE

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**ABSTRACT:** The interaction of the vestibular organs with the cardiovascular system is a relevant research field with clinical applications that contribute to the understanding of cardiovascular modulation due to movement and posture. The current noninvasive measurement of blood pressure (BP) consists of an inflatable cuff that is unsuitable to perform movement tasks. However, Pulse-Transit Time (PTT), an indirect method that estimates BP from electrocardiographic (ECG) and photoplethysmographic (PPG) recordings, may detect BP variations during dynamic experiments. Galvanic vestibular stimulation (GVS) is considered an equivalent to mechanical stimulation with movement of the head. Research with GVS has been done involving static and dynamic tasks. Our study aims to determine if PTT is suitable for GVS experiments to detect BP modulation. PTT was obtained for 16 healthy subjects during GVS while seated and standing. PTT increased during the stimulation period in both positions. However, the increase was statistically significant only for subjects standing. These findings follow previous GVS studies that monitor BP invasively in animal models. As we expected, an increase in PTT during GVS was observed. Additionally, the increase was slightly different for subjects seated and standing. Overall, results indicate that PTT is an effective method to estimate transient BP changes during GVS.

**KEYWORDS:** Galvanic Vestibular Stimulation, blood pressure, cardiovascular system, pulse transit time.

## 1 I INTRODUCTION

Home vital signs recording is a research area that has driven the development of non-invasive portable medical technologies (MAJUMDER, 2017). Heart rate (HR), pulse, oxygenation, respiratory rate, temperature, and blood pressure measured by non-expert users has been especially important during the current COVID-19 pandemic (SUN, 2020). Particularly, blood pressure (BP) is measured with two main approaches: (1) using an inflatable cuff or (2) combining methods that estimate cardiovascular resistance with changes in blood volume from the photoplethysmography (PPG). With the inflatable cuff method, the medical device calculates a discrete measurement for the systolic and diastolic pressure in mmHg estimated as the cuff remains inflated. However, this method's error could be as large as 10% (MURRAY, 2001). The PPG measurement of BP studies cardiac events that can be inferred from pulse recordings, related to beat-to-beat changes in peripheral blood volume and vascular resistance. The dicrotic notch of the pulse signal marks the end of the heart's systole and the beginning of the diastole (Figure 1); hypertension is associated with the disappearance of the dicrotic notch (VON WOWERN, 2015). To emphasize this morphological feature of the pulse signal, various mathematical strategies have been developed (HE, 2014; LI, 2018; SAWATARI, 2020).

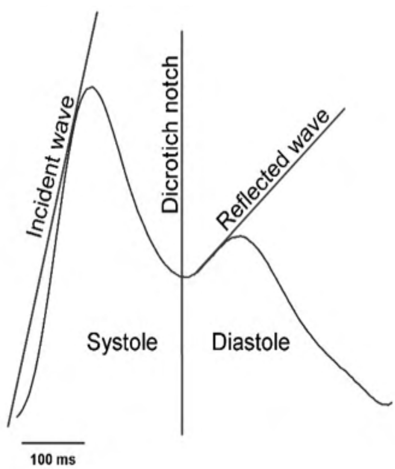


Figure 1. Morphological features of the pulse signal. The incident wave is formed by the containment of blood volume ejected in the ventricular contraction (systole) by the capillary walls. Dicrotic node, cardiac valves close, separates systole from diastole. The containment of blood forms the reflected wave during the diastole.

It is evident that, if BP measurement is performed during a movement task, the bracelet (cuff) method would not be feasible to use. However, PPG in combination with the electrocardiographic (ECG) recording has shown to be effective and accurate to indirectly estimate BP. Pulse transit time (PTT) is the delay between the R peak of the ECG, which occurs during ventricular depolarization, and the maximum amplitude of the PPG signal. Some authors use the delay between the R peak and the pulse signal derivative to stress the high frequency transitions (YOON, 2009). Computational models that study the incident and reflected waves of the pulse signal identified that, if the PTT increases, there is a distension of the vascular wall, associated with a BP decrease. On the contrary, the vascular wall is more rigid if the PTT decreases, so systolic BP increases (SHIN, 2017). Several research groups have worked with the PTT to achieve an acceptable approximation of BP using mathematical adjustments representing mechanic vascular characteristic (HE, 2014; LI, 2018; SAWATARI, 2020). For instance, the photoplethysmographic intensity ratio (PIR) performs a systolic, diastolic, and mean BP approximation from the initial and final amplitude of the pulse signal (SHARIFI, 2019). Figure 2 shows ECG signal and PPG first derivative. The solid circles show the two points in time used to calculate the delay between ventricular contraction and hemodynamic activity. Given the current characteristics of portable devices, PTT is the most promising method to estimate beat-to-beat BP even during tasks that involve movement.

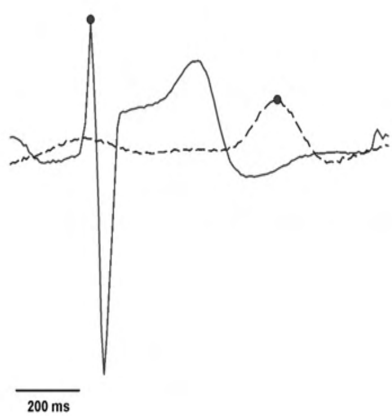


Figure 2. The electrocardiograph and first derivative of pulse signals. PTT is calculated from the difference in time of the points marked with a solid circle. ECG, solid line. PPG, dashed line.

Galvanic Vestibular Stimulation (GVS) activates the vestibular system non-invasively without involving other sensory input (GENSBERGER, 2016). GVS is used to study the influence of vestibular input during various static and dynamic tasks, such as quiet stance in Romberg's test (PLIEGO, 2019) and walking (HANNAN, 2021). Additionally, GVS has been used to study the cardiovascular response to vestibular stimulation in animal models and human beings. Animal models showed that HR and BP decrease during sinusoidal low-frequency GVS (0.025-0.5 Hz). These studies acquired physiological signals invasively in anesthetized animals (COHEN, 2011). In human subjects, a HR decrease, and HR variability increase was observed with GVS, even after a postural shift from sitting to standing, without a clear result on BP changes (PLIEGO, 2021). For these, it is necessary to use a BP measurement method, sensitive to beat-to-beat cardiovascular changes, able to be used in experiments that involve movement tasks in combination with electrical vestibular stimulation. Previous evidence suggest that PTT should increase (BP decreases) with GVS and return to a baseline after stimulation. Given the importance of beat-to-beat resolution on cardiovascular changes due to vestibular activation, PTT could be considered a reliable alternative to BP measurement, not possible with the inflatable cuff method.

## 2 I METHODS

### *A. Experimental procedure*

Sixteen healthy human volunteers participated, age 20 ± 2 years, 7 women and 9 men, with no previous history of neurological, cardiovascular, or vestibular disorders. Volunteers signed informed consent expressing their will to collaborate according to good practices for human experimentation, the Helsinki Declaration and to the Mexican normative NOM-012-SSA3-2012. The Research Ethics Committee of the Autonomous University of the State of Mexico (UAEMex) approved the protocol on November 25th, 2018. Experimental procedure was performed in the Instrumentation Laboratory of the School of Medicine of the Autonomous University of the State of Mexico. Two surface electrodes of 3 cm diameter were placed over the subjects' skull, one over the right mastoid process and the other in the middle distance between the mastoid and the nasion. The current intensity was fixed to the subject's tolerance (1.5 ± 0.6 mA). ECG lead DII was recorded with EL254 surface electrodes and the ECG100C BIOPAC module with a low-pass filter of 150 Hz and x1000 amplification. PPG signal was recorded with TSD124 transductor and OXY100C BIOPAC module. Both signals were digitalized with MP150 BIOPAC at 200 Hz. Each experimental test consisted of 30 s without stimulation (control), 30 s with GVS (GVS) and 60 s post-GVS (PS), total recording was of 120 s. To provoke an intentional cardiovascular response in the subjects, they were recorded first seated (120 s) and then standing (120 s). A reference BP measurement was obtained with an automatic Omron® system, before and after the experiment, with each subject.

### *B. Signal processing*

Detrend function was used on ECG and PPG signals. Recordings of 120 s were divided in three segments: Control, GVS and PS. Fifteen seconds were extracted from each segment to obtain PTT values. Normalization was performed from the maximum delay for each recording. All signal processing was performed using MATLAB®.

### *C. Statistical analysis*

For statistical comparison of the three experimental periods (Control, GVS and PS), we used the non-parametric Friedman test (data failed Shapiro-Wilk test). *Post-hoc* comparison was performed with Tukey's method. Significance was set to $p < 0.05$. For all statistical test we used Sigma Plot 11.0®

## 3 | RESULTS

A median increase of the PTT (Seated NS: mean = 0.3804 ms, median = 0.3544 ms, SD = 0.1089 ms; GVS: mean = 0.3892 ms, median = 0.3565 ms, SD = 0.0810 ms; PS: mean = 0.3961 ms, median = 0.3561 ms, SD = 0.1113 ms; Standing NS: mean = 0.3446 ms, median = 0.3471 ms, SD = 0.0244 ms; GVS: mean = 0.3441 ms, median = 0.3490 ms, SD = 0.0381 ms; PS: mean = 0.3439 ms, median = 0.3475 ms, SD = 0.0331 ms) value was observed in subjects seated and standing. Figure 3 show the temporal increment of PTT during GVS compared to control and in post-GVS, for all 16 subjects. The statistical analysis showed that the PTT increment is statistically significant only for subjects standing ($p = 0.022$). Paired comparison of PTT increase showed statistical significance between control and GVS periods ($p < 0.05$). The result is consistent with systolic BP values (mean ± standard deviation) measured with the Omron® system before (Systolic: 114 ± 4 mm Hg, Diastolic: 68 ± 8 mm Hg) and after (Systolic 111 ± 8 mmHg, Diastolic: 71 ± 7 mmHg) the experiment.

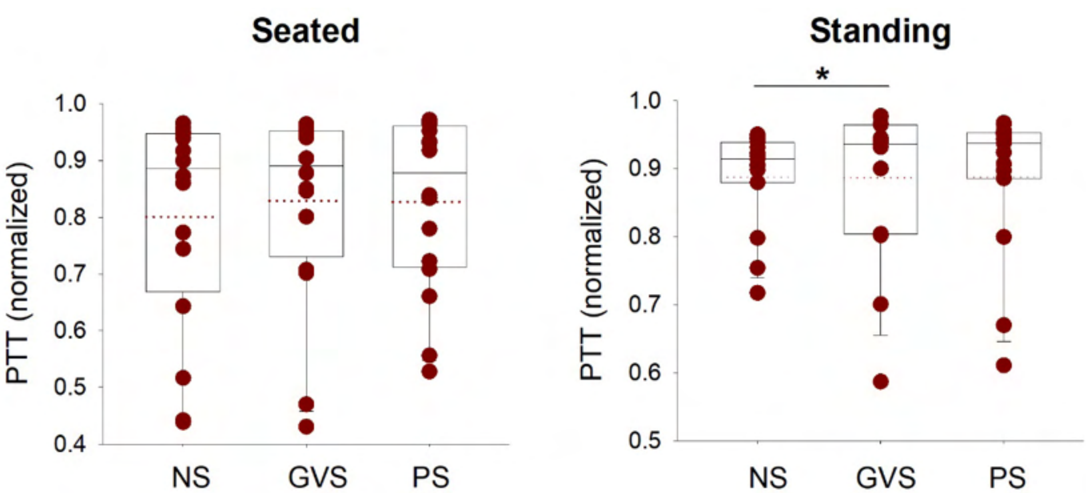


Figure 3. PTT normalized values of 16 human subjects seated (left) and standing (right) on NS, GVS and PS. Dotted line: mean value, solid line: median, Q1-25%, Q3-50%, whiskers 5% and 95 % of sample.

## 4 | DISCUSSION

The use of GVS to study cardiovascular modulation to vestibular input is a developing research area with a wide number of clinical applications. Modulation of the cardiovascular function must follow head and body movement to maintain an adequate vital organs irrigation. Vasovagal syndrome, for instance, is not an uncommon condition involving a late response of HR changes to posture (RAPHAN, 2021). We could not find a study the combines GVS with PTT to estimate BP and cardiovascular modulation. Previous research that combines beat-to-beat BP measurement and vestibular stimulation (movement) used a Finapres™ or Portapres™ system. These devices calculate BP from information of the volume changes in the PPG signal and an inflatable small bracelet placed in the index fingertip. The Portapres™ was used to evaluate cardiovascular performance during a movement task in 13 astronauts, before and after staying six months in space, and in 19 healthy subjects that remained supine with 6° tilt for 70 days in a tilting table test (MULAVARA, 2018). The cost of a Portapres™ system is over 25,000 USD, so in addition to technical difficulties for performing movement tasks, budget restrictions sum to developing new alternative methods to estimate BP. Our research aimed to determine if PTT is sensitive enough to detect transient cardiovascular changes provoked by GVS or a postural maneuver. Effectively, PTT increased in most subjects (decreased in one) during GVS. Our results represent the first experimental procedure, to our knowledge, that analyzes BP modulation with PTT to GVS and a postural change. PTT increment was moderate in seated subjects but more pronounced (statistically significant) on standing subjects. The different response between seated and standing subjects suggest a more susceptible (prepared) state of the cardiovascular system when standing (TANAKA, 1996). A more pronounced significant decrease of HR and HRV was also observed on a previous study with subjects standing compared to seated. The coupling of cardiovascular variables may also be studied using PTT with offline processing.

Our results indicate that it is possible to evaluate transient changes that occur to the vascular system with GVS and postural change with PTT. In the future, different strategies should be implemented to convert PTT into BP measurement in mmHg, helpful to monitor subject's general status in the lab and at home.

## 5 I CONCLUSIONS

Consistent with previous results obtained with animal models through invasive methods, PTT during GVS increased in subjects seated and standing. Therefore, as the experimental protocol will not be affected by technical difficulties from the physiological signal acquisition, it is relevant to include PTT estimation on vital signs recordings using GVS and postural changes.

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# ÍNDICE REMISSIVO


## A

Ações humanas rítmicas 85, 87, 98

Aeroporto 100, 103, 104, 106, 107, 108, 110

Água 15, 27, 28, 29, 30, 31, 32, 33, 103, 115, 122, 124, 169, 170, 171, 172, 174, 180, 181, 184, 194, 195, 197, 198, 199, 202, 203, 204, 205, 208, 209, 210, 216, 218, 219, 220, 221, 222, 223, 224, 225, 229, 230, 231, 252, 253, 254, 255, 256, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 274, 275, 276, 277, 279

Análise de conforto humano 85, 97

Análise de vibração 62, 63, 64, 65, 66, 98

Áreas contaminadas 112, 114, 115, 116, 117, 120, 122, 123, 124, 170, 181

## B

Background geoquímico 169, 170, 171, 172, 173, 176, 178, 180, 181, 182

Banho termostático 258, 259, 262, 269, 274

## C

Cobertura de pilha de estéril 251

Comunicação sem fio 1

Concessões 100, 108, 109, 110, 135

Consumo de água 27, 28, 29, 30, 32, 220

Controle de nível 27, 28, 29, 30, 31

Controle Fuzzy-PID 35

Cultura 27, 61, 138, 139, 140, 141, 142, 143, 144, 146, 148, 149, 150, 151, 168, 232

Curva de koch 1

## D

Desativação de atividades 112

Desativação De Atividades 112, 113, 119

Descarte emergencial 197, 198

Desemulsificação 258, 259, 266

Desestabilização da emulsão 269, 273

Desfluoretação 219

Drenagem ácida de mina 184, 252

## E

Emulsão O/A 258, 259, 269

Energias renováveis 14, 15, 16, 17, 20, 232

## F

Fermentação alcoólica 35, 36, 39, 41, 44, 48

Ferro fundido cinzento 62, 64

Fluorose 219, 220

## I

IoT 2, 27, 28, 29, 33

## L

Lixiviação de metais 183, 185, 186, 187, 193, 194, 195, 252

## M

Mancal 62, 63, 64, 65, 66, 67, 68, 69, 70

Maturidade 138, 139, 142, 143, 144, 146, 147, 148, 149, 150

Medição de grandes rios 204

Método do molinete 204, 205, 215

Microrredes 14, 15, 21, 23, 24

Mineração de ouro 197, 251

## N

Normas 13, 24, 79, 97, 98, 102, 105, 112, 113, 115, 116, 117, 119, 122, 134, 139, 141, 142, 181, 195, 203, 281

Normatização 14, 15, 17, 18, 20, 24

## O

Organização 15, 28, 128, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 220

## P

Parcerias público-privadas 100, 102, 103, 104, 109, 110

Pisos mistos de edificações 85

## Q

Qualidade da energia 14, 19, 20

Quebra da emulsão 258, 259, 261, 264, 265, 269, 273, 274

## R

Recirculador 62, 63, 69, 70

Residencial 27, 29, 31

## S

Segurança 18, 20, 21, 39, 43, 50, 106, 118, 120, 133, 138, 139, 140, 141, 142, 143, 144, 145, 146, 148, 149, 150, 151

Separação O/A 269

Setor aeroportuário 100, 101, 109

Sistema multivariável 35

Sistemas supervisórios 35, 36

Sustentabilidade 17, 20, 102, 116, 123, 219

## T

Tensoativos 258, 259, 260, 261, 262, 264, 265, 266, 268, 269, 270, 271, 272, 274, 275, 276, 277, 278, 279

## V

Vazão 27, 31, 172, 198, 204, 205, 208, 209, 212, 213, 214, 215, 216

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