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In Oral and Technical Presentation, Recognition and Appreciation of Research Contributions to

6th INTERNATIONAL PARIS APPLIED SCIENCES CONGRESS
July 12-17, 2026 Paris/FRANCE
with the paper entitled
VIBRATION-BASED FAULT DETECTION IN A WIRE DRAWING MACHINE USING AN LSTM DEEP LEARNING MODEL

Prof. Dr. Işıl AYDIN
Head of Congress

Dr. Nadire KANTARCIOĞLU
UBSDER President



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EDITOR
Prof. Dr. Işıl AYDIN

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INSTITUTE CONTACT INFORMATION:
TURGUT ÖZAL MAH. AKKENT 6 TWINS TRADE CENTER ANKARA
TEL: 0 312 566 00 20 FAKS: 0 312 566 0021
Web : www.ubsder.org ubsder@ubsder.org.tr

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14.07.2026	HALL 1
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Asst. Prof. Dr. Dilek BOZOT KAYASAN Assoc. Prof. Dr. Pınar TEKİNSOY KARTIN Doç. Dr. Hasan AKKAYA	Niğde Ömer Halisdemir University Erciyes University	PRE-DISCHARGE EDUCATIONAL NEEDS OF PATIENTS WHO HAVE SUFFERED MYOCARDIAL INFARCTION
Prof. Dr. Şafak ÖZHAN KOCAKAYA	Dicle University	COMPUTATIONAL INVESTIGATION OF THE EFFECTS OF DIFFERENT SUBSTITUENTS ON SINGLET AND TRIPLET CARBENE STABILITY IN CARBENES

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CONTENT

CONFERENCE ID	I
ORGANIZING COMMITTEE	II
SCIENTIFIC BOARD MEMBERS	III
PROGRAM	V
CONTENT	VI

	AUTHOR(S)	TITLE	PAGE NUMBER
1)	Prof. Dr. Cennet OĞUZ Kübra Nur HACISEFEROĞULLARI	THE ROLE AND SIGNIFICANCE OF RURAL WOMEN IN VALUE-ADDED (HOME-BASED) PRODUCT PRODUCTION	1-11
2)	Prof. Dr. Fırat AYDIN Prof. Dr. Işıl AYDIN	ARSENİK'İN SPEKTROSKOPİK TESPİTİNDE SON GELİŞMELER	12-17
3)	Prof. Dr. Işıl AYDIN Prof. Dr. Fırat AYDIN	TÜRKİYE DE İLAÇ ÜRETİMİNİN TARİHÇESİ	18-25
4)	Lecturer Dr. Sevda BURAK ERGÜL Prof. Dr. Ümit Başar SEMİZ	PREVALENCE AND CLINICAL CHARACTERISTICS OF PATHOLOGICAL DISSOCIATION IN PATIENTS WITH SCHIZOPHRENIA	26-27
5)	Dr. Ferdi YAĞAN Assoc. Prof. Dr. Zöhre KAYA Dr. Şermin KAYA	A RESOURCE-BASED EXPLANATION OF POSTTRAUMATIC GROWTH: CONSERVATION OF RESOURCES THEORY IN THE CONTEXT OF THE 2023 KAHRAMANMARAŞ EARTHQUAKES	28-30
6)	Prof. Dr. Fırat AYDIN Prof. Dr. Işıl AYDIN	ASFALTİT KÜLÜNDEN CR TÜRLENDİRİLMESİ	31-36
7)	Prof. Dr. Işıl AYDIN Prof. Dr. Fırat ÜNAL Prof. Dr. Fırat AYDIN	GREEN SYNTHESIS OF A TRIMETALLIC FECUMN-BIOCHAR-CHITOSAN COMPOSITE FOR EFFECTIVE LEAD ADSORPTION AND PRECONCENTRATION	37-44
8)	Dr. Hasret ÖZTÜRK Assoc. Prof. Dr. Fatma ERTAŞ OĞUZ	MOLECULAR REPRESENTATION OF TÜRKİYE-ORIGIN TAENIA SPECIES IN GENBANK: A DATABASE-BASED ASSESSMENT OF SPECIES, MARKERS, HOSTS, AND METADATA CHARACTERISTICS	45-58

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9)	Prof. Dr. Nermin Meriç Prof. Dr. Murat Aydemir Prof. Dr. Cezmi Kayan Prof. Dr. Ahmet Kılıç Prof. Dr. Akın Baysal Prof. Dr. Feyyaz Durap	INVESTIGATION OF THE CATALYTIC ACTIVITIES OF CHIRAL MANDELAMIDE-BASED RU(II), IR(III) AND RH(I)-PHOSPHINITE COMPLEXES IN ASYMMETRIC TRANSFER HYDROGENATION IN AZEOTROPIC HCOOH/ET 3 N MEDIUM ***(POSTER)***	59-61
10)	Assoc. Prof. Dr. Hatice Karaer YAĞMUR	PHYSICOCHEMICAL PROPERTIES OF BIOFILMS CONTAINING ESSENTIAL OILS ***(POSTER)***	62
11)	Assoc. Prof. Dr. Nevin ARSLAN Osman AKMEŞE Uğur IŞIK Deniz CANBOLAT GÜLTEKIN	SYNTHESIS AND IN VITRO A-AMYLASE INHIBITORY ACTIVITY OF B -HYDROXYAMIDE DERIVATIVES BASED ON 2-HYDROXYNICOTINIC ACID ***(POSTER)***	63-64
12)	Assoc. Prof. Dr. Nevin ARSLAN	SYNTHESIS OF BIOFILMS CONTAINING ROSEMARY ESSENTIAL OIL ***(POSTER)***	65-66
13)	Assoc. Prof. Dr. Mehmet KONAR Assoc. Prof. Dr. Erkan Caner Özkat Ahmet Pişmişoğlu	VIBRATION-BASED FAULT DETECTION IN A WIRE DRAWING MACHINE USING AN LSTM DEEP LEARNING MODEL	67-75
14)	Assoc. Prof. Dr. Ebubekir YÜKSEL Mohammad Ikram AZİZİ	POTENTIAL BIOLOGICAL CONTROL AGENTS IN THE CONTROL OF THE CONFUSED FLOUR BEETLE, Tribolium confusum (Jacquelin du Val, 1868) (Coleoptera: Tenebrionidae): ENTOMOPATHOGENIC NEMATODES	76
15)	Asst. Prof. Dr. Dilek BOZOT KAYASAN Assoc. Prof. Dr. Pınar TEKİNSOY KARTIN Doç. Dr. Hasan AKKAYA	PRE-DISCHARGE EDUCATIONAL NEEDS OF PATIENTS WHO HAVE SUFFERED MYOCARDIAL INFARCTION	77-92
16)	Prof. Dr. Şafak ÖZHAN KOCAKAYA	COMPUTATIONAL INVESTIGATION OF THE EFFECTS OF DIFFERENT SUBSTITUENTS ON SINGLET AND TRIPLET CARBENE STABILITY IN CARBENES	93
17)	Assistant Professor Muhammad FAISAL	ZERO-TRUST PROJECT MANAGEMENT: AI-DRIVEN CONTINUOUS AUTHENTICATION IN DECENTRALIZED DEVELOPMENT	94
18)	Assistant Professor Muhammad FAISAL	EDGE-DEPLOYED COMPUTER VISION FRAMEWORKS FOR AUTOMATED INFRASTRUCTURE HEALTH AUDITING IN PUBLIC TRANSIT CORRIDORS	95
19)	Ayodele Elizabeth AGOI Moses Adeolu AGOI Emmanuel Taiwo AGOI Hendri Hermawan ADINUGRAHA	IOT-ENABLED SMART INFRASTRUCTURE: ENGINEERING INNOVATIONS FOR SUSTAINABLE ECONOMIC GROWTH	96-106

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20)	M.Sc. Mech. Eng.Fatih ÖZKAN Prof. Dr. Uğur AKYOL Assoc. Prof. Dr. Dinçer AKAL	EXPERIMENTAL INVESTIGATION OF PHOTOVOLTAIC ENERGY YIELD ON TILE AND SANDWICH PANEL ROOFS	107-116
21)	Chinedu Okafo Fatima Suleiman	PUBLIC HEALTH STRATEGIES FOR INFECTIOUS DISEASE CONTROL IN SUBSAHARAN AFRICA	117
22)	Halim DAYANAN Prof. Dr. Ali AKDAĞLI Asst. Prof. Dr. Timur LALE	DIABETES PREDICTION USING MACHINE LEARNING METHODS	118-131
23)	Asst. Prof. Dr. Elif ÇELİK GÜRBULAK Eda BAŞKURT Prof. Dr. Aytaç AKÇAY Prof. Dr. Kutlay GÜRBULAK	INVESTIGATION OF ADVERSE EVENTS ASSOCIATED WITH HORMONAL PREPARATIONS IN VETERINARY PHARMACOVIGILANCE USING THE APRIORI ALGORITHM	132-133
24)	Muhammed Sadi KADER Dr. Elif CİLAVDAROĞLU Prof. Dr. Umut Sami YAMAK	COMPARISON OF INCUBATION RESULTS OF GERZE, AUSTRALORP AND GERZE x AUSTRALORP CROSSINGS	134-143
25)	Dr. Elif CİLAVDAROĞLU Muhammed Sadi KADER Prof. Dr. Umut Sami YAMAK	COMPARATIVE EVALUATION OF SELECTED GROWTH AND LAYING TRAITS IN BLACK AND BLUE AUSTRALORP VARIETIES	144-155
26)	Fadime İBİŞ Prof. Dr. Elmas ERDOĞAN	CULTURAL HERITAGE AREAS, CONSERVATION AND REVITALISATION: KAYAKÖY CASE	156-183
27)	Prof. Dr. Elmas ERDOĞAN Fadime İBİŞ	CULTURE, ARCHITECTURE, FORM AND THE ANATOLIAN TURKISH HOUSE	184-211
28)	Ümit KAMBUR Prof. Dr. Ramazan KURT	THE EFFECTS OF ORIENTATION ON SOME PHYSICAL, MECHANICAL, AND COMBUSTION PROPERTIES OF PARALLEL STRAND LUMBER	212-214
29)	Lecturer Lale KARASU Prof. Dr. Mahmut KILIÇ	DEVELOPMENT AND PSYCHOMETRIC TESTING OF THE PHYSICAL, CHEMICAL AND BIOLOGICAL RISK AWARENESS SCALE (PCBRAS): A METHODOLOGICAL AND CROSS-SECTIONAL STUDY	215-216
30)	Asst. Prof. Dr. Bedriye URAL Zeynep DOĞAN Özlem GÜNEY ÖZCAN	DIETARY HABITS, GUT HEALTH, AND BODY MASS INDEX AMONG UNIVERSITY STUDENTS: A CROSS-SECTIONAL STUDY	217-218

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31)	Asst. Prof. Dr. Bedriye URAL Esra DURBAKAN Fatma Nur ÇAKIN	WORK STRESS AMONG EMPLOYEES: ASSOCIATIONS WITH SLEEP QUALITY AND DIETARY HABITS	219-220
32)	Lecturer Merve ARI Prof. Dr. Kemal ÖDEV Sudenaz TATLI Kübra GÜZEL Kübra Bahar DOĞAN	THE RELATIONSHIP BETWEEN RADIATION PROTECTION KNOWLEDGE, BURNOUT, AND QUALITY OF LIFE IN HEALTHCARE WORKERS EXPOSED TO IONIZING RADIATION	221-230
33)	Lecturer Merve ARI Prof. Dr. Nursen İLÇİN Assoc. Prof. Dr. Çağlar SOYLU Asst. Prof. Dr. Özlem AKKOYUN SERT	EFFECTS OF NEUROATHLETIC EXERCISE ON GAIT SPEED, FALL RISK, AND COGNITIVE FUNCTION IN OLDER ADULTS: RANDOMIZED CONTROLLED TRIAL	231-233
34)	Expert Dr. Cemile Cansu ALPEREN Prof. Dr. Meryem ÇETİN Assoc. Prof. Dr. Şirin ÇETİN	FREQUENCY, SEASONAL DISTRIBUTION, AND ENDOSCOPIC FINDINGS of HELICOBACTER PYLORI STOOL ANTIGEN POSITIVITY in DYSPEPTIC PATIENTS	234-240
35)	Assoc. Prof. Dr. Serpil Yorganci Prof. Dr. Murat Ssbasi	STUDENT ENGAGEMENT IN GEOGEBRA-SUPPORTED BLENDED AND ONLINE LEARNING ENVIRONMENTS: A COGNITIVE LOAD THEORY PERSPECTIVE	241-247
36)	Assoc. Prof. Dr. Serpil Yorganci Prof. Dr. Murat Ssbasi	THE EFFECT OF A GEOGEBRA-SUPPORTED BLENDED LEARNING ENVIRONMENT ON THE MATHEMATICS ACHIEVEMENT OF LOW-ACHIEVING STUDENTS: A COGNITIVE LOAD THEORY PERSPECTIVE	248-257
37)	Assoc. Prof. Dr. Yaşar AY	INVESTIGATING SPHERICAL PLASMA FOCUS DEVICE PARAMETERS USING H, D, AND T GASES	258-259
38)	Assoc. Prof. Dr. Yaşar AY	INVESGIGATING ARGON PLASMA DYNAMICS AND X-RAY YIELD WITH RESPECT TO DEVICE GEOMETRY AND GAS PRESSURE IN SPHERICAL PLASMA FOCUS DEVICE	260-261
39)	Assoc. Prof. Dr. Erhan ONAT Assoc. Prof. Dr. Selma EKİNCİ Gamze USLU	ACTIVATED CARBON PRODUCTION FROM ADİLCEVAZ GREEN WALNUT HUSK: OPTIMIZATION OF ACTIVATION AND CARBONIZATION CONDITIONS	262-271
40)	Assoc. Prof. Dr. Erhan ONAT Assoc. Prof. Dr. Selma EKİNCİ Gamze USLU	REMOVAL OF CHROMIUM IONS FROM AQUEOUS SOLUTIONS USING ACTIVATED CARBON PRODUCED FROM ADİLCEVAZ GREEN WALNUT HUSK	272-281
41)	Ezgi ARI ASLAN Prof. Dr. Mustafa COŞKUN Dilara KISA	DETERMINATION OF LC_{50} VALUES OF FLUPYRADIFURONE ADMINISTERED BY INJECTION AND DIETARY EXPOSURE IN GALLERIA MELLONELLA (LEPIDOPTERA: PYRALIDAE) LARVAE	282-283

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42)	Rakhmanov Shokhzodbek	TUMOR MARKER DIAGNOSTICS IN CANCER DISEASES	284-291
43)	Rakhmanov Shokhzodbek Tursunboyev Muzaffar	DEVELOPMENT OF ENCEPHALITIS IN COVID DISEASE	292-296
44)	Madaminov Sodik Madaminovich Bazarbaeva Gulmira Azimzhonovna	EFFECTIVENESS OF FIT AND COLONOSCOPY IN THE DIAGNOSIS OF COLON ADENOCARCINOMA IN UZBEKISTAN	297-302
45)	M.I. Kamalova M.S. Israilov	AGE- RELATED FEATURES OF THE MORPHOLOGICAL STRUCTURE OF THE MUCOUS AND SUBMUCOUS LAYERS OF THE SIGMOID COLON IN CHILDREN	303-307
46)	Ortikov Bobomurod Baymamatovich	HYGIENIC ANALYSIS OF MORBIDITY AMONG WORKERS	308-309
47)	Ortikov Bobomurod Baymamatovich	HYGIENIC ASSESSMENT OF THE NUTRITIONAL STATUS OF WORKERS ENGAGED IN POTASSIUM PRODUCTION	310-311
48)	Muxamediyeva Irodaxon Baxtiyorxo`ja qizi Muxamediyev Muxammad Muzaffarovich	ROLE OF MITOCHONDRIA IN THE BIOENERGETICS OF CARDIAC AND SMOOTH MUSCLE CELLS	312-316
49)	Muxamediyeva Irodaxon Baxtiyorxo`ja qizi Muxamediyev Muxammad Muzaffarovich Sultanov Samadjon Xasanboy o'g'li	OPTIMIZING EXERCISE LOAD AND TYPES OF PHYSICAL ACTIVITY IN STUDENTS WITH ISCHEMIC HEART DISEASE	317-319
50)	Kamoliddin Haydarovich Rahmonov Diyorbek Jahongir o'g'li Abdulazizov	MODERN APPROACHES TO EARLY PRIMARY DIAGNOSIS OF ISCHEMIC HEART DISEASE IN PATIENTS WITH TYPE 2 DIABETES	320-324
51)	Nishonova Dilafruz Tajimatovna	CAUSES, CLINICAL FEATURES, DIAGNOSTIC APPROACHES, AND MODERN TREATMENT STRATEGIES OF UTERINE FIBROIDS	325-327
52)	Tashaliyeva Jamila Ismatovna Qobilova Yoqitxon Chingizovna	CYTOGENETIC ANALYSIS OF CHROMOSOMAL DISORDERS USING FISH METHOD	328-330

ISBN: 978-625-90699-0-6

53)	Dilovar Imomnazarovna Khudoyberdieva Shukhrat Toshtemirovich Niyozov	CLINICAL AND MOLECULAR CHARACTERISTICS OF PROGRESSIVE MULTIFOCAL LEUKOENCEPHALOPATHY IN CHILDREN	331-335
54)	Rakhmonberdiyev Siddiqjon Sodiqjon ugli	MORPHOLOGY OF THE PANCREAS UNDER HYPOKINESIA AND EXPERIMENTAL HYPOTHYROIDISM	336-342
55)	Parpiyeva Odinakhon Rakhmanovna Nazarova Diyora Mutabarova Mohinora Muminjonova Shohzoda	COMPREHENSIVE APPROACH TO INFECTION PREVENTION THROUGH ASEPSIS AND ANTISEPSIS IN SURGERY	343-346
56)	Parpiyeva Odinakhon Rakhmanovna Khakimova Nafisa Oybekovna	SALIVARY METABOLOMICS AS A NON-INVASIVE DIAGNOSTIC TOOL FOR EARLY DETECTION OF PERIODONTAL DISEASES	347-350
57)	Muxamediyeva Irodaxon Baxtiyorxo`ja qizi Pozilov Mamurjon Komiljonovich	EFFECT OF F-24 AND F-4 ISOQUINOLINE ALKALOIDS ON SWELLING OF RAT HEART MITOCHONDRIA UNDER $PbCl_2$-INDUCED OXIDATIVE STRESS CONDITIONS	351-356
58)	Parpiyeva Odinakhon Rakhmanovna	EARLY DETECTION OF BREAST CANCER AMONG THE POPULATION OF FERGANA REGION IN THE LAST 5 YEARS: SCREENING PROGRAMS AND THEIR ANALYSIS	357-363
59)	Sobirov Alijon Axmadovich	PERIODONTAL TISSUE ALTERATIONS ASSOCIATED WITH DENTOALVEOLAR ANOMALIES AND ORTHODONTIC TREATMENT: A COMPREHENSIVE REVIEW OF BIOMECHANICAL, MICROBIOLOGICAL, AND IMMUNOLOGICAL FACTORS	361-362
60)	Berdiev Ergash Abdullaevich	EFFICIENCY OF ENDOCHURGY IN THE TREATMENT OF ACUTE SURGICAL DISEASES OF ABDOMINAL ORGANS IN CHILDREN	363-376
61)	Saidullaeva Kamila Mirshodovna Мадаминжонова Угилой	HYGIENIC ASPECTS OF PROPER NUTRITION FOR SCHOOL-AGE CHILDREN	377-379
62)	Saloxidin Alavdinov Ziyovutdinovich	CLINICAL AND LABORATORY METHODS FOR THE DIAGNOSIS OF DENTAL DISEASES AND EVALUATION OF TREATMENT EFFECTIVENESS IN PATIENTS WITH BRONCHIAL ASTHMA IN THE FERGANA REGION	380-385
63)	Azimova Mayram Kurbanovna	HYGIENIC ASSESSMENT OF THE ECOLOGICAL STATE OF THE CITY OF FERGANA	386-390

ISBN: 978-625-90699-0-6

64)	PhD. Ashurova Manzura Jaloldinovna	PROMOTING A HEALTHY LIFESTYLE AS A KEY ELEMENT OF PREVENTIVE TRAINING FOR MEDICAL UNIVERSITY STUDENTS	391-396
65)	Assistant, FERUZA Kutliyeva Alloberganovna Doctor of Medical Sciences, Professor Alisher Khudayberdievich Rakhmanov Doctor of Medical Sciences, Professor Ziyaviddin Zainutdinovich Hakimov	PREVENTIVE EFFICACY OF CELAGRIP IN EXPERIMENTAL CHRONIC ARTHRITIS INDUCED BY FREUND'S AJUVANT IN PREPUBERTAL RATS	397-398
66)	PhD. Madmarov Mahmud Ma'rufovich	GENETIC BASES OF IMMUNOPATHOGENETIC MECHANISMS OF CARDIOVASCULAR PATHOLOGY FORMATION IN MILITARY PERSONNEL AGAINST THE BACKGROUND OF CHRONIC DENTAL DISEASES	399-403
67)	Senior Lecturer Rakibov Fakhriddin	HYGIENIC AND METHODOLOGICAL FOUNDATIONS FOR THE APPLICATION OF ARTIFICIAL INTELLIGENCE MODELS IN PREDICTING HEAVY METAL MIGRATION FROM CERAMIC WARE	404-410
68)	PhD. dotsent Egamberdiyev Dilmurod Kamolitdinovich Assistant. Qurbonov Nuriddin Panji o'g'li	COMPARATIVE EVALUATION OF MINIMALLY INVASIVE TREATMENT TECHNIQUES FOR PATIENTS WITH LARGE CALCULI IN THE UPPER URINARY TRACT	411-416
69)	Head Teacher Abdukarimov Nadir Mamurovich	EAGLE SYNDROME AN INTERDISCIPLINARY ANALYSIS OF PATHOGENESIS, PRECISION DIAGNOSIS, AND TREATMENT STRATEGIES	417-420
70)	Dr. Nattapong Wattanakul Kanya Srisuk	ONE HEALTH APPROACH IN THE SURVEILLANCE OF EMERGING ZOONOTIC DISEASES IN SOUTHEAST ASIA	421
71)	Somchai Phanich Dr. Anongchai Lertwattanapong	ANTIMICROBIAL RESISTANCE TRENDS IN VETERINARY CLINICAL PRACTICE	422
72)	Adebayo Olumide Johnson	COMMUNITY-BASED NURSING INTERVENTIONS IN MALARIA PREVENTION PROGRAMS	423
73)	Chinedu Okafo Fatima Suleiman	PUBLIC HEALTH STRATEGIES FOR INFECTIOUS DISEASE CONTROL IN SUB-SAHARAN AFRICA	424
74)	Dr. Leyla Huseynova	HEALTHCARE SYSTEM RESILIENCE AFTER PANDEMIC OUTBREAKS: A REGIONAL ASSESSMENT	425

ISBN: 978-625-90699-0-6

75)	Kazimova Sevara Bakhtiyorovna	EPIDEMIOLOGICAL CHARACTERISTICS OF CHRONIC BRONCHITIS: GLOBAL TRENDS AND REGIONAL FEATURES	426-429
76)	Aliyeva Gavharoy Abdumutalipovna	CHANGES IN CHILDREN'S PHYSICAL DEVELOPMENT IN THE MODERN WORLD	430-437
77)	Aliyeva Gavharoy Khabibullayev Ne'matillo	MEASUREMENT OF VITAL LUNG CAPACITY FOR ORIENTATION INTO SPORTS DISCIPLINES	438-442
78)	Qodirov Fayzullo Khabibullayev Ne'matillo	HEALTHY LIFESTYLE – THE MAIN FACTOR IN DISEASE PREVENTION	443-447
79)	Qodirov Fayzullo Khabibullayev Ne'matillo	PRIMARY, SECONDARY, AND TERTIARY PREVENTION OF DISEASES: MODERN APPROACHES	448-453
80)	Aliyeva Gavharoy Khabibullayev Ne'matillo	CHANGES IN NORMAL LUNG DEVELOPMENT AMONG PEOPLE LIVING IN POLLUTED AIR	454-459
81)	Aliyeva Gavharoy Khabibullayev Ne'matillo	THE EFFECT OF GADGETS ON CARDIAC PHYSIOLOGICAL ACTIVITY	460-464
82)	Qodirova Dilfuzaxon Abduraxim qizi	NAIL DEFORMATIONS ETIOLOGICAL FACTORS AND DIAGNOSTIC APPROACHES	465-471
83)	Gayratova Sarvinoz Shuhrat qizi	CLINICAL AND IMMUNOLOGICAL ASSESSMENT OF RISK FACTORS FOR ALLERGIC DERMATITIS IN CHILDREN WITH ACQUIRED IMMUNODEFICIENCY AND OPTIMIZATION OF AN EARLY PREVENTION SYSTEM	472-474
84)	Abduvaliyev Begali Sherali o'g'li	PATHOPHYSIOLOGICAL MECHANISMS OF NEURALGIC PAIN SYNDROMES IN CHILDREN AND THEIR CLINICAL SIGNIFICANCE	475-478
85)	Sobirjonova Shakhzodakhon G'offorjon qizi	ALLERGIC DERMATITIS CAUSES, PATHOGENESIS, AND PREVENTION STRATEGIES	479-484

ISBN: 978-625-90699-0-6

86)	Sattarov J.B. Khaydarov N.S Asqarov D.A., Boboyev M.Sh	OPTIMIZATION OF THE CHOICE OF TREATMENT TACTICS AND METHODS FOR THE PREVENTION OF ADHESIVE DISEASE OF THE ABDOMINAL CAVITY IN CHILDREN	485-495
87)	Assistant Soliyeva Gulchehra Abdurakhmonovna	HEPATOCELLULAR BALLOONING AND FIBROSIS AS PREDICTORS OF MASLD SEVERITY: EVIDENCE FROM AN EXPERIMENTAL STUDY	496-497
88)	Mamatova Shaxnoza Ilxomovna	PETROLEUM COKE AND ITS PROPERTIES: PHYSICAL-CHEMICAL ANALYSIS AND SANITARY-HYGIENIC IMPACT ON WORKERS' HEALTH	498-499
89)	Sodikjon Toirovich Musoev	EPIDEMIOLOGICAL ASSESSMENT OF RISK FACTORS FOR THE DEVELOPMENT OF CHRONIC CHOLECYSTITIS AND POSSIBILITIES FOR ITS PREVENTION	500-511
90)	Khabibjonova Yoqutkxon Khamidullo kizi	DEVELOPMENT OF INDIVIDUAL ORAL HYGIENE PROTOCOLS AND ASSESSMENT OF ORAL ANATOMICAL AND FUNCTIONAL STATUS IN ORTHODONTIC PATIENTS	512-518
91)	Aliyeva Mavluda Tursunaliyevna	LONG-TERM USE OF FIXED PROSTHODONTIC RESTORATIONS: A COMPREHENSIVE ASSESSMENT OF THE ANATOMICAL AND FUNCTIONAL STATUS OF THE ORAL CAVITY	519-528
92)	Musa-Axmatova Saidabonu Alisher qizi	EFFECTIVENESS OF MINIMALLY INVASIVE SURGICAL METHODS IN COLOPROCTOLOGY	529-532
93)	J.T. Mamasaidov N.R. Madrakhimova	"DYNAMICS OF MORPHOLOGICAL CHANGES IN LIVER TISSUE UNDER CONDITIONS OF EXPERIMENTAL Gallstone Disease"	533-546
94)	Senior Lecturer Temur Alisher o'g'li Olimjonov	CLINICAL AND EPIDEMIOLOGICAL PROFILE OF ZYGOMATICOORBITAL COMPLEX FRACTURES: A RETROSPECTIVE ANALYSIS OF 120 CASES	547-548
95)	Senior Lecturer Temur Alisher o'g'li Olimjonov	EFFICACY OF TITANIUM IMPLANTS AND ENDOPR OSTHETIC MESH IN SURGICAL RECONSTRUCTION OF ZYGOMATICO-ORBITAL COMPLEX FRACTURES	549-551
96)	Atayeva Farzona Nuriddinovna Tursunboyeva Lobarxon Ikirambayevna	EARLY DIAGNOSIS OF EXTERNAL GENITAL ENDOMETRIOSIS AMONG NULLIPAROUS WOMEN OF REPRODUCTIVE AGE	552-561

ISBN: 978-625-90699-0-6

97)	Atayeva Farzona Nuriddinovna Karimova Sug'diyona Ravshanbek qizi	MODERN DIAGNOSTIC APPROACHES TO FETAL GROWTH RESTRICTION IN PREGNANT WOMEN WITH IRON DEFICIENCY ANEMIA	562-568
98)	Shadmanova Hargiza Abidovna Sayidmirzayeva Nazokat Gayratjonovna Asatova Nafisa Baxodirovn	BACTERIAL ETIOLOGY OF ACUTE INTESTINAL INFECTIONS IN THE REGIONS OF UZBEKISTAN: A COMPARATIVE RETROSPECTIVE ANALYSIS OF REPRESENTATIVES OF THE GENERA SALMONELLA SPP.	569-582
99)	YULDASHEVA KHONZODA AKHMADOVNA DR. ATABEKOV NURMAT SATINIYAZOVICH DR.ISKANDAROVA GULNOZA TULKINOVNA DR.SHADMANOVA NARGIZA ABIDOVNA ASS0C.PROF. DR. SAPAEVA FIRUZA RUZUMBAEVNA MATKARIMOV SANZHARBEK RAKHIMBAEVICH BEKMURATOVA GULNORA UBAIDULLAEVNA	PRODUCTION OF ANTIMICROBIAL RESISTANCE ENZYMES (BETALACTAMASES, METALLOCARBAPENEMASES) BY HOSPITAL-ORIGIN GRAMNEGATIVE BACTERIA	583-591
100)	Assist., Boynazarov A.A Assist. Boynazarova Z.L	STATISTICAL INDICATORS OF EPIDEMIOLOGICAL DISEASES AT THE FERGANA REGIONAL MULTIDISCIPLINARY CHILDREN'S POLYCLINIC	592-601
101)	Gulmira Kakhkharovna Mirzaeva Sodikjon Toirovich Musoev	CLINICAL AND BIOCHEMICAL PREDICTORS OF COMPLICATED COURSE OF CHRONIC CHOLECYSTITIS	602-607
102)	Sodikjon Toirovich Musoev	CLINICAL AND EPIDEMIOLOGICAL CHARACTERISTICS OF SURGICAL PATIENTS IN A HOSPITAL	608-613
103)	Dilnurabegim Bagirovna Yashinova Sodikjon Toirovich Musoev	THE INFLUENCE OF METABOLIC FACTORS ON THE CLINICAL COURSE OF CHRONIC CHOLECYSTITIS	614-618
104)	Tursunaliev Ziloliddin Zaylobidin o'g'li	DIAGNOSIS OF AESTHETIC DISORDERS IN PATIENTS WITH DENTAL ARCH DEFECTS AND THEIR COMPREHENSIVE REHABILITATION	619-623

ISBN: 978-625-90699-0-6

VIBRATION-BASED FAULT DETECTION IN A WIRE DRAWING MACHINE USING AN LSTM DEEP LEARNING MODEL

Doç. Dr. Mehmet KONAR[1]
[1]Erciyes University, Department of Aviation Electrical and Electronics, Kayseri, Turkey
[1]ORCID ID: https://orcid.org/0000-0002-9317-1196

Doç. Dr. Erkan Caner ÖZKAT[2]
[2]Recep Tayyip Erdoğan University, Department of Mechanical Engineering, Rize, Turkey
[2]ORCID ID: https://orcid.org/0000-0003-0530-5439

Ahmet PİŞMİŞOĞLU[3]
[3]Erciyes University, Graduate School of Natural and Applied Sciences, Kayseri, Turkey
[3]ORCID ID: https://orcid.org/0009-0008-7877-159X

ABSTRACT

Predictive maintenance has become an essential strategy for improving reliability, reducing unexpected downtime, and optimizing maintenance planning in modern manufacturing systems. In industrial production lines, early detection of abnormal machine behaviour plays a critical role in maintaining stable operation and preventing costly failures. Among various condition monitoring techniques, vibration analysis is widely used because it can capture mechanical changes associated with wear, friction, and structural degradation in rotating machinery. However, conventional vibration monitoring approaches often rely on handcrafted statistical indicators or fixed threshold values, which may not adequately capture complex temporal patterns in non-stationary industrial signals.

This study proposes a vibration-based fault detection framework for an industrial wire drawing machine using a deep learning approach based on Long Short-Term Memory (LSTM) networks. The investigated wire drawing system operates under continuously varying mechanical loads and tribological conditions, which may lead to gradual degradation of components such as drawing dies, lubrication systems, and drive elements. To monitor these conditions, vibration signals were collected from eight production blocks of the line and analysed through a data-driven signal processing pipeline implemented in Python.

The acquired vibration signals were segmented into fixed-length time windows and normalized to reduce the influence of operating condition variations. Instead of converting the signals into time–frequency images, the proposed approach directly utilizes the sequential structure of the vibration data. The segmented sequences were then used as input to an LSTM autoencoder network, which learns temporal dependencies and degradation-related patterns within the vibration signals and flags abnormal behaviour through reconstruction error.

Experimental results obtained from approximately 47,700 sensor readings collected over a seven-week monitoring period demonstrate that the LSTM-based model can effectively detect abnormal vibration behaviour and distinguish normal from abnormal operating conditions, reaching an accuracy of 96.4% and an F1-score of 0.646 when evaluated against an independent statistical reference, since verified fault records were not available for this dataset. The results highlight the potential of time-series deep learning methods for developing practical predictive maintenance solutions in industrial wire drawing systems.

Keywords: Predictive maintenance, vibration monitoring, deep learning, LSTM, wire drawing machine, fault detection.

INTRODUCTION

Wire drawing is a fundamental metal-forming process in which a metal rod is progressively reduced in cross-section by pulling it through a sequence of dies. Industrial wire drawing lines typically consist of several successive drawing blocks operating at increasing line speeds, each subjected to high mechanical stress, friction, and heat generation. Because the blocks are mechanically coupled through the wire itself, a localized fault in one block, such as die wear, bearing degradation, or lubrication failure, can propagate and affect the stability of the entire line (Tiboni, Remino, Bussola, & Amici, 2022). Unplanned stoppages caused by such faults are costly, both in terms of lost production time and material waste, which makes early and reliable fault detection a priority for manufacturers.

Vibration-based condition monitoring is one of the most established approaches for detecting mechanical degradation in rotating and reciprocating machinery (Tiboni et al., 2022). Vibration signals carry rich information about the dynamic state of a machine, since changes in stiffness, mass distribution, or friction are reflected as changes in the amplitude, frequency content, or statistical properties of the measured signal. Traditional vibration-based diagnostics commonly rely on handcrafted statistical features, such as root-mean-square (RMS) value, peak amplitude, kurtosis, or crest factor, combined with fixed alarm thresholds defined by international standards such as ISO 20816-1 (ANSI/ASA S2.80-2019/Part 1, 2019). While effective in many stationary contexts, these approaches struggle to characterize the complex, non-stationary temporal dynamics typical of industrial processes such as wire drawing, where operating speed, load, and friction conditions vary continuously.

In recent years, deep learning has emerged as a powerful alternative for condition monitoring and fault diagnosis, owing to its capacity to automatically learn discriminative representations directly from raw or lightly processed sensor data (Zhao, Yan, Chen, Mao, Wang, & Gao, 2019). Among deep learning architectures, Long Short-Term Memory (LSTM) networks are particularly well suited to vibration-based fault detection because they are explicitly designed to capture long-range temporal dependencies in sequential data, which makes them attractive for modelling the evolving dynamics of mechanical degradation (Krichen & Mihoub, 2025). Several recent reviews have demonstrated that deep architectures applied directly to raw vibration signals can outperform traditional feature-engineering approaches in noisy and variable operating conditions (Tama, Vania, Lee, & Lim, 2023), including bearing and gearbox fault diagnosis tasks based on LSTM networks (Lei, Yang, Jiang, Jia, Li, & Nandi, 2020).

A practical challenge that frequently arises in real industrial settings, including the wire drawing line investigated in this study, is the absence of verified fault labels. Several systematic reviews of the predictive maintenance literature have repeatedly identified this label scarcity as one of the main barriers to deploying supervised machine learning methods in real production environments (Carvalho, Soares, Vita, Francisco, Basto, & Alcalá, 2019; Hector & Panjanathan, 2024). Production data are continuously collected by supervisory systems, but maintenance events are not always recorded with the granularity required to build a fully supervised fault classifier. This motivates the use of unsupervised or semi-supervised deep learning approaches, such as autoencoder-based anomaly detection, in which a network is trained to reconstruct normal operating patterns and abnormal behaviour is identified through elevated reconstruction error (Lee, Park, Kim, Ahn, & Jeong, 2024). A recent comparative review of deep learning architectures for predictive maintenance similarly highlights autoencoder-based and recurrent models as the most suitable choices when labelled fault data are scarce or unavailable (Serradilla, Zugasti, Rodriguez, & Zurutuza, 2022). Beyond fault diagnosis specifically, deep learning methods have increasingly been adopted across the

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broader smart manufacturing domain for tasks ranging from quality inspection to predictive maintenance (Xu, Kovatsch, Mattern, Mazza, Harasic, Paschke, & Lucia, 2022).

This study proposes a vibration-based fault detection framework for an industrial wire drawing machine consisting of eight sequential drawing blocks. An LSTM autoencoder is trained on sliding time windows extracted from RMS velocity, RMS acceleration, peak acceleration, and line speed signals collected from the production line. The reconstruction error produced by the trained network is used as a continuous health indicator, and abnormal operating periods are identified through a statistically derived threshold. The remainder of the paper is organized as follows: the Research and Findings section describes the dataset, the proposed methodology, and the experimental results; the Conclusion section discusses the implications of the findings and outlines directions for future work.

RESEARCH AND FINDINGS

Dataset Description

The dataset used in this study was collected from an industrial wire drawing line equipped with condition monitoring sensors on eight sequential drawing blocks (Block 2 through Block 9). For each block, three vibration-related indicators were recorded: RMS velocity, RMS acceleration, and analog peak acceleration. In addition, the actual line speed was recorded as a global operating parameter. Data were sampled at an average interval of approximately 30 seconds and span a continuous monitoring period of seven weeks, yielding a total of 47,706 multivariate observations across 25 sensor channels (24 vibration indicators plus line speed). No missing values were present in the raw dataset.

Table 1 summarizes the descriptive statistics of the vibration indicators for each of the eight monitored blocks. Mean peak acceleration increased gradually from Block 2 (25.5 mm/s²) to Block 8 (30.0 mm/s²), consistent with the higher drawing speeds and tension typically observed in later blocks of a wire drawing line. A similar gradual increase is visible in mean RMS acceleration, from 5.61 mm/s² at Block 2 to 6.32 mm/s² at Block 8.

Table 1. Descriptive statistics of vibration indicators by block

Block	Mean RMS Vel.	SD RMS Vel.	Mean RMS Acc.	SD RMS Acc.	Mean Peak Acc.	SD Peak Acc.
2	1.12	0.73	5.61	2.64	25.49	12.51
3	1.15	0.74	5.75	2.74	26.4	13.07
4	1.17	0.76	5.9	2.83	27.26	13.37
5	1.16	0.75	5.86	2.82	27.22	13.55
6	1.19	0.77	6.11	3	28.74	14.31
7	1.21	0.78	6.23	3.04	29.63	14.64
8	1.23	0.79	6.32	3.1	30.05	14.94
9	1.2	0.79	6.1	2.96	28.68	14.12

Prior to modelling, samples corresponding to idle or stopped conditions (actual line speed below 0.5 units) were excluded, retaining 46,951 active operating samples (98.4% of the dataset). This filtering step ensures that the model learns the dynamics associated with the wire drawing process itself, rather than the trivial distinction between operating and idle states.

ISBN: 978-625-90699-0-6

Methodology

Because the dataset does not contain verified fault event labels, the proposed framework adopts an unsupervised anomaly detection strategy based on an LSTM autoencoder, following established practice in predictive maintenance research where ground-truth failure records are unavailable (Hector & Panjanathan, 2024). This combination of dimensionality reduction followed by an LSTM autoencoder mirrors a methodology recently validated on vibration-based anomaly detection in wind turbines, where the same two-stage pipeline was shown to achieve reliable outlier detection on unlabelled field data (Lee, Park, Kim, Ahn, & Jeong, 2024). The methodology consists of four stages: (1) data preprocessing and windowing, (2) dimensionality reduction, (3) LSTM autoencoder training, and (4) anomaly scoring and threshold-based classification.

Data preprocessing and windowing. The 25 active sensor channels (RMS velocity, RMS acceleration, and peak acceleration for each of the eight blocks, and actual line speed) were standardized to zero mean and unit variance using a z-score transformation fitted on the training partition. The continuous multivariate signal was then segmented into fixed-length sliding windows of 30 consecutive samples (corresponding to approximately 15 minutes of operation at the average sampling rate), with a stride of 5 samples between consecutive windows. This procedure produced 9,385 overlapping windows, preserving the sequential structure of the data required by the LSTM model.

Dimensionality reduction. To make the recurrent network training computationally tractable while retaining the great majority of the signal information, Principal Component Analysis (PCA), a classical dimensionality reduction technique widely used as a preprocessing step in machine learning pipelines (Salih Hasan & Abdulazeez, 2021), was applied to the standardized features, reducing the 25-dimensional feature space to 10 principal components. The retained components explained 99.9% of the total variance in the data, indicating negligible information loss.

LSTM autoencoder architecture and training. The proposed network follows an encoder–decoder architecture, in which an encoder LSTM compresses each window into a fixed-length latent representation and a decoder LSTM reconstructs the original sequence from it (Krichen & Mihoub, 2025). The encoder is a single-layer LSTM with 12 hidden units that processes each 30-step window and compresses it into a fixed-length latent representation corresponding to its final hidden state. The decoder is a second single-layer LSTM with 12 hidden units that reconstructs the original 30-step sequence from the latent representation, followed by a linear output layer that maps the decoder's hidden states back to the 10-dimensional principal component space. The network was implemented from first principles, including the forward LSTM gating equations and the backpropagation-through-time (BPTT) gradient computation widely used in recurrent network training, and optimized using the Adam algorithm, which remains a strong and widely adopted default choice among modern deep learning optimizers (Schmidt, Schneider, & Hennig, 2021), with an initial learning rate of 0.006 and exponential decay of 0.92 per epoch.

The data were partitioned chronologically into training (70%, n = 6,569 windows), validation (15%, n = 1,408 windows), and test (15%, n = 1,408 windows) sets, preserving the time order of the production process. The model was trained for 18 epochs, with the reconstruction mean squared error (MSE) as the optimization objective. Training the autoencoder exclusively on the chronologically earliest portion of the data reflects the predictive maintenance scenario in which the model is required to recognize deviations from previously observed normal behaviour.

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Anomaly scoring and reference labels. For every window, the trained autoencoder produced a reconstruction error (MSE between the input and the reconstructed sequence). An anomaly threshold was defined as the mean reconstruction error of the training set plus three standard deviations ($\mu + 3\sigma$), following the classical statistical process control (SPC) convention that remains widely applied in industrial quality and condition monitoring contexts (Tiboni et al., 2022). Windows with a reconstruction error exceeding this threshold were classified as abnormal. Because no verified maintenance records were available to evaluate detection performance directly, an independent statistical reference label was constructed directly from the raw peak acceleration signals (without involving the LSTM model), using the same 3σ control-limit principle applied to the maximum peak acceleration observed across all eight blocks within each window. This reference, rather than constituting confirmed fault ground truth, provides an objective, model-independent benchmark against which the unsupervised LSTM-based detector can be quantitatively validated.

Results

Figure 1 shows the evolution of the training and validation reconstruction error across the 18 training epochs. The training loss decreased steadily from 0.69 to 0.43, confirming that the network successfully learned to reconstruct the normal operating patterns present in the training data. The validation loss remained considerably higher and more variable throughout training, which is expected in this anomaly detection setting: the validation partition, corresponding to a later period of the production line's operation, contains genuine deviations from the patterns learned during training, and the resulting elevated reconstruction error is precisely the signal exploited for fault detection.

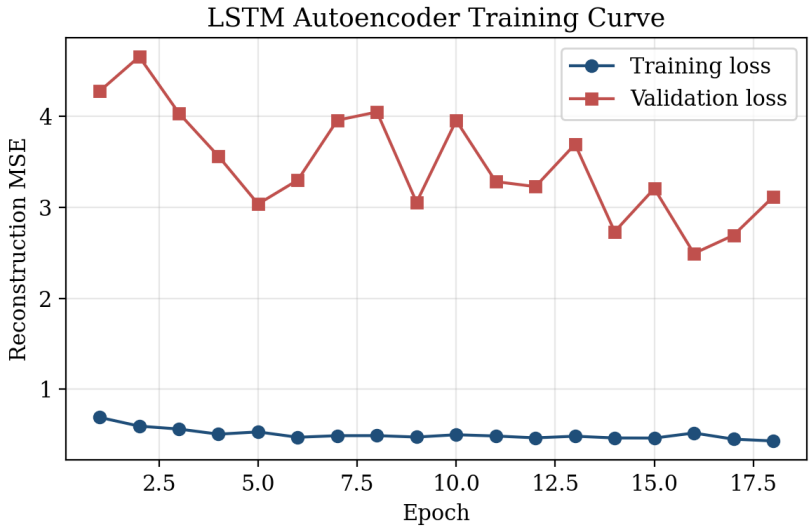

Figure 1. Training and validation reconstruction error (MSE) across training epochs

Figure 2 presents the reconstruction error for all 9,385 windows across the full chronological monitoring period, together with the anomaly threshold derived from the training distribution. A pronounced and sustained cluster of high reconstruction error is visible at the boundary between the training and validation partitions, indicating a period during which the vibration signatures of the line deviated substantially from previously observed normal behaviour. Outside this cluster, the reconstruction error remains close to the baseline level observed during training, suggesting that the autoencoder generalizes well to normal operating conditions it has not explicitly seen before.

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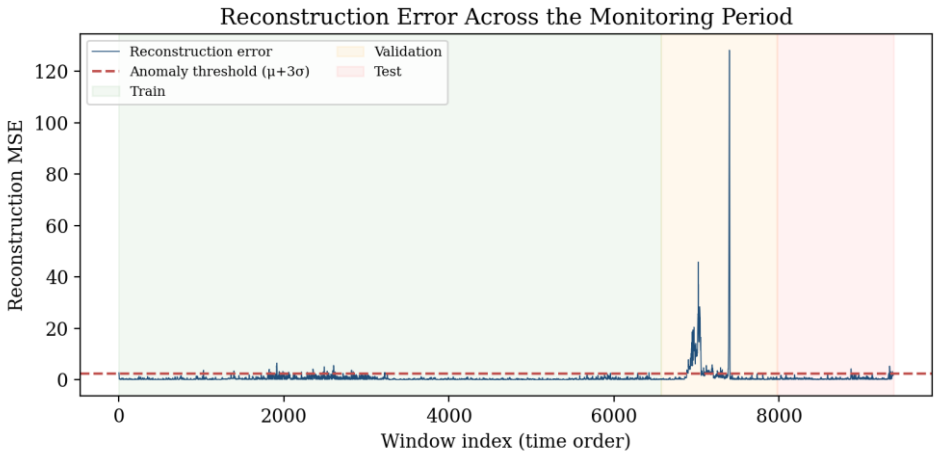

Figure 2. Reconstruction error across the full monitoring period, with the anomaly threshold (μ + 3σ) and train/validation/test partitions indicated

Table 2 reports the classification performance of the LSTM autoencoder against the independent statistical reference labels described above. The model achieved an overall accuracy of 96.4%, a precision of 59.6%, a recall of 70.6%, an F1-score of 0.646, and a ROC-AUC of 0.974. The recall indicates that the majority of windows flagged as abnormal by the independent reference were also identified as anomalous by the LSTM autoencoder, while the ROC-AUC value close to 1.0 indicates good overall separability between normal and abnormal windows based on the reconstruction error score, largely independent of the specific threshold chosen.

Table 2. Classification performance of the LSTM autoencoder against the statistical reference labels

Metric	Value
Accuracy	0.964
Precision	0.596
Recall	0.706
F1-score	0.646
ROC-AUC	0.974

Figure 3 displays the confusion matrix corresponding to the threshold-based classification. Of the 9,385 windows analysed, 8,742 were correctly identified as normal (true negatives) and 307 were correctly identified as abnormal (true positives). The model produced 208 false positives and 128 false negatives, corresponding to a false alarm rate of approximately 2.3% of all normal windows. The false-negative count suggests that some early-stage anomalies may manifest more clearly in the electrical signature of the drive motors than in vibration alone, a limitation discussed further below.

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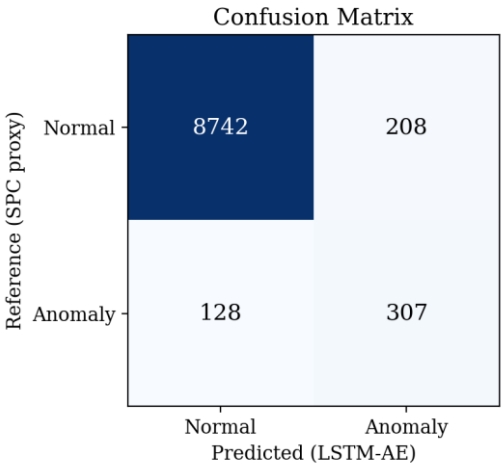

Figure 3. Confusion matrix of the LSTM autoencoder anomaly detector versus the statistical reference labels

Overall, the experimental results confirm that the proposed LSTM autoencoder can effectively learn the normal temporal dynamics of the wire drawing process from the multiple vibration channels recorded across the eight blocks, and can flag deviations from this learned behaviour, though with a moderate false-negative rate. The relatively moderate precision and recall, driven by the 208 false positives and 128 false negatives, are consistent with the conservative nature of the 3σ statistical reference, which is itself only a proxy for true mechanical degradation rather than a confirmed fault record; consequently, some windows flagged by the LSTM model may represent genuine early-stage anomalies that the simpler statistical reference does not yet capture, while some misses may reflect degradation patterns that are not fully observable from vibration signals alone.

CONCLUSION

This study presented an LSTM autoencoder-based framework for vibration-based fault detection in an industrial wire drawing machine composed of eight sequential drawing blocks. Using approximately 47,700 vibration sensor readings collected over a seven-week monitoring period, the proposed model was trained in an unsupervised manner to reconstruct normal operating patterns from sliding time windows of RMS velocity, RMS acceleration, peak acceleration, and line speed signals. Abnormal operating conditions were identified through elevated reconstruction error relative to a statistically derived threshold.

The experimental results demonstrated that the proposed approach achieved an accuracy of 96.4%, a recall of 70.6%, an F1-score of 0.646, and a ROC-AUC of 0.974 when evaluated against an independent statistical reference derived directly from the raw peak acceleration signals. It is important to emphasize that these figures quantify agreement with this statistical reference, not with confirmed fault events, since no verified maintenance records were available for the monitored line; the reported accuracy should therefore be read as a measure of internal consistency between the unsupervised LSTM autoencoder and a classical 3σ control-limit rule, rather than as a validated fault-detection accuracy in the conventional supervised sense. With this caveat in mind, the results indicate that the LSTM autoencoder is capable of capturing temporal degradation patterns in vibration data that may not be fully reflected by simple statistical indicators alone, supporting its potential as a practical tool for predictive maintenance in industrial wire drawing systems, pending validation against real maintenance records.

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The findings of this study should be interpreted in light of certain limitations. First, in the absence of verified maintenance records, model validation relied on a statistically derived reference rather than confirmed fault events, and future work should seek to incorporate maintenance logs to allow a fully supervised evaluation. Second, the dimensionality reduction step, while preserving 99.9% of the variance in the original signals, may have discarded fine-grained information relevant to specific fault types; future studies could explore architectures capable of operating directly on the full sensor space. Third, the present framework relies exclusively on vibration signals; since the monitored line also provides motor current measurements for each block, incorporating these electrical signals alongside vibration in a future multivariate extension of this framework may further improve detection sensitivity, particularly for fault modes that manifest primarily through changes in motor loading rather than mechanical vibration. Finally, extending the proposed framework toward fault-type classification and remaining useful life (RUL) estimation, a closely related and well-established direction in deep-learning-based predictive maintenance research (Wu, Wu, Tan, & Xu, 2024), rather than binary anomaly detection alone, and validating it across multiple wire drawing lines and operating regimes would further strengthen its practical applicability for predictive maintenance in the wire and cable manufacturing industry.

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